Myth and Geology

Edited by

L. Piccardi and W. B. Masse

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Myth and Geology

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Myth and Geology

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Preface

This volume provides an overview of the study of the geological foundation to human myths, an emerging discipline in the Earth sciences called 'geomythology'. This term was coined by Dorothy Vitaliano, in her pioneering book *Legends of the Earth: their geologic origins* (1973), as 'the study of the actual geologic origins of natural phenomena which were long explained in terms of myth and folklore'. That book represented the first systematic approach to such matter in a systematic way. More than thirty years later, the present volume aims to make this discipline a recognized scientific research field, by providing the first peer-reviewed collection of papers discussing the study of the geological reality lying behind myths and legends of the past.

The publication of this volume was inspired after the 'Myth and Geology' session held at the 32nd International Geological Congress in Florence, Italy, in August 2004. Dorothy Vitaliano presented the keynote address to the symposium and her address is presented as the first chapter. It outlines the great strides that have been made during the past three decades and the potential for future growth and change. Most of the papers included in this volume were presented at that session; they analyse a variety of myths, legends and ancient folk tales, that is historical documents derived from oral tradition, whose origins appear to contain memories of geological phenomena that occurred in the past. Such phenomena were codified in terms of the local knowledge of the time and gave rise to well credited myths which spread abroad and influenced the local cultures for centuries, in many cases lasting up to the present time.

The term 'geomythology' is not yet enlisted in vocabularies and encyclopaedias. Hence, the term has been used with very different meanings, from 'world mythologies' to 'false ideas supposedly based on geological data' or 'wrong geological concepts which have attained large popularity'. It is due to the preparation of the current volume that this term is now accepted by respected scientific journals (e.g. *Science*, 4 November 2005) and, following an entry of December 2005, it is defined on the on-line encyclopaedia Wikipedia (http://en.wikipedia.org/wiki/) as follows: '*Geomythology is the analysis of mythological stories to learn about geological events portrayed in them. Sometimes this gives very valuable information about old earthquakes, tsunamis, floods, etc. which are either scientifically not known or hard to know. These stories give scientists hints and clues about old unknown geological events which can then later on be analyzed and scientifically studied in detail*'. This definition still remains restrictive. Geomythology indicates every case in which the origin of myths and legends can be shown to contain references to geological phenomena and aspects, in a broad sense including astronomical ones (comets, eclipses, meteor impacts, etc.). As indicated by Vitaliano (1973) '*primarly, there are two kinds of geologic folklore, that in which some geologic feature or the occurrence of some geologic phenomenon has inspired a folklore explanation, and that which is the garbled explanation of some actual geologic event, usually a natural catastrophe*'.

The famous myth of the Chimera (represented on the volume cover), the indestructible three-headed fire-breathing dragoness, provides a perfect example of a geomyth. The Chimera was slain at her lair by the hero Bellerofronte. Being an indestructible dragon, her fire-tongue remained forever burning at that place. It can still be visited today, on the coast of Turkey, at the site called Yanartaş (burning mountain). There, high on a slope facing the sea, one can see ignited gas emissions (probably methane) that continue to burn after millennia. These flames have been used by sailors, since ancient times, as a natural lighthouse. Similar natural flames exist at many sites in the world, and their origin is always explained by a myth.

The interpretation of geological folklore, to be correctly and exhaustively carried out, requires the integration of knowledge in the fields of geology, archaeology, history, comparative mythology and anthropology. The geological study of mythology and legendary accounts may reveal encoded memories of past geological events, thus providing a reservoir of geological information. On the other hand, it also helps to provide new insight to historical, archaeological and anthropological research, opening a new window on a field traditionally reserved for anthropologists, and improving the 'self knowledge' of Man, by shedding new light on his early perception of the world. '*Know thyself*' was the motto inscribed on the temple of the most famous sanctuary of antiquity, the Oracle of Apollo at Delphi. The myth at the origin of this Oracle has recently been the subject of one of the best case histories in geomythology.

In addition to outlining the relationship between myth and geology, this volume will inspire its readers to look deeper into the roots of culture and our perception of the natural environment, through various case histories of myths, legends, folk tales and oral traditions from around the world.

The editors wish to acknowledge reviews by the following colleagues:

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Geomythology: geological origins of myths and legends

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Abstract: Myths and geology are related in several ways. Some myths are the result of man's attempts to explain noteworthy features of his environment, such as striking landforms or unusual smaller features, whereas others try to account for conspicuous natural processes, such as earthquakes, volcanic phenomena, and floods. Local myths have sometimes proved helpful in solving geological problems, and even the geological nomenclature is indebted to mythology. Examples of each kind of relationship are given.

As a child, I loved to read Greek and Roman mythology. Later, in my professional work, I was intrigued to encounter occasional references to these myths in geological papers, and I began to collect them just out of curiosity. Then, when the first papers linking Santorini and Atlantis appeared, I gave a review of that theory to the Department of Geology at Indiana University. A member of the Indiana University Press was present, and after the talk he said, 'Why don't you do a book on Atlantis?' I replied, 'There already have been many books written on Atlantis, but I could do one on the relationship between myth and geology'. At the time the book appeared (Vitaliano 1973), I did not realize that geomyths would prove to have very practical applications, and would be taken seriously enough to find a way into a scientific symposium at an International Geological Congress.

Myth and geology are related in several ways. First, man has always sought to explain his natural environment. A good example of this is Devil's Tower in the state of Wyoming (Fig. 1). Originally interpreted as a volcanic neck or plug, closer study revealed that it is the eroded remnant of a more extensive body, a laccolith. Two Indian tribes living in the vicinity have slightly different stories accounting for its unique shape (Mattison 1967), but both involve a group of people being pursued by a giant bear, appealing to their deity for help, and having the ground on which they stood uplifted beyond the reach of the animal (Fig. 2). The fluting of the columns, a classic example of columnar jointing, is explained as the claw marks made by the bear as it tried to reach them.

Another example of a myth inspired by unusual topography is the island of Mangaia, one of the Cook Islands in the South Pacific (Fig. 3). The central core of the island is an eroded volcano, which is surrounded by a moat-like depression, and this in turn is surrounded by a raised platform of eroded coral rock called the Makatea, 110–210 feet above sea level. A terrace at the base of this cliff slopes gently toward the sea, ending in a low cliff, and surrounded by a fringing reef of coral.

According to the myth, the island was once smooth and regular, with gentle slopes (Marshall 1927). One day the god of the sea and the god of rain had a contest to see which was more powerful. The sea god, aided by the wind god, attacked the island and eroded it to the height of the Makatea. Then the rain god caused it to rain for five days and nights, washing clay and stones into the ocean and carving deep valleys into the slopes, until only the flat top of the original surface remained. The inhabitants of the island took refuge on this peak, and as their situation became more and more precarious, their chief appealed to their supreme god, who ordered the others to stop the contest.

This myth explaining the island's unique shape reflects an appreciation of the role of running water and storm waves in shaping the landscape. In geological terms, the island was a volcano built up on the sea floor. After its activity had ceased, it was eroded down to sea level. Then it was elevated above sea level and subjected to weathering and erosion, while a fringing reef of coral grew around it. Gradual subsidence then allowed the coral to grow upward to become a barrier reef, separated from the land by a lagoon. Re-elevation of the land left the barrier reef high and dry, forming the Makatea, and the lagoon became the moat-like depression.

The Pacific islands have inspired many other landform myths, including a number of 'fishing-up' myths which explain the presence of certain islands (Nunn 2001, 2003). 'Fishing-up' myths generally tell of a god who, while fishing, hooks his line on the sea bottom and hauls up rocks and other features that assume the specific configurations of the islands in question.

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Fig. 1. Devil's Tower, Wyoming.

Nothing is too small to inspire geomyths. In volcanic eruptions, small droplets of molten lava can be blown by winds from the surface of a lava flow, or from a lava fountain, usually trailing a thread of spun glass. These can pile up (Fig. 4) into what the Hawaiians call Pele's hair (the threads)—Pele being the Hawaiian volcano goddess—and Pele's tears (the droplets). These terms have been adopted into the scientific nomenclature, and that fact constitutes yet another example of the relationship between myth and geology. For that matter, we are indebted to mythology for the very word volcano, from Vulcan, the Roman god of fire, whose forge was thought to be in Mt Etna.

Fig. 2. The Indian legend explaining the shape of Devil's Tower, Wyoming. (Courtesy of the US National Park Service.)

The Hawaiians believed that Pele came to the islands because she was fleeing the anger of her older sister, whom she had somehow offended. First she came to the northwesternmost island, where she dug a pit in search of fire, but her sister chased her to the next island, and the next, and so on down the chain until she took up residence in Halemaumau, the fire pit on Kilauea volcano (Fig. 5). Then the sister gave up the chase, and there Pele and her relatives are said to live today.

This myth indicates that the Hawaiians were keen observers of their environment, for the volcanism becomes younger as one progresses down the chain, all activity in historic times being confined to the big island, Hawaii, except for the last eruption on its neighbouring island, Maui. That is because the island chain is passing over a hot spot in the earth's mantle. Submarine eruptions SE of the big island indicate that a new island is in the process of being created.

Myths have also been invoked to explain geological processes, particularly those manifested violently, such as earthquakes, volcanic eruptions and floods. In Japan it was believed that a giant catfish in the earth was responsible for earthquakes (Ouwehand 1964). This catfish was usually pinned down by the Kashima deity (Fig. 6), but when this god had to pay attention to other matters, the catfish was left free to wriggle and a quake resulted. The association of catfish with earthquakes may not be entirely fanciful. Unusual activity in catfish was long believed to portend a quake. Elsewhere in the world, unusual behaviour in various creatures has also been taken to be a sign of an impending shock, and it has been suggested that they might be sensitive to small changes in one of the Earth's force fields, such as the geoelectrical field. At Tohoku University in Japan, experiments were actually carried out to test this idea. A small stream was diverted to flow through a tank of catfish, and their response to a tap on the glass was recorded. It did seem as though the fish were more agitated by the tapping shortly before a shock, but the results were not definitely conclusive.

Some geomyths actually constitute a record of major geological events. Beautiful Crater Lake in the state of Oregon in the United States is a volcanic caldera (Fig. 7). It was created by an eruption of

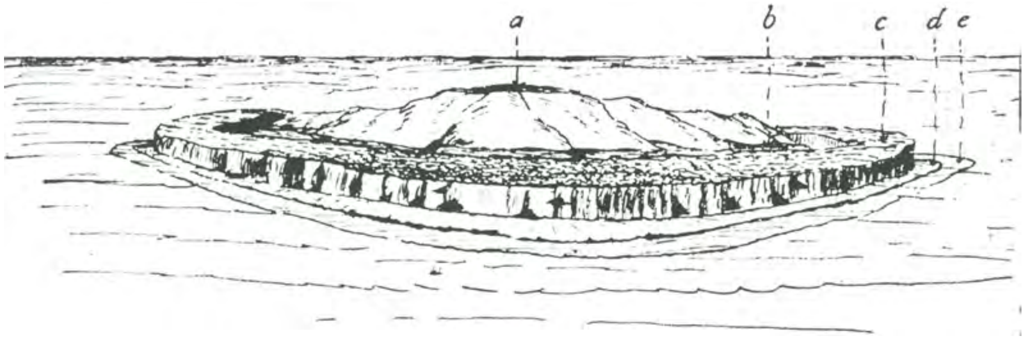

Fig. 3. The island of Mangaia in the South Pacific (after Marshall 1927).

Mt Mazama in the Cascades Range (Fig. 8). According to the myth of the Klamath Indians, Llao, the chief of the Below World, standing on Mt Mazama, was battling Skell, the chief of the Above World, who stood on Mt Shasta in California, about a hundred miles away (Clark 1953). They hurled rocks and flames at each other, and darkness covered the land. The fight ended when Mt Mazama collapsed under Llao and hurled him back into his underworld domain. The large hole that was created then filled up to form Crater Lake.

This sounds like an eye-witness account of such an eruption, and it undoubtedly is, for Indian artifacts have been found buried in the Mazama ash. The eruption has been radiocarbon-dated to about 6500 years ago on the basis of Indian sandals found in the ash, but had no datable materials been found, this myth alone would have served to date the eruption as post-Pleistocene, because this part of the world was first inhabited by people who crossed the Bering Land Bridge and migrated down through Alaska and Canada into the northwestern United States.

A myth also helped to solve a geological problem for the German volcanologist Jörg Keller. He was able to date the last eruption in the Lipari Islands, off the coast of Italy, on the basis of a local legend (Keller 1970). Ash from that eruption overlies Roman ruins on Vulcano that date from the fourth and fifth centuries AD (Fig. 9). According to a local tradition, a hermit named Calogero, who lived on Lipari and was later made a saint, was credited with having driven the devil and his fires from Lipari (Fig. 10) to Vulcanello, and as that was still too close for comfort, on to Vulcano. As St Calogero is known to have lived from AD 524–AD 562, Dr Keller inferred that the eruption must have occurred some time between AD 500 and 550.

Flood legends appear in the mythology of so many cultures that a universal flood has often been invoked to explain their prevalence. Many of them, however, appear to be purely of local origin. The myth of the Makah Indians on the Pacific coast of the state of Washington is such a one (Andree 1891). The sea is said to have risen and fallen several times in the course of a few

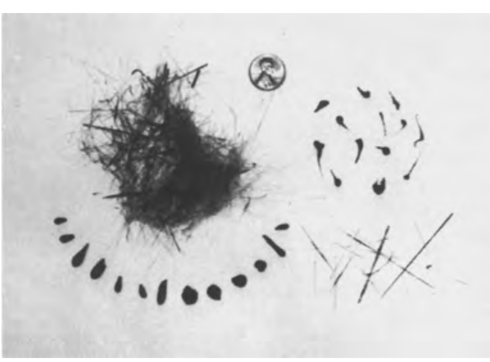

Fig. 4. Pele's hair and Pele's tears, formed from wind-swept molten lava. (Photo by C. J. Vitaliano.)

Fig. 5. Halemaumau, the 'fire pit' of Kilauea volcano. (Photo by C. J. Vitaliano.)

Fig. 6. The Kashima deity immobilizing the catfish believed to cause earthquakes. (Drawing by Kenzo Yagi.)

days. The people took to their canoes and rode it out safely, though some of them were carried far to the north and stayed there. Such a rise and fall of the sea is typical of tsunamis, and the west coast of Canada and the United States is very susceptible to tsunamis resulting from Alaskan earthquakes, such as the one recorded at Crescent City in northern California in 1964.

Noah's flood is a story so compelling that for centuries it has demanded a scientific explanation. The story clearly refers to an inundation so large that its survivors assumed that the whole world had been affected. People have long sought to tie the Flood to a specific event and location, but only recently has a plausible explanation, based on sound scientific research, been proposed. Ryan & Pitman (1999) hypothesize that postglacial melting elevated sea levels to the extent that the Mediterranean broke through into the Black Sea depression, drowning out so many settlements that a universal flood legend resulted. I am not only convinced that this is the true explanation of the Flood, but I am also impressed with how quickly and effectively these two scientists have brought this long-elusive story into the realm of science-based geomythology.

The Flood is a prime example of a famous story that has generated a powerful demand for scientific explanation, a process that appears to be driving much current geomythological research. Another one is the Atlantis story, which has probably given rise to even more speculation as to its origin than the Flood. There are very few parts of the world that have not been proposed as the location of Atlantis, but not until 1960, when the Bronze Age eruption of Santorini in the Aegean Sea was suggested as the cause of the demise of Minoan Crete (Galanopoulos 1960), did there seem to be a truly plausible geological basis for the idea. True, it was not a whole continent that disappeared, only most of a small island, but a great empire appeared to have declined quite suddenly.

My late husband and I became involved in that problem as a result of our having been invited to the first Santorini congress in 1969, and the two subsequent congresses in 1978 and 1989. Because no artifacts were found on Santorini which represented the latest Minoan period, the time when they were at the very peak of their power, the ash layers deposited in that eruption were initially interpreted as the result of a three-stage eruption (Fig. 10): first, a violent phase which frightened the inhabitants away, then a period of intermittent minor eruptions, during which time they returned to recover their possessions (Fig. 11), and finally another violent stage, which drove them away and left nothing for them to return to.

The first congress was convened by Professor Spyridon Marinatos, who was excavating Santorini, to bring archaeologists and geologists together in the hope that they could determine the duration of the middle stage of the eruption to see if it fitted with this interpretation of the archaeological data (Marinatos 1971). To make a long story short, having observed that there was considerable misunderstanding among the archaeologists concerning the preservation of ash deposited in such an eruption, my husband and I offered to examine samples collected in archaeologically dated levels. We were also invited to do such collecting ourselves in many digs on Crete and on Melos. The results proved conclusively that the Santorini eruption occurred about two generations before the collapse of Minoan Crete, enough of a time lag to rule out cause-and-effect (Vitaliano & Vitaliano 1978). So, reluctantly, we had to recognize that the Santorini–Atlantis theory does not have a scientific basis and that the entire Atlantis story itself may ultimately prove to be nothing more than a fiction, made up by Plato to prove a philosophical point.

These and other important myths and stories, many of classical or biblical origin, are stimulating current scientific research in geomythology because previous explanations have generally failed to

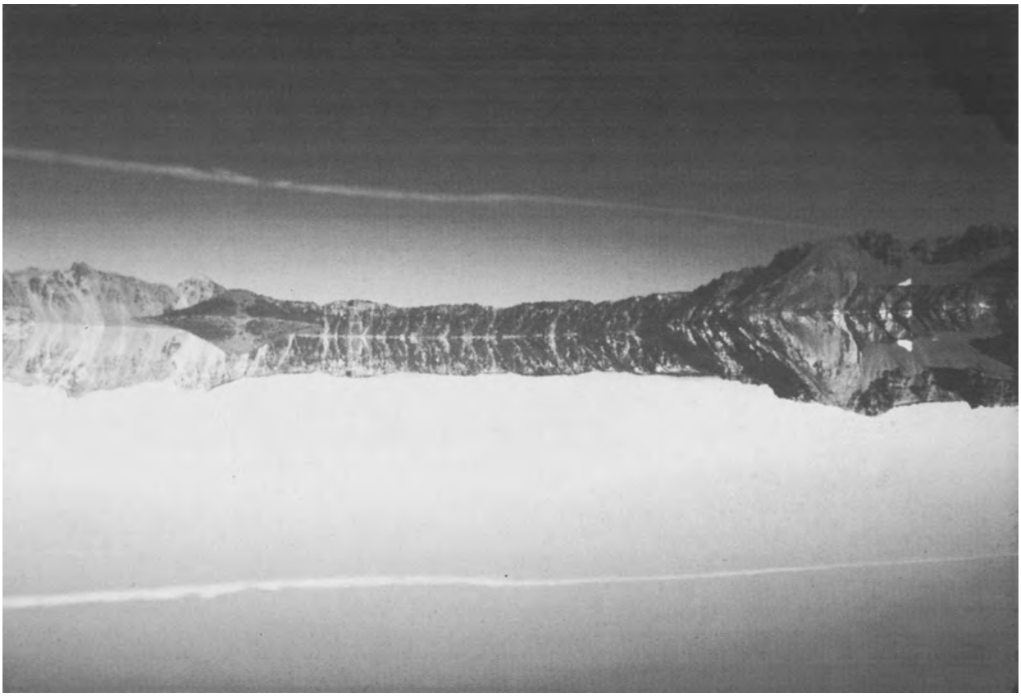

Fig. 7. Crater Lake, Oregon. (Photo by C. J. Vitaliano.)

withstand scientific scrutiny. Others include the Oracle of Delphi, the parting of the Red Sea, the destruction of Sodom and Gomorrah, and the Loch Ness monster.

It is interesting to compare the various outcomes of geomythological research aiming to shed light on these famous stories. Whereas Noah's Flood appears finally to have found a sound explanation, Atlantis now seems unlikely to find one. Interestingly, the Oracle of Delphi may have a geological explanation that confirms ancient accounts of intoxicating gases emanating from underground fissures (Piccardi 2000; De Boer *et al.* 2001), following an interim where early modern scientists had concluded that there was no such explanation for the Oracle's prophecies. As for the parting of the waters before the fleeing Israelites, the destruction of the sinners in Sodom and Gomorrah, and the

Fig. 8. Artist's concept of Mt Mazama in eruption whose collapse created the Crater Lake caldera. (Painting by Paul Rockwood on exhibit at headquarters of Crater Lake National Park.)

Fig. 9. Roman ruins on Vulcano, overlain by ash from the last eruption of Vulcanello.

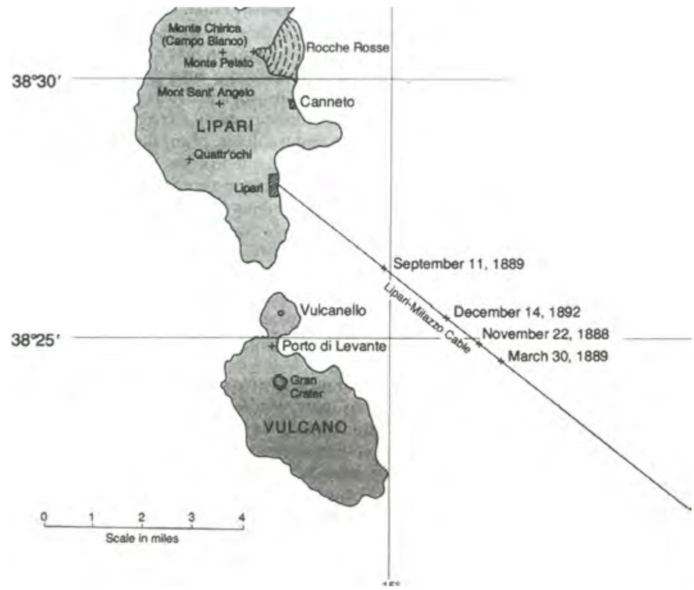

Fig. 10. Map of the Lipari Islands, showing geographical relationships of Lipari, Vulcanello and Vulcano.

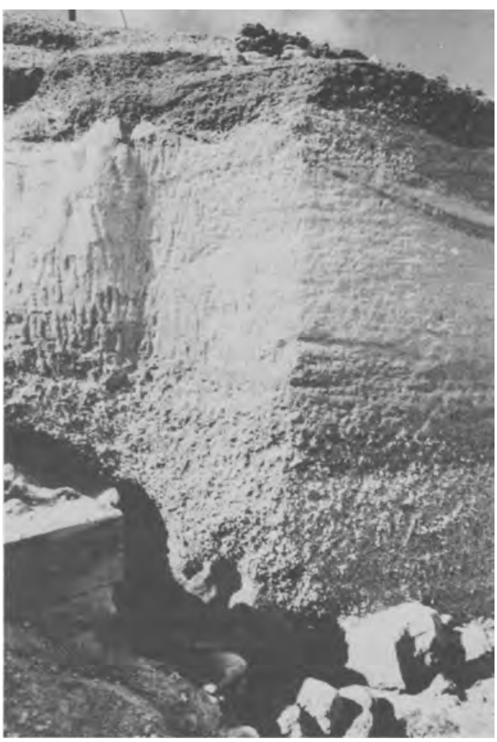

Fig. 11. Volcanic ash deposit on Santorini, showing evidence of a three-stage eruption coincident with the decline of Minoan civilization.

Loch Ness Monster, on the other hand, I think that more research is needed before we can be confident that these have found convincing geomythological explanations.

I am honoured to have been invited to deliver the keynote address for the Myth and Geology symposium at the 32nd International Geological Congress. Please allow me to feel just a little responsible for, and proud of, the progress made in this field and the status it has now achieved in the geological profession. It was exciting, and at the same time humbling, for me to see the variety of topics offered at that session and to survey the recent scientific literature in the field. It is one of the major satisfactions of my professional life to have been part of such a fascinating undertaking.

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Exploring the nature of myth and its role in science

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Abstract: The scientific study of myth is dominated by a paradigm that recognizes myth as having been viewed as truthful narrative history by past traditional cultures and yet is considered false or otherwise suspect by the modern scholars who study myth. Although virtually all scholars recognize that myth was of critical importance for traditional cultures, the attempt to elicit scientific reasons for this importance has led to many competing theories, few of which place an emphasis on the validity of myths as representing the product of actual observed historical natural events. This paradox may hinder our understanding of the origins of myth and prevent us from fully appreciating a critical aspect of why myth was so highly valued by past cultures. To set the stage for our examination of the possible natural history core of myth, we discuss briefly the history of the western scientific study of myth, with an emphasis on geological sciences. We then explore the cognitive structure of myth and provide working principles about how the historical information contained in these myths can be transmitted faithfully through successive generations and can be elicited by scientific study. Although recognizing the extreme complexity of myth as a cultural product, our data indicate that a science-based natural history approach can lead to important insights regarding the nature of myth.

The modern study of myth is an important component of a number of academic disciplines in the social sciences and humanities including anthropology, art history, classics, comparative religion, folklore, psychology, and theology (Dundes 1984). Thousands of scholarly books and tens of thousands of articles and papers have been written about the topic of 'myth' and its study. The roots of myth go back in time to the very dawn of human history, and it is clear from the popularity of recent television shows such as *Xena*, and blockbuster movies such a *Star Wars* and the *Lord of the Rings* that myth continues to be a robust part of contemporary popular culture.

Despite such popularity, the study of myth is beset by a tangled web of claims and contradictions. Although there are some generally accepted notions of what constitutes a myth, most scholars note that there is no universally accepted definition of the term, nor is there a consensus view of its nature and how it should be studied.

Most typically, myths, along with legends and folktales, are viewed in the context of a division of orally transmitted prose or poetic narrative into three often overlapping components (e.g. Bascom 1965). Folktales are non-religious fictional stories meant to entertain, although they often teach a practical lesson or draw a moral. They are also non-historical in that they are not set in any particular place or time. Folktales should not be confused with the term 'folklore', the latter representing folktales and other creative verbal expressions (including also myth and legend) that are studied by folklorists using literary and ethnological techniques.

'Legend' and 'myth' are largely synonymous terms, as is evident in the various contributions contained in this volume. Legends for the most part are semi-historical stories believed true by the cultures in which they are told. They serve to establish local customs, recount the migrations of people, and account for the deeds of heroes. Legends typically combine realism with supernatural and mythic elements. Epic narratives are lengthy stories that often cross the boundary between legend and myth, often told in poetry or rhythmic prose or chant, the telling of which can last for hours or even days. Most traditional cultures had epics,

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among the more famous of which are the Greek *Iliad* and *Odyssey*, the Icelandic *Edda*, the Hindu *Mahabharata*, and the Hawaiian *Kumulipo* genealogical chant.

Myths are cultural accounts of major events that typically happened in the remote past of that culture, when the world was different to today. They are considered truthful by the traditional knowledge keepers who transmit the stories, and mostly are profoundly sacred or at least are imbued with strong religious and ritual overtones. Myths use supernatural characters (gods, demigods or animals) and storylines to express the limits and workings of the world and the place in nature of one's cultural group—the latter also being a general concept commonly referred to as one's 'world view'. Anthropologist William Haviland (1975, p. 337), perceptively, stated that 'The concepts of world view and science are intimately related, and it may be said that myth is the science of cultures which do not verify 'truth' about nature by means of experiment'. The fact that virtually all traditional knowledge keepers believe myths (and legends) to be historically true whereas nearly all scientists presume they do not represent factual historical events is a disquieting conundrum that tells us more about the biases of western science than the nature of myth.

The great diversity of the scholarly works on myth shows that, although being one of the most studied subjects in the history of the social sciences and the humanities, it has not yet been entirely understood. At the crux of this confusion is the simple and straightforward question of whether or not the storyline content of myth has any basis in historical events or processes.

A disdainful view of myth is easily demonstrated by a simple citation analysis of the editorial use of the term 'myth' in headers for articles and reports (none listed), and other sections (such as book reviews, correspondence, and research news; a total of ten cases) in the generally well-respected journals *Nature* and *Science* during the ten-year publication period of 1996 through 2005. Both the infrequency of the use of the term and its implied meaning are striking. The few times that 'myth' is used are virtually always in a pejorative sense, such as 'time to bury misleading myth', 'dispelling a myth', and 'making reality fit the myth'. The two occurrences of the term in *Science* in 2005 ('Sifting myths for truths about our world', May 27; and 'Tracking myth to geological reality', November 4) defy this trend in that they specifically refer to work included in or written by authors of the present *Myth & Geology* volume.

It can be demonstrated beyond any doubt that at least some myths and categories of myth are based on the observation of specific real natural phenomena and events that can be accurately placed in both space and time and can be linked to various types of physical evidence for the historical event. That we can make such unquestionable matches is because pertinent myth storylines contain rich details about the natural events and phenomena, and that one can find unambiguous confirmation and field evidence of their factual occurrence in the places indicated in the account. These accounts also appear to have structural rules and principles that shape the content and oral transmission of myth.

In this paper, we briefly explore past scientific notions of myth and attempt to provide a somewhat different conception of those myths whose roots appear to lie in the observation of natural phenomena and events, in particular geological events. This perspective is slanted toward western science and the myths of western civilization. Throughout Asia and the Indian subcontinent, myth and science evolved together much more parsimoniously in that myth was never considered as being entirely separate from history (e.g. Lowe & Shaughnessy 1999, pp. 11–13; **Chandrasekharam**). For example, the sceptical contempt currently attached by western scholars and historians to China's admittedly fragmentary and reconstructed *Bamboo Annals* (Legge 1994, pp. 105–188), with its striking mysterious and supernatural rulers and culture heroes, might change in the face of an analysis viewed in the context of its traditional roots and with our suggested framework by which to view its mythic content (see also Masse 1998). Certainly the encouraging results of the past several decades of dedicated research expended on identifying the realities of geophysical processes and events in the Bible (e.g. Greenberg 2005; **Roberts**; **Trifonov**) should serve to underscore the rich potential of Asian and Indian historical religious texts.

Because many geologists are largely unfamiliar with the multidisciplinary science of cognition, we summarize basic deductions regarding the cognitive structure of myth that subjected myth to systematic (but reconstructible) distortions through time, and then show that the traditional transmission of myth was generally efficient and conservative. We also discuss how celestial and Earth phenomena and events make up a large portion of myth storylines. Our focus here is on myth in geology, or geomythology (*sensu* **Vitaliano** 1973, and this volume), which we define as 'the study of the geological origin of myths and legends'. Astronomy shares with the Earth sciences a kindred relationship in that both can be used not only to demonstrate the reality of many myths but also to serve as vehicles by which to mine myths for important information about these natural processes and events (Masse 1995; Masse & Espenak 2006; Masse *et al.* 2007).

An overview of past and present scientific trends in the study of myth

Scholars and scientists have puzzled over the nature and meaning of myth since the beginnings of western science more than 2500 years ago, as evident in a sampling of recent literature on the topic (Dundes 1984; Veyne 1988; Patton & Doniger 1996; Brisson 1998; Naddaf 1998; Lincoln 1999; Doty 2000; Schrempp & Hansen 2002). There are far too many scholars, theories, and permutations of theories in the history of the study of myth to do more than provide a brief overview of general trends through time, focusing on those aspects that best serve to highlight our own emphasis on the historical content of myth.

The term mythology stems from the Greek *mythos*—'word' or 'story'—and *logos*, a term that also meant 'word' in the sense of speaking (from the verb *legein* 'to speak'). Thus Greek *mythologia* appropriately meant '[speaking] words about stories'. The ancient Greeks had plenty of things to say about myth (e.g. Brisson 1998; Veyne 1988; Kirk 1974; Graf 1993). Plato considered myth and poetry, such as Homer's *Iliad* and *Odyssey* and Hesiod's *Theogony* and *Works and Days*, to be a linguistic art form, and he often debunked the truth claimed for portions of myth storylines. His main criticism is philosophical in that because myth existed in the context of oral tradition, it was therefore 'unfalsifiable' (Naddaf 1998; Brisson 1998). Plato suggested that one could understand the secrets of the gods by etymological interpretation of their names and epithets, and that the concept of gods originated when people began to observe the regular movement of the fixed celestial heavens. However, Plato's scorn for the historical reality of myth storylines did not prevent him from mentioning the particulars of several myths and thus perpetuating them, perhaps most notably that of the infamous destruction of Atlantis.

Early Greek historians such as Herodotus used the term *mythos* in a derogatory manner to denote false or 'very silly' stories, but still faithfully reported a number of other orally transmitted stories as having merit. He championed the notion that the Greek gods were borrowed from a variety of other cultures, and that interpretations of the names of these other gods and their attributes demonstrated this connection. Thucydides took this derision of myth a step further and denounced all oral tradition (including that used by Herodotus) because of its reliance on memory for its transmission. Later Roman historians continued such rhetoric and polemics through the fourth and fifth centuries AD (Rohrbacher 2002). Roman historians specifically coined the term *fabulae* with respect to myths, from which are derived the modern terms fable and fabulous. This is a clear indication that most Roman historians did not consider myth to represent factual history.

Among the more interesting historical theories of myth was that expressed in the writings of the novelist Euhemeros and echoed by Herodotus and Prodicus, who suggested that the gods were all once living people whose significant deeds became glorified and distorted through time so that their human origins became forgotten. The term 'euhemerism' has been applied to this theory by modern scholars of myth. A similar but still distinct theory was advocated by Palaephatus, a possible contemporary of Aristotle, who provided rationalizations for a number of stories about early heroes and monstrous creatures (Stern 1996). Palaephatus (1996, p. 29) states:

> Now some people, who have no acquaintance with philosophy or science, are too credulous and believe everything that is said to them. Others, of a more subtle and inquisitive nature, totally disbelieve that any of these tales ever happened. My own belief is that there is a reality behind all stories.

Palaephatus uses a number of different types of rationalization (e.g. confusion of human and animal names; puns and double meanings; misunderstood metaphorical expressions) to explain these stories, only a few of which actually relate to natural (e.g. geological) events and phenomena. Unfortunately, despite his claims, it is not possible to judge the actual historicity of the rationalizations by Palaephatus.

Other early theories in antiquity about myth included the likelihood that allegory portrays spiritual qualities and natural phenomena; sociological explanations involving priests and rulers inventing deities with fearful powers so as to maintain social order, popularized by the sophist Critias; and various psychological interpretations (Honko 1984).

Between the time of Plato in the fourth century BC and the Renaissance of the AD 1300–1600s, myth was largely ignored, being replaced by a rigorous adherence to biblical scriptures and text. The rediscovery during the Renaissance of ancient classical texts and the discovery of the New World led to a new exposure to worldwide myths, but the Bible was still the standard against which all new myth from other cultures was weighed.

During the first half of the eighteenth century Enlightenment, considerations of myth were largely divided into three main camps (Feldman & Richardson 2000). For Christians, the Bible was 'gospel truth' whereas myth consisted of pagan fables and religion. Deists tended to include Biblical tradition within the rubric of fables in their search for an initial pure primal religion. Rationalist views, such as by Voltaire, Hume, and Fontenelle, tended to dismiss myth as savage or foolish, and an example of primitive approaches to explanation of the natural world.

Because of the current prevalence of psychological and structural models of myth in the social sciences, it might be anticipated that most modern theories of myth arose during the rise of modern anthropology and psychology in the nineteenth and early twentieth century. In fact, most of these theories had their roots in eighteenth century Enlightenment rationalism and deist thinking (Manuel 1959; Feldman & Richardson 2000). An example is Bernard Fontanelle's precocious but depreciative essay on the origin of fables (i.e. myths), originally written in the 1690s. While avoiding religious polemics, his studies anticipated the comparative psychological approach to mythology. Fontanelle (2000) suggested that primitive ignorance of natural processes and events led to the formation of some myths, and attempted to demonstrate that principles of myth were due to universal mental processes that were separate from climate and the passage of time. Many other Enlightenment scholars contributed to an upsurge of interest in myth. These included David Hume, who focused on the psychological origins of religion and myth; Christian Gottlob Heyne, who drew attention to philological aspects of myth, separating it from poetry but pointing out the effects of poetry on mythology; and Johann Gottfried Herder, who put the empirical study of myth centre-stage in the humanities.

During the late 1700s and early 1800s, Romanticism swept through Europe (Manuel 1959; Feldman & Richardson 2000). It began in Germany (e.g. Friederich and August Schlegel, Wilhelm and Jacob Grimm) and then on to England (e.g. Keats, Shelley, Coleridge, Byron), France (e.g. Chénier, Balzac, Hugo, Michelet), and finally the Americas (e.g. Emerson, Thoreau, Whitman). Myth assumed a 'larger than life' importance during the Romantic era. Knowledge of myth from the Indian subcontinent (e.g. Hindu myth), Egypt, American Indians, and Polynesia coupled with the expansion of philology greatly stimulated the nascent disciplines of culture, language and history. Romantics viewed myth as having a religious quality, allowing modern men the ability to redeem themselves and return to an earlier simplistic relationship between God and nature. For example, the early work by the brothers Grimm with folktales ('fairytales') was an attempt to glean German folklore in order to find mythic evidence of an earlier Germanic heroic period comparable to that of early Greece. It was their assumption that the oldest German history and its associated spiritual forces could be reconstructed from German folklore. Similar efforts were made by other scholars in other countries, thus leading to the use of myth by which to promulgate and glorify nationalism.

During the nineteenth century, the retelling of classical myths became fashionable. Notable was the *Wonder Book for Boys and Girls* by Nathaniel Hawthorne, *The Heroes* by Charles Kingsley, and *The Age of Fables* by Thomas Bulfinch which were all originally produced in the 1850s (Feldman & Richardson 2000). These and similar anthologies bowdlerized the myths, using Victorian prose and sentiment to turn them essentially into nonsense stories.

The modern study of mythology is often attributed to the work of (Friedrich) Max Müller in the latter half of the nineteenth century. Müller was an extraordinary philologist whose mastery of ancient and modern languages was phenomenal. He hypothesized that similar to Latin being the forerunner of modern romance languages, 'Aryan' was the forerunner of Greek, Latin, Sanskrit, Zend, Celtic, and Gothic (Feldman & Richardson 2000). The Aryan language of this earliest 'mythopoeic era' was incapable of abstraction, therefore descriptions of the actions of the living Sun (myths) were substituted for our common terms such as sunrise and sunset. After the end of the mythopoeic era and the creation of new nations and languages, the old words describing the actions of the Sun remained in vocabularies but their origins could no longer be understood. Thus degenerated stories (new myths) were created as explanatory devices. Comparative mythology took the form of studying myths from related cultures to attempt to work back in time through this 'disease of language' (as earlier coined by Friedrich Schelling) so as to uncover the original pure myths and their meanings.

Müller's 'solar mythology' fell completely out of favour towards the end of the nineteenth century, with his philological approach to comparative mythology being replaced by more fashionable comparative anthropological, sociological and linguistic/symbolic approaches (Dorson 1955; Lincoln 1999). These late nineteenth and early twentieth century scholars included E.B. Tylor, Andrew Lang, Sir James George Frazer, Émile Durkheim, Marcel Mauss, and Arnold van Gennep. They perceived myths as being embedded in oral rather than textual traditions, to be studied in association with ritual performances and certain social constructs, rather than solely in the context of language and literature.

The modern twentieth century theories of myth that evolved from this post-Müller intellectual milieu can be divided into four general but not necessarily mutually exclusive categories (Honko 1984; see also Lincoln 1999; Doty 2000). The first is that of the 'psychological school' of myth, initially deriving from Freud's analysis of myths, but more recently allied with Jung's view of the presence of universal archetypical motifs and complexes. More recent notable practitioners include Mircea Eliade and Joseph Campbell. Myth variously serves as a source of cognitive categories; as a form of symbolic expression; as a projection of the subconscious; and as an integrating factor in our adaptation to life or world view. The Hungarian classical scholar, Carl Kerényi, who worked closely with Jung, glimpsed the possibility that natural processes (such as Moon phases) could have an influence on myth and cosmology, in contradistinction to Jung (Kerényi 1993). However, Kerényi focused on observed cosmic processes as opposed to specific natural (e.g. geological) events as being the source of 'mythologems' or recurrent themes of myth (Jung & Kerényi 1993).

Joseph Campbell is perhaps best known proponent of the psychological school of myth, which in one form or another likely includes most current folklorists and anthropologists. His approach to myth is perhaps best stated in response to the question of why people tend to use the word 'myth' to mean something that is untrue or an erroneously held belief (Campbell 1989, p. 21):

> I can understand why that idea arose. Myth is metaphor. The imagery of mythology is symbolic of spiritual powers within us: when these are interpreted as referring to historical or natural events which science in turn shows could not have occurred, then you throw the whole thing out.... Myths come from where the heart is, and where the experience is, even as the mind may wonder why people believe these things. The myth does not point to a fact; the myth points beyond facts to something that informs the fact.

The second school of myth, the 'sociological' or socio-functional, derives from Durkheim's view that myths arise in the human response to social existence. They mirror the manner in which society represents the world and humanity, and serve as a moral system and cosmology, and as history. Myths and their associated rituals renew human belief systems and strengthen social ties. Durkheim rejected the notion that myth arises out of extraordinary manifestations of nature. Rather, myth serves as a charter of behaviour; as a legitimization of social institutions; as a marker of social relevance; and as a mirror of social structure and culture. More recent adherents to the socio-functional school of myth include Bronislaw Malinowski and Anthony F. C. Wallace.

One of the more interesting and comprehensive theories popularized during the twentieth century is that of the structural analysis of Claude Lévi-Strauss, which constitutes our third school of myth (Lincoln 1999; Doty 2000). 'Structuralism' descends from the nineteenth century synchronic structural linguistic theories of Ferdinand de Saussure, along with the more recent rational and patterned organizational approach of Georges Dumézil in the early to mid-twentieeth century. Lévi-Strauss was interested in explaining why myths from cultures around the world have so many striking similarities. He favoured studying the structure of myth rather than its content. He considered that myths are made of units that are put together according to certain structural rules, and that these units form relationships with each other, based on binary opposites. The ahistorical (or even antihistorical) approach of Lévi-Strauss (1969, p. 240) is well captured in the following observations from his study of South American myth:

> In granting that myths have an astronomical significance... the astronomical context does not provide any absolute point of reference: we cannot claim to have interpreted the myths simply by relating them to this context. The truth of the myth does not lie in any special content. It consists in logical relations which are devoid of content, or, more precisely, whose invariant properties exhaust their operative value, since comparable relations can be established among the elements of a large number of different contents.

The fourth of these defined schools of twentieth century myth has been termed 'historical' (Honko 1984) although we would suggest that a more salient term would be 'historical context'. This school does not actually consider the potential historical content of myth but rather the impact of the social and historical environment in which myth is told. From this point of reference, myth serves as the result of a historical situation; as religious genre; and as religious communication.

A number of useful recent edited volumes (e.g. Patton & Doniger 1996; Schrempp & Hansen 2002) and syntheses (e.g. Lincoln 1999; Segal 1999; Doty 2000; Von Hendy 2002) regarding theories of myth in the social sciences and the humanities have attempted to characterize these general theories and their proponents, and to bring them forward through the end of the twentieth century into our era of semiotics, hermeneutics, deconstruction, and postmodernism. These have one fundamental shared characteristic—none is seemingly willing to suggest that a real observed natural process or event may lie at the core of myth storylines, other than perhaps as an aside to their overall theories. Even the degenerative or transformed history of Euhemeros, still popular in the nineteenth century, is no longer viewed as a viable theory by most scholars of myth (Alan Dundes, pers. comm. 2005).

There are important exceptions to the general statement that most modern theories of myth lack consideration of the historical observation of natural process as being part of the myth storyline. These exceptions represent the potential contribution of the physical and cognitive sciences and our own nascent theoretical school of geomythology, as expressed by Dorothy Vitaliano (1973) and various indigenous scholars who know and understand the value of their own myths (e.g. Deloria 1995), and of course by the many contributors to this volume.

Geology and myth

As we have seen, the study of myths is an extremely complex and faceted subject, and much effort has been devoted to its understanding. Many authors have, since antiquity, recognized the potential historical value of myths. A large part of Greek myth is now known to be politico-religious history. The destruction of Troy described in the *Iliad* was finally recognized to be real history only in 1870, when Heinrich Schliemann unearthed the ruins of ancient Ilion. Also, among many other examples, the history of Theseus killing the Minotaur in the Palace of Cnossos, is commonly regarded as a refracted image of the historical final defeat of the Minoan power in the Aegean region (*c.* 1400 BC). Similarly, at Delphi, the slaying of the snake-dragon Python who guarded the sacred chasm of Ge, the Earth, by Apollo, and the consequent shift of ruler of that famous Oracle, has been suggested as a description of the religious passage from the feminine cults of the matrilineal system to the more patriarchal deities.

An example that can serve to illustrate the historical reality lying behind the mythological narration is provided by the famous combat between Heracles and the Hydra of Lerna. The analysis of this famous story deserves some attention because it can provide useful insight regarding the origin and factual basis of a myth, as well as other mechanisms of myth-making (see Piccardi 2004).

The slaying of the Hydra has been one of the myths most widely considered, since antiquity, to rest on natural processes. The always regenerating many heads of the Hydra have been interpreted as a symbol of the many water-sources feeding the large swamps near Lerna, and the struggle between Hercules and the monster therefore an image of the draining effort. After finally chopping her main 'head', said to be immortal, the hero buried it forever, putting a huge and heavy rock on it. Kirk (1974), following an interpretation first proposed by Palaephatus, maintains instead that this myth more likely records ancient political events. In a manner similar to the killing of the Minotaur in the Palace of Knossos, the killing of the Hydra at Lerna, as well as the related myth about the killing of the Nemean lion (the first two labours of Heracles, the Mycenaean hero), seems to contain memories of ancient political events in addition to references about fertility rites.

Strong connections are known to have existed between Lerna until the Early Bronze Age (Lerna III), and the Cretan civilization. The end of Lerna III was in part evidently due to the invasion of the Indo-European Greeks in *c.* 2200 BC. These patriarchal Indo-European-speaking invaders, from whom later the Mycenaeans would originate, marked the end of the Early Bronze Age in many areas of the East Mediterranean. According to typical Minoan settlement patterns, the political and religious centre and the 'head' of the local community, would have been the Palace of Lerna ('House of Tiles'). The destruction of the Lernean Palace (2300–2200 BC) is marked by the peculiar singularity, seemingly unique in the whole of Greece, that the Palace was buried by the conquerors under an enormous funerary tumulus (e.g. Caskey & Blackburn 1997), considered nevertheless an enigma by archaeologists because it contains no tombs.

This unusual tumulus, deliberately positioned above the 'head' of the defeated society, strictly corresponds to the huge mythological rock placed by Heracles above the head of the beast (Piccardi 2004). As such, the facts described by tradition largely coincide with what can be observed on the site. Even the position of the buried Palace, corresponds to the location of the head of the Hydra, buried in the myth on the side of the road to Elaeus. The mythological account can therefore be regarded as quasi-historical, recalling an Early Bronze Age phase of the Mycenean conquest of the Greek mainland against the Lernean Minoan related settlement. The seeming truth behind the myth, and the relevance of the tumulus itself, apparently was already forgotten by the end of the Middle Helladic period (*c.* eighteenth–seventeenth century BC), as indicated by the fact that the tumulus was then reoccupied by the village after being left untouched for nearly 500 years. We can thus consider this date as the moment when the local historical memory transmitted by oral tradition became a new myth as transmitted by Hesiod, Ovid, Apollodorus and other ancient writers, because the politico-religious factual story lying behind the myth had been forgotten.

Western scientific thought started at the turn of the sixth and fifth centuries BC, with Greek philosophy. As discussed by Karl Popper (1972), what was new then, was a new attitude toward the myths, jealously preserved by priests:

> In place of a dogmatic handing on of the doctrine we find a critical discussion of the doctrine .... Doubt and criticism now become,

in their turn, part of the tradition of the school. ... It is only in the course of this critical discussion that observation is called in as witness. ... On the other hand, ... the task which science sets for itself [that is the explanation of the world] and the main ideas which it uses, are taken over without any break from prescientific mythmaking.

Geology is a relatively young discipline. The term 'geology' was used for the first time by Richard of Bury, Bishop of Durham, in 1473, to indicate jurisprudence as 'terrestrial' doctrine as distinct from theology. The term gains a meaning nearer to the actual one with the pioneering works of Agricola (Giorgio Bauer, 1494–1555), Ulisse Aldovrandini (1522–1605) and Stenone (Niels Steensen, 1638–1686). It was with James Hutton (1726–1797) and his book *Theory of the Earth* (1795), Abraham G. Werner (1749–1817) and Charles Lyell (1797–1875), with *Principles of Geology* (1830–33), that geology attained the rank of a science.

Before geology became a recognized science, and for a long time after (through the first half of the nineteenth century), canonical belief regarding the nature and origin of the universe was as described in the Bible. An interesting summary of the conflict between religion and science and of the evolution of the scientific thought in recent times is given by the extensive work of White (1898), and can be found in **Roberts**.

In particular Noah's flood was considered a scientific truth, and was invoked as explanation for many geological phenomena, such as the finding of fossil shells on high mountains and the formation of moraines and other young sedimentary deposits. It was only in 1840, with the recognition of the theory of glaciations proposed by Louis Agassiz (see **Berger**), that geology finally separated from the literal biblical view. On the other hand, the development of comparative mythology, by recognizing the similarity and derivation between the biblical narrations and other world mythologies, in particular from the Middle East and Mesopotamia, helped to circumvent the dogma of biblical 'truths'. Fundamental to this aim was the discovery and translation of the Mesopotamian account of the deluge (the Gilgamesh epic) in 1872. Biblical catastrophism was thus surpassed in favour of the modern theory of uniformitarism. (See Masse 1998, 2007 for the surprising results of a recent comparative mythology and environmental archaeology analysis of the flood myth).

There is evidence that, from the Palaeolithic, for more than 30 000 years, a principal divinity may have been the *Great Mother Goddess*, alleged Lady of Life as well as of death (see Goodison & Morris 1998, for a recent balanced treatment of this concept). Seemingly, rituals and cults were not directed so much upwards, to the celestial heavens, but rather downwards, to 'Mother Earth'. For example, archaeology and ethnographic literature document the ritual placement of various kinds of offerings (including occasional human sacrifices) into trenches, natural crevasses, volcanic craters, wells and other holes in the ground. Fissures and caves have been of special importance worldwide to past cultures (e.g. Piccardi 2000; **Aringoli *et al.***). It is not surprising therefore that much attention would have been paid to geological phenomena, and in particular those more connected with the underworld, such as volcanoes and earthquakes. Such impressive phenomena, which aroused awe and wonder, likely would have been linked cognitively to the 'womb' of Mother Earth. Regardless of the merits of such an argument (e.g. for a differing view of early deities see Hodder's (2006; Balter 2004) research at the Neolithic town of Çatalhöyük), it is clear from the pantheons of new divinities, both male and female, appearing from the fifth to the second millennium BC that the geophysical forces of nature were well represented among the attributes of these deities and demigods.

In a similar vein, geological phenomena and events have likely always played a central role in myths because of their critical importance to traditional cultures. Stability of the landscape and climate were expected. Water was the primary source for life, so that springs, rivers and lakes attained special consideration. Caves were among the first dwellings of men during the Stone Age (... brush shelters were also used but do not well preserve in the archaeological record), and stone was a primary material for making tools. Rocks, such as flint and obsidian, were particularly valued for their cutting and visual properties (**Hodgson**) and large scale trade of these stones was developed and perpetuated. Huge fossils bones were interpreted as remains of giants or dragons (**Agnesi *et al.*, Berger**, and **Mayor**). Other fossils attracted some sacredness and were incorporated into sacred architectures (**McNamara**) or venerated on altars (**Chandrasekharam**). Mythical explanations are also typically found for meteorites (**D'Orazio** and **Masse & Masse**).

Myths were also created to explain unusual landscape features and natural landmarks, and were commonly prompted by mountains, rocks and boulders seeming to be out of place. Examples of these latter are described by **Motta & Motta** and many similar cases are known elsewhere in the world. Ancient sacred lore abounds in such mythical explanations for the remarkable appearance of certain natural geological formations and structures.

In recent years there is an increasing awareness, at least among geologists, that some legends and myths are based on natural phenomena and that, by using a multidisciplinary approach, there is the possibility of identifying records of past geological events in particular narratives (e.g. Vitaliano 1973; Bentor 1989; Guidoboni 1989; Nur 1991; Vogt 1991; Ryan & Pitmann 2000; Ryan 2004; Piccardi 2000, 2005; Ludwin et al. 2005).

One of the more useful applications of geomythology includes the possibility of adding to the historical record on natural catastrophes, thus helping their hazard mitigation. Several of the most damaging geophysical catastrophes like earthquakes, tsunamis, volcanic eruptions or meteorite impacts, were probably recorded in myths, for two reasons: first because they were very unusual and mysterious phenomena, and, second, because their impact on local societies made them important events to be remembered. Various examples of mythological accounts of such catastrophic events are presented in this volume.

Probably the best known example concerning volcanic eruptions is found in the myth of the destruction of Atlantis, interpreted as a refracted image of the supereruption of the Thera volcano around 1625 BC (Friedrich *et al.* 2006; Manning *et al.* 2006). Similarly, the fight between Titans and Olympians, and the imprisonment of Typhoon under the volcano Etna, has been interpreted as a memory of some period of intense activity of Etna and other volcanoes in the Mediterranean (Wyatt 1996; Barber & Barber 2005).

A biblical example related to earthquakes, analysed by Bentor (1989) and Nur (1991), concerns the crossing of the River Jordan and the consequent famous destruction of Jericho's walls (Joshua 3, 4 and 6). In this case, the location of the site where the events occurred, and the details described in the text, permitted the identification in this account of a strong earthquake which induced the collapse of the nearly vertical banks of the river, at the spot where it crosses the major strike-slip Jordan Valley Fault. The same phenomenon happened again in the earthquake of 1546, when the water of the river was dammed and cut off for two days, and in the earthquakes of 1906 and 1927. The destruction of Jericho was listed as seismic event in a fifteenth century catalogue of earthquakes (Manetti 1457), and an earthquake link between the drying of the Jordan and the collapse of the walls of Jericho, was already recognized in antiquity (Psalm 114:3–8).

The most notable example of an important myth rooted in geology is the set of myths associated with the famous Delphic Oracle, in Greece, who continued her functions for almost 2000 years and whose influence spanned the ancient western world. The priestess was said to utter her oracles by inhaling vapours that arose from a chasm in the earth, above which she was seated. The existence of this sacred chasm had been dismissed by classical scholars as a mythological invention because no trace of it was discovered during modern archaeological excavations. Recent geological investigations have instead revealed that a natural gas-exhaling chasm in the earth indeed existed at the site of the oracle (Piccardi 2000; De Boer & Hale 2000), although it may have closed prior to the modern era. The oracle site is in fact positioned directly across the surface trace of a seismic fault which potentially could rupture during earthquakes, thus creating a fissure in the ground from which gases like carbon dioxide, hydrogen sulphide, or methane could originate. De Boer *et al.* (2001) and Spiller *et al.* (2002) have determined the modern presence of ethylene (ethene), although the ancient presence of other gases such as those previously mentioned is also possible at various times through the long history of this location. An earthquake, albeit clothed in mythological images, is described at the origin of the Oracle in the Homeric Hymn to Apollo, coincident with the slaying of the snake-dragon. It is reasonable to assume that other oracle locations in Greece and elsewhere may have similarly originated due to the presence of emitted gases.

Further examples of legendary earthquakes are provided by the myths of the apparitions of Archangel Michael at Colossae (AD 60, **Piccardi**) and at Monte Sant'Angelo (Piccardi 2005). The legend of the apparition of Archangel Michael at Monte Sant'Angelo (traditionally dated AD 490–3) distinctly reports a large earthquake, described as an '*immenso tremore*', affecting the area. A sanctuary, still existing today, was built where the 'footprints of the Archangel' were claimed to have been discovered, on the day after the main shock, in the epicentral area. Through use of a multidisciplinary approach, combining palaeoseismic and historical data, the legend can be demonstrated to represent a seismic surface faulting event before the eighth century AD. A recent, small scarp about 1 m high, on the Monte Sant'Angelo fault, can be related to this legendary earthquake which in turn seems to correspond to the local maximum magnitude ($M = 6.7$). The comparison of palaeoseismic evidence with the traditions of the sacred site and the evolution of the sanctuary has allowed the interpretation that the famous 'footprints' apparently were secondary ground ruptures related to surface faulting on the nearby local active fault (Piccardi 2005). The description of a strong earthquake at Monte Sant'Angelo is reported in two distinct legends. The two legends show remarkable similarities in that both refer to the same sacred site, and point (although in different ways) to ground ruptures related to the earthquake. The main witness in both tales is the unnamed first Bishop of the near town of Siponto. These parallel legends may represent two different traditions based on the same natural event: a large earthquake that produced surface faulting along the nearby active fault.

Toward a natural sciences conception of myth

It is our task to weave these many disparate historical threads of myth into a meaningful conceptual tapestry that can be understood and appreciated by modern science. In order to do so, we must first recognize three interrelated aspects of the context and character of 'traditional cultures', that is those groups not heavily influenced by the patterns of western culture and scientific thought.

First and most important, traditional cultures were/are largely holistic. These groups do not normally segment their natural universe, society, and knowledge systems into separate and independent components. It is a system in which everything is interconnected to one degree or another. Religion, myth, economics, subsistence, governance, kinship, and the events and processes of the natural world are all tied together in intricate interwoven layers. Thus events and processes in the natural world shape or influence other aspects of society.

This contrasts with modern western society in which we take great pains to divide our world into a number of small separate niches. Religion is separate from science, and tends to be separate from systems of governance. The sciences are typically divided into social science versus physical science and the life sciences. These sciences are each divided in a number individual disciplines, which in turn are divided into subdisciplines. It is not surprising that such segmentation of knowledge hinders our attempts to understand past holistic societies and the myths associated with those societies.

The second aspect of traditional culture and knowledge systems that modern western science has trouble grasping is that in a holistic world, major natural events and processes happening on the Earth and in the sky tend to be viewed as having a life of their own related to but separate from human lives. For example, the sky is not simply the fixed celestial heavens of regularly moving and largely predictable stars, constellations, planets, Sun and Moon, but also is the abode of a large number of transient phenomena and events such as comets, novae, meteors and meteor storms, eclipses, auroras, and other such celestial and meteorological happenings. To the naked-eye observer, these are of differing motion, colour, size, duration, and location, often with associated real sensory physical characteristics such as the sounds of bolides and the suite of physical effects that accompany total solar eclipses and meteorite impacts (Masse 1995; Masse 2007; Masse & Espenak 2006; Masse *et al.* 2007). A similar situation existed for Earthly geological events and processes. Thus the sky and the Earth were viewed as being occupied by real sentient beings that were other than pure human. In addition, certain sporadic natural events (such as the recurrence interval of volcanic eruptions) were viewed as divine or supernatural behaviours expected to recur in the future. We will return to these themes later in this paper.

The third aspect of traditional culture and knowledge systems was that the fact of being human was at times stressful and full of fearful events and consequences. Far from being a 'Garden of Eden', the world was periodically subjected to floods, earthquakes, droughts, volcanic eruptions, disease, pestilence, cosmic impacts, and other powerful natural events. Cultural groups had a collective memory of such events and other processes reaching back in time hundreds and even thousands of years. This is evidenced, for instance, by the fact that a surprising number of different cultures seemingly recognized precession, the slow predictable apparent movement of the fixed celestial heavens (particularly the zodiac) due to the tilt of the Earth's axis, a process lasting nearly 26 000 years for a complete sequence through the zodiacal constellations. Partly in order to buffer such stress and fear, an attempt was made by traditional cultures to systematically organize their natural and social world into harmonious cosmological packages, which were in turn reinforced by ritual observances and performances. The fixed celestial heavens and common geological processes became a part of these cosmological packages.

And this brings us back to our attempt to provide a satisfactory and straightforward definition for myth concerning our exploration of the relationship between myth and geology. A possible definition especially for those myths occurring as part of the religious cosmological and cosmogonic core of a given traditional culture is the following:

> Myth is a structured narrative, in general derived from oral transmission, and typically created or assembled and perpetuated by knowledge specialists who use supernatural elements and images in order to categorize and explain observed natural phenomena and events that are of perceived vital importance or of special relevance to the social order and well-being of a given culture

Having stated our definition of myth, we do not wish to demean the value and insights of the many other theories of myth. Although we choose to emphasize the natural roots of myth, myth does not lack ritual aspects, psychological content, dichotomous or binary-opposite structural rules, historical bias, or literary value. It has all of these and more, as should be evident from the various studies contained in the present volume.

The cognitive structure of myth

To understand how certain myths can carry information about natural events and how to work with that information, one needs to understand certain principles about how myths develop (see Barber & Barber 2005 for a much fuller account). These principles, originally collected empirically over many years, are closely connected to what cognitive scientists and linguists now know about how the human brain handles language, raw data, memory (including memory failure), and explanation, a junction of cognitive anthropology and anthropological linguistics on the one hand (e.g. D'Andrade 1995; Foley 1997) and cognitive psychology or neuropsychology on the other (e.g. Rubin 1995; Eichenbaum 2002; Ashcraft 2005). Several of our observations regarding the cognitive structure of myth are referred to as 'principles' here and elsewhere (Barber & Barber 2005); however, the use of this term specifically emphasizes its sense as an empirical deduction. Our use of these principles is meant to enable the reader to visualize aspects of the cognitive structure and diachronic properties of myth. Ultimately, these stated principles will require additional study and validation.

Mythology is a function of the oral transmission of linguistically encoded data. In a non-literate culture, a young person learning an important practical craft like hunting, cooking, weaving, or toolmaking learns it primarily by watching his or her elders and by practising, by visual and kinaesthetic apprenticeship rather than through words. But information about important past events cannot be learned that way. The events must be encoded into language and transmitted entirely by talking and the next generation will then have to remember these tales. Why should they try? Because the information in the stories is important, nay crucial, for the preservation of the group; as crucial as knowing how to make fire or obtain food. After the devastating tsunami of 26 December 2004, in the Indian Ocean, it was reported (CBS News 2005; National Geographic News 2005) that certain tribes in the Andaman Islands survived because of a myth passed down over the generations about 'a wave that eats people'. This wave (actually seven waves according to the story) was said to be brought on by the angry spirits of the ancestors, and could only be avoided by immediately running to high ground if the ocean is observed to recede rapidly.

Consider another type of important information: how to navigate by the stars. The stars are a bunch of more-or-less randomly distributed points of light, so how are you going to remember which is where? We still use the system devised by the old myth-makers: start by dividing the stars into Rorschach-groups. Call this prominent group, say, a hunter (Orion); that one looks like seven sisters (the Pleiades). Fine, now it's easy to remember: the hunter is forever chasing the sisters across the sky! (A story of hunters chasing a bevy of girls is a lot more likely than girls chasing a hunter, so even the direction of movement is encoded memorably.) Add the previously mentioned notion that the sky is a real place populated by sentient beings (deities and demigods) who are capable of 'motion-freezing' and thus immortalizing people and events in the fixed celestial heavens, and likewise throw in notions about the appearance of the Pleiades in relation to agricultural and annual cycles of renewal. Myths are not just 'silly cultural fiction', they are carriers of information once deemed extremely important.

Recovering that original information, however, is not always easy or even possible, for several reasons. The most crippling reason is the 'Silence Principle' (Barber & Barber 2005, pp. 17–33):

What everyone is expected to know already is not explained in so many words

Myths can't afford to waste precious words on what the members of that culture should already know; so it isn't said. Unfortunately: What is never said may eventually be forgotten entirely.

We can glimpse this process in the writings of Snorri Sturluson, who lived and wrote in Iceland just after it became Christian. Precisely because people were rapidly forgetting the traditional knowledge, Snorri strove to write down the old myths and sagas, sometimes stating explicitly the 'assumed' knowledge that was getting lost. Thus, in telling how Loki, chained to the rocks beneath a venomous serpent as punishment for his misdeeds, would shudder whenever the poison dripped onto his face, Snorri adds: 'You call that an earthquake' (Sturluson 1971, pp. 85–86).

Because of lost assumptions, we cannot hope to reconstruct everything about every myth. But we can help ourselves along by at least recognizing our own unstated assumptions that get in our way. Consider the Klamath Indian story of why the Klamath viewed as lethally dangerous a magnificent lake in their territory, the one we now call Crater Lake, Oregon (see also **Vitaliano**). According to this tale (written down very soon after Europeans first arrived), the Chief of the Below World got angry at the Klamath tribe and came up to the mouth of his tall mountain, threatening to send the Curse of Fire; whereupon the Chief of the Above World challenged him to battle.

The former spewed fire, burning ash, and red-hot rocks, followed by a river of fire that came all the way down the mountain. Terrified, the Klamath sent two medicine men who sacrificed themselves by jumping into the great firepit up above. Then the Chief of the Above World pushed the entire top of the mountain in on the Chief of the Below World, whose voice was never heard again and slowly over the eons the hole filled with water (Clark 1953, pp. 53–55).

Geological analysis confirms that there was once a mountain on that spot, and that it erupted violently, spewing around 50 km^3 of magma, ash, and lava-bombs until the emptying of its magma chamber caused the caldera walls to collapse inward, forming a pit some 4000 feet deep that later filled with water (Bacon 1983; Klug *et al.* 2002), just as the myth says. Since the eruption happened almost 7700 years ago (Zdanowicz *et al.* 1999), this myth must have been carried down for nearly eight millennia.

Our own (typical) assumption, as we read something like the Klamath myth, is that since we do not agree with the Klamath explanation for this fiery occurrence, there is nothing worth looking at scientifically in the story. But one of our problems as modern observers of myth (or even observers of events such as car accidents) is that people tend to present their observations and their assumed explanations all tangled up together. On the other hand, if we *strip away the explanations proffered but keep and investigate the observations*, we can see that the observations in myths are fairly accurate (as far as they go), and at the very least they alert us to something of geological interest that happened in a particular place. Furthermore, if we take for the moment the Kalamath step of *assuming* that the Curse of Fire was caused by a wilful being (more of this below), then we can see that the quite logical strategy is to placate that being—with a gift, bribe, or sacrifice—which is exactly what they did in their attempt to prevent or delay future destructive eruptions. That is, the myth unrolls logically from its own premises—it is not haphazard. In fact, there are many myths concerning geological events in the Pacific Northwest (e.g. **Ludwin *et al.***), where until the nineteenth century the population remained stable, that is unreplaced by cultures that had not witnessed the events and therefore did not know what was referred to.

Paying attention to the reported response can help us ferret out what the underlying explanations and unstated assumptions were, which usually come down to us all tangled up with the observations. From little observational 'snapshots', an entire newsreel is constructed. Everything is set out in terms *not* of what was observed but of assumed explanations. For example, the normal natural decomposition processes of a corpse in a coffin can become a macabre tale of horror to uninformed observers (Barber & Barber 2005, pp. 31–33). Barber & Barber (2005, pp. 30–33) have nicknamed this common myth-making process the 'Movie Construct'. Seriously mismatching courtroom recollections of accidents and crimes show that the impulse to indulge in the Movie Construct is quite as strong with us as with ancient people.

Why are we humans, ancient and modern, so hell-bent on explanation? Cognitive scientists have a lot to say about that; what matters to us here is that we do demand explanation of some sort, and if we can't stockpile enough data to figure out the true cause and effect we turn elsewhere. In particular, we explain things by saying, 'It's this way because it's like *X*'. In mythology, this can be stated as the 'Analogy Principle' (Barber & Barber 2005, pp. 34–40):

> If any entities or phenomena bear some resemblance in any aspect, they must be related

So if I like to hurt those who have hurt me, then probably the Chief of the Below World does too, that's *why* he is sending the Curse of Fire. And if, when I'm angry, I might relent if the offender gives me a major present, then, by analogy, the Chief of the Below World may relent if offered the greatest of sacrifices. Analogical reasoning is everywhere in mythology, but it gets tangled up with another problem that we must investigate before we can proceed.

Most of the time we navigate through life by probability rather than by logic. We become habituated to routine behaviour and develop routine expectations. Our brains accumulate a lot of practical observations, and when something new happens, we look for the closest match in our data rather than assess the logic of the situation (which takes us much longer).

This type of reasoning can lead to deadly consequences. In the case of the 2004 Indian Ocean tsunami, it is likely that some coastal villagers who were used to the subsistence gleaning of reefs at extreme low tide, saw the (much too rapidly) exposed bare reef as an opportunity to collect stranded fish rather than as a signal to immediately run to high ground. Such an unfortunate response has been reported elsewhere in similar circumstances. For example, hundreds of Hawaiians flocked to various exposed reefs immediately prior to a tsunami event in 1837, dozens of whom drowned in those locations where the heights of runnup were greatest (Jarves 1843, pp. 20–22). Interestingly, many other Hawaiians were observed to be greatly alarmed at the initial receding waters and sought the shelter of higher ground, perhaps mirroring the self-preserving behaviour of those Andaman tribes in December 2004 who were influenced by their oral traditions.

An implication and its reverse are not automatically equivalent. In mythology, as in practical life, we often behave as if they were and apply rather liberally what logicians call the *Fallacy of Affirming the Consequent*. In the above example, we know that if (P) when it is the farthest ebb of a spring tide, then (Q) fish and other subsistence items will be exposed on the reef. But it doesn't follow that if there are fish exposed on the reef (Q), it's due to the ebb of a spring tide (P).

Perhaps the furthest-reaching application of this fallacy for mythology is what has been called the Wilfulness Principle (Barber & Barber 2005, pp. 41–52):

> Humans will things to happen, then set about to make them happen. Therefore, if something happens, it must have been willed

If hot rocks fly out of a mountain, someone must be lobbing them. If the Nile suddenly rises each summer, it must have *chosen* to do so. If a tree falls over, or a house or a mountain falls down, or if islands suddenly appear or disappear (**Nunn & Pastorizo**) someone must have pushed or pulled it. (Surely this is an easier hypothesis than our modern one concerning gravity) Our literate modern world permits the massive storage of knowledge that both allows us to overcome wilfulness as an explanation for natural phenomena, but also blinds us to the logic of those wilful explanations that are present in myth.

The Wilfulness Principle provides a rationale for spirits and deities, often invisible, who can be anywhere and do anything, and can provide explanations for practically everything. Thus we get fantastic animals and associated place names, such as the earthquake-related Fenris wolf and his abodes in Nordic tradition (**Morner**); the eruptive products of Hawaiian volcano demigoddess Pele and her large supernatural family (Easton 2004); historical figures transformed to supernatural heroes such as the role of Ali, son-in-law of the Prophet Mohammad in creating and destroying the travertine dams and lakes of Afghanistan (**Bourrouilh-Le Jan *et al.***); or even the 'sweat' of the Argonauts staining the rocks of Elba Island (**Dini *et al.***).

This Wilfulness Principle, in turn, is subject to what has been termed the Kinship Principle (Barber & Barber 2005, pp. 44–49):

> Since family members typically resemble each other, phenomena that resemble each other must be kin

The Sun and Moon are often viewed as (wilful) siblings, as are the winds, while the volcanoes of the Pacific Northwest are typically viewed either as siblings or as the Sky Spirit's various wives—who throw rocks at each other when they become jealous, just as human rivals might.

And now we come to another major hurdle for modern thinkers. We expect *one* explanation for something, but mythical thinking celebrates the Multiple Aspects Principle (Barber & Barber 2005, pp. 53–70):

> A phenomenon may be explained mythically as many times as it has 'significantly' different (analogizable) aspects

Thus we view it as 'inconsistent' that the ancient Greeks or Egyptians should have had several different sun gods. We see one sun, so we expect one god. But the sun has many important aspects, each of which affects us differently. Thus Greek Helios (like Egyptian Aten) refers to the round disk of the sun that shines fiercely above you; but Greek Hyperion (literally 'going over') encapsulates the sun crossing the sky each day (Fig. 1); Eos and Hesperus represent the sun respectively in its crucial aspects of coming up in the morning (creating the day) and going down in the evening (cutting off the day); whereas Apollo, that vibrant and handsome youth, represents the sun's life-giving properties (among other things).

With so many aspects of 'single' phenomena represented in a culture's mythology, we must cultivate the habit of moving our mental cameras around to as many viewpoints as we can find, so as to help solve what is called the Camera Angle Problem (Barber & Barber 2005, pp. 56–59):

> To understand what a story is talking about, we may have to observe the situation from a very particular viewpoint.

Multiplicity of aspects can come from another source, however, than simply the variety of possible analogies that one person or culture can come up with. We must also recognize that the same event may end up being viewed from different camera angles by different groups of people for geographical reasons. For instance, during a major volcanic eruption, people engulfed some distance away by the volcano's ash cloud will have very different experiences to encode into myth than the people swamped by flows of lava or mud, let alone than those people who saw only its glow from afar. Thus the *c.* 1625 BC catastrophic eruption of Thera in the Aegean generated such wildly different myths among the surrounding peoples that it takes a 'zonal analysis' (see also **Masse & Masse**), based on modern geological findings, to puzzle the pieces back together to see that they all record (different aspects of) the same event (Barber & Barber 2005, pp. 75–87). Thus the myths from Egypt record in scattered form the ash cloud, distant glow, and tsunami; those from the Greek mainland, nearby but fortunately upwind, record as a divine battle the tremendous heat, ear-splitting

Fig. 1. The god of the Sun, Helios (Hyperion), driving his chariot across the sky. Greek krater dated 435 BC. [Courtesy of the British Museum.]

noise, and flying ejecta, as well as the tsunami; and the myths from the Hittites in central Turkey sing of a bellowing young giant standing in the sea and growing up rapidly until it challenged the sky god himself—a wonderful image of the towering column of ejecta as seen from afar and, taken as wilful!

Not only are there different physical perspectives of a single event, but those affected by a natural catastrophe typically expend a great amount of effort in trying to survive. They will not feel exactly the same physical sensory experiences as other victims, but certain experiences will be remembered more clearly and others not. Had Pliny the Elder somehow managed to survive the AD 79 eruption of Mt Vesuvius, his story may well have emphasized different aspects of the eruptive phenomena from that of his nephew, Pliny the Younger, who witnessed the event from a safe distance. Blong (1982) in his exquisite analysis of the myths associated with the seventeenth century Long Island plinian eruption off the coast of Papua New Guinea, not only documented significant differences in myth storyline due to geographic location, but also discovered that no one cultural group had myths containing all of the elements of the eruption. It was only by looking at the myths from all of the widely distributed cultural groups that he was able to get the best composite picture of the overall eruption.

There are other problems, however, in trying to interpret the origin of a myth, problems that arise because of changes that inevitably occur as myths are told and retold. Because the human memory-channel is restricted, information regularly gets compressed, and may do so in ways that obscure certain facts. One of the principal mechanisms of compression is what is referred to as the Principle of Attraction (Barber & Barber 2005, pp. 113–117):

> Once the stories around something/someone achieve sufficient mass, that thing/person attracts yet other stories, via any 'significant' point of resemblance

Points of attraction include the same type of event, same place, or same name. Thus, in the Bible, all Egyptian pharaohs end up rolled into what appears to be one person, 'Pharaoh'. (This makes it hard, of course, to know under whose reign an event happened. The point of attraction is the name.) In Greece, if something happened that must have required prodigious strength, such as a river changing course suddenly, it must have been done by that strong-man, Heracles (point of attraction: a quality), or if it occured in Athens, it must have been done by Theseus (point of attraction: place).

Another parameter that gets compressed is time, expressed in the Perspective Principle (Barber & Barber 2005, pp. 117–120):

> As we get further from an event, our perspective gets flatter, and we can no longer distinguish earlier from later events so easily. It's all 'back then' some time

For example, we ourselves can easily see that Abraham Lincoln preceded John F. Kennedy by a century; but we have a much harder time if we jump back a couple of millennia and ask who came first, Pliny or Vergil, two famous people also separated by a century. Or try Cheops and Sargon, back another 2500 years. Thus, the Exodus now seems to be a compression of several trips from Egypt back to Palestine, spread out over perhaps as much as 800 years and rendered as a single account (written down several centuries after the last of these, when all sense of their separateness in time had been lost; Barber & Barber 2005, pp. 86, 91–92; Assmann 1997).

Various other things happen to myths as they pass down through the oral pipeline. But the principles presented here should be sufficient to show the reader that myths are not hopelessly 'off the wall', but that with care one can begin to use them as a guide to interesting past events, particularly in the realm of geology and astronomy. For as long as the tellers of these myths could look up and *see* direct reminders of the events—actual volcanoes, stars, bodies of water, and the like—they had continuous anchors to reality as well as prompts reminding them to keep telling the tale.

Conservation in the traditional oral transmission of myth

Jan Vansina (1985) has eloquently argued that oral history (the oral transmission of historical information) is a valid and extremely rich type of history. While recognizing several of the problems discussed in the previous section, he also notes that orally transmitted history is structured and is amenable to analysis. Vansina (1985, pp. 188–189) explicitly recognizes the potential value of geology and astronomy to serve as a chronological anchor, although based on twentieth century attempts to apply these two disciplines, he suggests that 'absolute dating will not be as easily achieved as once believed'. Vansina (e.g. 1985, pp. 166–167) also shows some ambivalence towards myth as a faithful vehicle for transmitted oral history.

We suggest that there are several 'conservation principles' (once again emphasizing these as empirical deductions for eventual validation) that influence and actually help to enhance the accuracy of the oral transmission of myth down through successive human generations despite the perturbing influences noted in the previous section. Polynesia, particularly traditional Hawaiian culture, provides a unique and exquisitely historical model of myth transmission that illuminates the conservation processes perhaps better than that observed for any other past complex society (Masse 1995; Masse *et al.* 2007). In Hawaii, myths and legends were typically attached to royal chiefly genealogies; that is, actual specific mythic events were described as having taken place during the reigns of specific chiefs whose names appear in royal genealogies. Some Hawaiian genealogies extend back in time more than 95 generations prior to King Kamehameha in the late eighteenth century. Evidently, such genealogically-situated oral records of events were a common practice among many complex societies, often being eventually transcribed into written texts. For example, we see fragments of such oral records in Nahuatl and Mixtec codices in Mexico, in ancient Mesopotamian king lists, in Hesiod's Theogony, in the third century BC 'Bamboo Annals' of China, and in the annals of fourth century BC Egyptian priest and historian, Manetho (see also Masse 1998). But for various reasons that will become evident below, Hawaii has a much better preserved record of orally-transmitted myths and their linkages to genealogies than is the case elsewhere in the world.

That Hawaiian myths encode dateable natural events was first demonstrated through the analysis of a series of myths relating to the volcano goddess Pele (see also **Vitaliano** 1973, this volume). In these myths, specific named and historically known lava flows were described as having been formed by Pele during 'battles' with demigods that were linked to the reigns of chiefs appearing in the genealogies, or in some cases, the battles were between Pele and the genealogical chiefs themselves. An analysis of radiocarbon dates of burned vegetation associated with these named lava flows, collected by scientists from Hawaii Volcanoes Observatory (e.g. Holcomb 1987), indicated a close match with dates assigned to the genealogies when the length of an average 'royal chiefly generation', that is the birth of a royal chief to the birth of his or her first-born heir, was estimated at between approximately 20 to 25 years (Masse *et al.* 1991). There are at least eight such matches between radiocarbon-dated eruptions and genealogical chiefs, with the earliest mythicised eruptions occurring

42 generations (*c.* 880 years) prior to Kamehameha (Masse *et al.* 2007). A ninth possible match remarkably even suggests the witnessed observation of a major eruption in the young Kilauea caldera in the seventh century AD, roughly coincident with the presumed initial Polynesian colonization of the island chain.

In perusing Hawaiian mythology more closely (Masse 1995; Masse *et al.* 2007), it could be demonstrated that a remarkable number of known (from Asian, European, and Middle Eastern records) or reconstructible historic transient celestial and meteorological events were detailed in the storylines of myths attached to the genealogies. These included a sizeable number of unusual comets (including the coincidence of the AD 1301 apparition of Comet Halley with a massive Kilauea Volcano flank eruption), periods of great meteor storms, an auroral substorm, and at least five Hawaiian total solar eclipses (AD 975, 1104, 1257, 1480, 1679) whose paths and characteristics were reconstructed by astronomer Fred Espenak of NASA Goddard (Masse *et al.* 2007). The unique characteristics of a sunset Samoan total solar eclipse in AD 761 has been determined as the basis for a set of famous Polynesian myths about the demigod chief Mauiakalana (an early chief in the royal Hawaiian genealogies) who snared the Sun and held it still so that his mother would have more time to dry her *tapa* barkcloth (Masse *et al.* 2007). Another solar eclipse in AD 605 may have been witnessed in the Tuamotua archipelago by ancestral Hawaiians prior to their colonization of Hawaii.

Thus we have a relatively-ordered genealogical, and in some cases absolutely dated, chronology of orally-transmitted myths of observed natural events in Hawaii (and earlier ancestral island groups) stretching back in time more than a thousand years. Because of the multiple cases of exact matches between specific myths and historic natural events, we know when these myths were created, with whom they were associated, and many details regarding the principles of their construction and how the myths were used in Hawaiian culture (e.g. religion, cosmology, myth performance, astrological prognostication, chiefly reification and power). These are even competing storylines of the same witnessed natural event created by different social groups on different islands in the Hawaiian archipelago, which give a sense of how different observers fashioned their stories.

In Hawaii, major transient celestial and meteorological events, along with volcanic eruptions and tsunami, were both the persona and property of the royal chiefs, serving as *mana*, a powerful supernatural force believed to dwell in a person or object. When a royal chief of proper lineage was initially conceived, priests spent the next several months scanning the skies (and the Earth) for various 'signs of royalty' (Masse *et al.* 2007). A similar natural event encoding practice was conducted around the time of circumcision (subincision) rites for the children of royal chiefs. When signs such as a comet, meteor shower, or rainbow were found, priest specialists created stories about these signs, occasionally in the form of procreational exploits ('genital chants'), which then became forever euhemeristically identified with the chief. The more spectacular the royal sign (or royal signs in the case of multiple co-occurring natural events), the more extravagant and filled with supernatural overtone the story became, and the greater *mana* was bestowed upon the newborn or newly circumcised royal chief. Several of the most spectacular natural events even became embedded in royal genealogical chants, such as the 2102-line *Kumulipo* genealogy which was chanted to Captain James Cook at the *Makahiki* New Year's festival in December 1778, when Cook was thought to be an incarnation of the Hawaiian god Lono (Liliuokalani 1978; Beckwith 1972; Johnson 1981).

These observations regarding Hawaiian/Polynesian myth (Masse 1995; Masse *et al.* 2007) suggest four conservation 'principles' pertaining to the preservation of information content in the oral transmission of myths encoding natural events. The first can be termed the 'Snapshot Principle':

> Sometimes myth storylines are created during or immediately after the observation of a major natural event

This observation belies the long-held assumption, stemming at least back to Euhemeros, that myths are formulated long after the events in question (generation and perhaps centuries), and that the true facts of a story are eventually forgotten, transforming into a supernatural myth. The Hawaiian data instead indicate that myths are a naked-eye snapshot of a natural event, and that the supernatural images are present from the very beginning. The supernatural character of the story simply represents an attempt at explanation by holistic cultures who believe that the sky and Earth are inhabited by sentient beings (e.g. gods and demigods) that are not human, as noted earlier for the Wilfulness Principle. This principle does not exclude the possibility that some of the distorting mechanisms noted in the previous section may impact a myth storyline.

The analogical character and snapshot construction of Hawaiian myth from natural events is evident in a legend that describes a total solar eclipse in 1679, less than 100 years before Captain James Cook first landed in Hawaii.

Briefly told, the legend is about a poor commoner, Kapo'i (*ka-po-i*, the great darkness), on Oahu Island, who being hungry, discovered some owl eggs in the grass. He was about to cook them when a large owl appeared in his window. The owl begged for the lives of his children, and Kapo'i, feeling sorry for the owl, gave the eggs back. The grateful owl told Kapo'i to build a small temple to honour the owl, which would ensure that good fortune would follow him. Kapo'i builds the temple. Unfortunately, this was at a time when the King of Oahu Island (Kakuhihewa, who appears in the royal genealogy of Oahu Island), had prohibited anyone from building shrines and temples except for himself. Kapo'i was seized and placed in the custody of the priest of Kakuhihewa's temple at Waikiki Beach, and was told that he would be sacrificed at sunrise the following morning so as to help dedicate Kakuhihewa's temple. The next morning, immediately prior to the execution and as the first rays of the sun begin to hit the ground, several huge bands of supernatural owls flew out of the mountains and began to attack Kakuhihewa's priests and cover the rising Sun so that its light was extinguished. A fearful Kakuhihewa released Kapo'i, the owls disappeared and the sunlight returned, and Kapo'i became an honoured and respected lesser chief.

The rich details of this myth unquestionably capture to an extraordinary degree the details of the observed natural event that took place. A total solar eclipse, whose path was centred on Waikiki Beach, took place at sunrise on 10 April 1679. This coincides in genealogical time when Kakuhihewa was an aged chief (other stories indicate that he may have ruled more than 50 years). The April date also coincides with the season during which indigenous Hawaiian owls (*pueo*) are most likely to lay eggs. As for Kapo'i himself, there is no indication whether he was a real person with an extraordinary bit of good fortune, or instead was the symbolic manifestation of the divine forces responsible for the eclipse (as suggested by his literal name). We suspect the latter.

The second oral transmission conservation technique can be referred to as the Expertise Principle, particularly as applied to myths forming the religious cosmology and cosmogony of a given culture:

> Myths were likely created and perpetuated by highly trained and gifted experts.

Hawaiian royal storytellers were not casual artists. They were extremely knowledgeable priests who were born into the role and trained to read auguries and to tell stories that extolled the virtues and *mana* of their chiefs. Some of these stories, particularly genealogical chants, could be hundreds or even thousands of stanzas in length, and would take many hours or days to tell in their entirety. Because of the implications for royal lineages and the chiefly reification process, the accurate transmission of oral history was not only highly valued but was mandatory, and priests who did their job 'poorly' were liable to be put to death. Other complex societies had similar institutional levels of expectation, and even less complex societies used and enforced mechanisms to ensure that the transmission of myths, particularly sacred creation and cosmogonic stories, were entrusted to well-trained and gifted individuals.

Bentor (1989) describes an example of how geological events, in particular catastrophic ones, became eventually encoded in the Bible as chronological markers. The time of the beginning of the teachings of prophet Amos, for instance, is '*two years before the earthquake*' (Amos, 1:1). Archaeological evidence of this earthquake was found after excavation the city of Hazor, in Galilee, providing a date of around 760 BC. The earthquake was still remembered at the end of fourth century BC, 450 years later (Zechariah 14:5).

The third oral transmission conservation technique of myth transmission is referred to as the Performance Principle:

> The oral transmission of myth was not simply spoken but was 'performance driven'; that is, myth storylines were systematically acted out in rituals using a wide variety of reinforcing media and mnemonic devices

Stories commemorating the royal birth signs for Hawaiian chiefs were created, rehearsed, and staged several times prior to the actual birth or circumcision of the chief. Sections of the story were put into song or chant, and at least some of the story was performed as a hula dance, seemingly re-enacting aspects of the observed characteristics of the natural event, such as the behaviour of rocks and lava during Pele's battles or the manner in which a comet transited through the fixed celestial heavens. These birth event stories would continue to be periodically performed during the life of the chief, and those embedded in royal chief genealogies would be performed once or more a year for as long as the lineage was in existence. Some stories were performed at specific times of the year, matching the annual timing of the original natural event, or within the context of important seasonal festivals such as the New Year or summer and winter solstice.

The fourth and final conservation technique of myth transmission noted here can be termed the Redundancy Principle:

> Key aspects of a myth storyline are often repeated so as reinforce the importance of that portion of the story and the ability of the audience to remember it

This principle should be obvious and does not require much in the way of explanation. However, such redundancy greatly annoyed nineteenth and early twentieth century folklorists who often resorted to streamlining or otherwise retelling myths in order to make them acceptable to their perceptions of literary tastes, as exemplified by the following note to a compendium of New Zealand Maori myths (Izett 1904, p. iv–v):

> It will be discovered at a glance that in this work the language of the translators has been thrown wholly aside, and any supposed obligation to adhere to the Maori form of arrangement has not been recognised. It has been sought to preserve the spirit and the detail of each legend whilst robing them in entirely new garments .... Conversations have been extended or introduced such as, under the circumstances of each situation, might naturally be expected to have taken place; here and there little bits of description have been ventured.

Of course the problem with such modern retelling is that original storyline details become mixed in sequence, embellished, made fictional, or lost entirely. This technique greatly reduces our ability to understand and reconstruct the natural event(s) being portrayed in a given myth.

Having outlined these principles, a final question and challenge for future researchers must be raised. Is the model of conservation principles presented here, largely derived as it is from insights into Hawaiian and Polynesian myth, applicable across the world?

The answer to this question is both a qualified 'yes' and 'no'. Yes, because these principles seem to apply to myth in many areas with cultural groups of greatly differing social complexity but also with strict religious codes of how cosmological oral history and sacred mythology is transmitted, for example Native Americans (both North and South America), Australian Aborigines, and many SE Asian societies.

The 'no' stems from the fact that there are multiple transmission methods by which myth can be perpetuated through the generations. Operating simultaneously with sacred myth transmitted by priests and shamans using the conservation principles outlined above are myths for which the context of transmission is family-based or popular in nature. Eugenia **Shanklin** provides an excellent example of such kin-based and popular myth in her discussion of the Lake Nyos catastrophe. The problem with the historical content of such myth is that it has not been rigorously subjected to the strictures of the conservation principles and therefore may be less likely to reflect the reality of the original observed natural phenomena.

We suggest that anthropologists, folklorists, and other students of myth have not carefully examined this problem and may mix these distinct genera of transmitted myths. Also, particularly in the case of ancient myths, it is often difficult to know for certain what myths may have been created by individuals who were neither knowledge specialists nor gifted observers. These situations may be at least partially responsible for the failure by western science to understand better the historical observational foundation of myth. The topics of multiple systems of myth transmission and the skills of the original mythmaker are potentially critical for any and all attempts to derive historical information from myth storylines and deserve additional future scrutiny. Detailed contextual analyses of the myths themselves may yield important clues for how they should best be categorized and studied.

The future of myth in science

> Whether myth has a future depends on its capacity to meet the challenge posed by modern science .... Modern challenges to myth have been made on intellectual, theological; and political grounds .... The chief modern challenge, however, has come from natural science, which does so well what myth had long been assumed to do: explain the origin and operation of the physical world .... To accept the scientific explanation of the world is to render the mythic one both superfluous and outright false—superfluous because superseded by the scientific account, false because incompatible with the scientific one (Segal 1996, p. 82).

Fortunately, it is not necessary to make the sobering and difficult choices outlined in the essay by Robert Segal, to ensure the survival of myth in our modern scientific world. It should be evident from this book that myth is neither superfluous nor false. Rather, myth presents us with the surprising opportunity to extract from the historical cultural record of many regions an unprecedented view of the impact of geological and solar system process and events during the past several thousand years.

The process of extracting from myth such records of natural events and processes in most cases will not be easy. It will require the application of a number of geological, astronomical, and archaeological tools, as well as those from the cognitive sciences, history, and the humanities. We still have much to learn about the theory and methods of our nascent discipline of geomythology. Not all myths are amenable to such analysis, and fewer still provide the details necessary to identify actual geological processes much less specific datable events such as major earthquakes, volcanic eruptions, floods, and cosmic impacts. However, it is certain these defined events provide us with the opportunity to understand local geological histories and the actual risks posed by certain types of natural phenomena.

We should not downplay the fact that myths also shed light on aspects of cognition, and the historical, social, and literary context of cultural evolution and human thought. We are not about to claim that just because most modern scholars have somehow missed the possible natural history core of myth that their own studies and insights are cheapened or otherwise diminished by such oversight.

On the other hand, we would gently suggest that if there is a historical kernel to many or most traditional/ancient myths, then this may warrant some new ways of thinking about the sociology of myth. Indeed, if myth somehow provided a competitive advantage for certain cultural groups to continue their existence in contradistinction to other groups, whether or not due to psychological advantage (e.g. stress reduction), the advantages of increasing social complexity fostered by mythic thought, or the advantages of real information on natural risks being contained in the myths, this might be construed as a socio-biological dimension deserving of further study. We do not necessarily subscribe to such a purely socio-biological viewpoint for myth, but find it an interesting topic worthy of further scrutiny.

We cannot overemphasize the likelihood that geomythology can contribute to a better understanding of geophysical hazards and risks for specific regions, enhance our knowledge regarding present uncertainties in modelled geophysical processes, and potentially can facilitate improved efforts at risk reduction. One example in this volume is the work by **Bryant *et al.*** on potential tsunami effects associated with oceanic cosmic impact (see also Bobrowsky & Rickman 2007; **Masse & Masse**). In respect to risk, we need systematically to develop databases to aid in our identification and analysis of geophysical information in historic texts and oral traditions, such as that being implemented for the Mediterranean area by **Vittori *et al.*** The geomythological study of risk should not only focus on the myths themselves but also on a systematic reappraisal of the complete set of images contextually associated with past cultures. The work performed by **Hough** in looking at Native American archaeological rock art in relation to California earthquakes exemplifies such an approach.

And finally, we agree with **Lanza & Negrete** that myth can serve as both a model and a marvellous narrative tool for educating the lay public about geology and our place in the natural world. Such education can range from the increased careful use of myth, where appropriate, as an adjunct to the public interpretation of geological parks and formations (as noted by **Motta & Motta** and by **Mayor**), to video documentaries and other creative interpolations that blend myth and the visual arts.

The case studies in this book are but a small sample of the myths that can be studied through the techniques of geomythology. Like the proverbial tip of the iceberg, much useful natural history information is undoubtedly lurking in the large body of as yet unanalysed world myths. Such study should complement and add to our understanding of Earth process and Earth history. At the very least, our various geomythology researches provide us with a profound respect and appreciation for the observational powers of our ancestors, and help to demystify the mythological past.

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Geo-mythology of India

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Abstract: In all the Indian legends, whether it is the Ramayana or Mahabharata, one can find embedded elements of geological processes. Perhaps due to the lack of a sound scientific basis for recognizing geological processes in ancient Indian civilization, such processes were believed to be the acts of 'Gods' (Suras) and 'Demons' (Asuras) and hence they formed an integral part of these legends. Even in the present age where science is able to explain several geological processes, the Hindu faith is such that these myths and legends continue to be passed on to succeeding generations. The fact that these geological processes are contained in these epics helps to sustain truth (dharma) and maintain harmony. Ancient Indian civilization adopted this doctrine and its continuance will remain a fresh and vital part of future generations in India.

Hindu mythology centres around gods, demigods, their supremacies and related stories. Basically the philosophy in all these legends is to teach humans the values of Dharma (justice) and how God prevails in sustaining *'dharma'* in the world (Sinha 1954; Rajendranath Seal 1958). Initially, all these were Smrirtis (sacred teachings) and subsequently were documented in the form of books (Vedas) by great saints (Rishis). All these ancient books were originally written on palm leaves and preserved for centuries, some of which are still preserved, even today.

During the creation of these legends several geological phenomena and events became embedded within them either knowingly or unknowingly. Whether it is Ramayana, Mahabharata or Puranas, these doctrines are presented in the form of folklore, or mythological stories. Hinduism always preaches dharma in order to maintain world peace and to curb evil by any living being (Rajendranath Seal 1958). This paper discusses how geological events and processes became entangled in these epics. All these stories refer to events that happened on Earth (or occasionally in the heavens) and hence geological processes became an integral part of them. Though examples of several such close relationships between geology and mythology exist in Hindu texts, only a few are elaborated in this paper. A similar relationship between myths and thermal springs over the world was compiled by the Geothermal Resources Council in their volume *Stories from a Heated Earth* (Cataldi *et al.* 1999).

Hindu eras in relationship to stratigraphy and the origin of Earth

According to Hindu Vedic cosmology, the age of the entire universe is divided into four yugas (eras): Satyuga, Trethayuga, Dwaparayuga and Kaliyuga. The time span of each yuga varies in a manner similar to geological eras. According to the Hindu mythology the Satyuga lasted for 1.728 Ma; Trethayuga lasted for 1.296 Ma; Dwaparayuga lasted for 0.864 Ma; and the Kaliyuga, the present era has so far completed 0.432 Ma (Somayaji 1971). The Trethayuga and the Dwaparayuga are the most important eras since they encompass the most important epics of India, the Ramayana and the Mahabharata, respectively.

This four fold stratigraphic division of time-scale is similar to that used in geology (cf. Precambrian, Palaeozoic, Mesozoic and Cenozoic). Some authors consider each yuga as *'Maha Yuga'*, meaning that each should be multiplied by 1000 years. In which case the sum of all these yugas amounts to the age of the Earth (*c.* 4.3 billion years) which constitutes a day for Lord Brahma (Brahma day), the creator of the universe (Somayaji 1971; Bhaktivedanta Swami Prabhupada 1986). The destruction of the universe is called *'pralaya'* or catastrophe—synonym to the present day floods, earthquakes and tsunamis. In each era, Lord Vishnu, the saviour, emerges into this world in the form of *'avatar'* (incarnation). According to the Hindu mythology, these *'avatars'* are in the form of animals or semi-animal demigods (part is human and part is animal: Fig. 1). In each avatar, he destroys the evil and restores *'satya'* (justice) in the world. The ten avatars are *Matsya* (fish), *Koorma* (tortoise), *Varaaha* (boar), *Narasimha* (the man lion), *Vaamana* (the dwarf), *Parasurama* (the angry man), *Rama* (the perfect human; avatar in Trethayuga), and *Krishna* (the divine statesman; avatar in Dwaparayuga). The tenth avatar which is yet to appear is *Kalki* (Pandey 1979).

Lord Vishnu is always seen with his conch and Chakra (Vishnu Chakra; the wheel) in his hands.

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Fig. 1. *Varaha (boar) avatar* of Lord Vishnu.

He is reborn (as a new *avatar*) after a major catastrophe (*pralaya*) when the entire species on Earth becomes extinct. After every Brahma day, Lord Brahma creates new life on Earth. In Hindu mythology it is said that after one such catastrophe, Brahma was busy creating new life on Earth and did not pay attention to the Demon Hiranyaksha who had pushed the mother Earth into (*Patal lok*) the Ocean (i.e. trying to destroy the Earth). Brahma, realizing that his new creation of life has to live on Earth, pleaded with Vishnu to save the Earth. Vishnu took the form of *Varaha* (Fig. 1: Subramnya Sastri 1989; Pandey 1979) and lifted the Earth with his tusks from the ocean bottom and reinstated it in its proper orbit. One may interpret this geologically as the birth of the planet Earth or an analogy of seafloor spreading at mid-ocean ridges where new material is created.

Rahu, Ketu and the eclipses

Lunar and solar eclipses are natural phenomena of the solar system and for that matter an eclipse is common to all the planetary bodies. However, in Indian mythology it is a chase between Rahu and the Moon and Ketu and the Sun (Dave 1991*a*). Indra, one of the celestial gods or '*Suras*', was cursed by Durvasa for insulting him by throwing away the flowers offered by him. By nature, Durvasa is short-tempered and cursed Indra and all the gods that they would lose their vigour and strength. So the gods started losing power while the '*Asuras*' (demons) started gaining power. The gods pleaded with Vishnu to help them to regain their power so that the demons would not overtake their kingdom.

Vishnu advised the gods to churn the milky sea using serpent 'Vasuki' mount Mandara as a stirrer to obtain celestial nectar (elixir) that would restore their power (Fig. 2). Thus both the gods and the demons churned the ocean and the nectar emerged from the ocean. Vishnu deceived the demons by taking the form of a beautiful lady (Mohini) and diverted their attention while the gods consumed the elixir. However, two '*Asuras*' (Rahu and Ketu), aware of Mohini's trickery, took the guise of gods and also consumed some of the celestial nectar and became immortal. The Moon and the Sun reported this incident to Vishnu who became furious and chopped off their heads with his Chakra (see Fig. 3). Since Rahu and Ketu consumed the nectar, they remained in the universe and started chasing the Moon and the Sun as an act of revenge. Thus in Hindu mythology Rahu and Ketu are regarded as celestial bodies that swallow the Moon and the Sun thus causing lunar and solar eclipses respectively. Indian astronomers as early as AD 300 discounted this myth and presented the orbital paths of the planets and their moons thus accounting for lunar and solar eclipses (Somayaji 1971; Dave 1991*a*).

Mahakal crustal extension zone and Mahakaleswar

While Rahu and Ketu were consuming the celestial nectar, a few drops fell on Earth. Wherever drops of the celestial nectar or the elixir spilled, those places became divine or holy shrines for Hindus. Ujjain is one such place. Ujjain is located within the northern flank of the mid-continental Narmada rift. The Mahakal rift zone extends from the NE part of Madhya Pradesh to SW part extending up to Ujjain. (Venkata Rao & Nayak 1995; Fig. 4). The famous Tattapani thermal springs in Chattisgarh district (east of Jabalpur, not shown in Fig. 4)

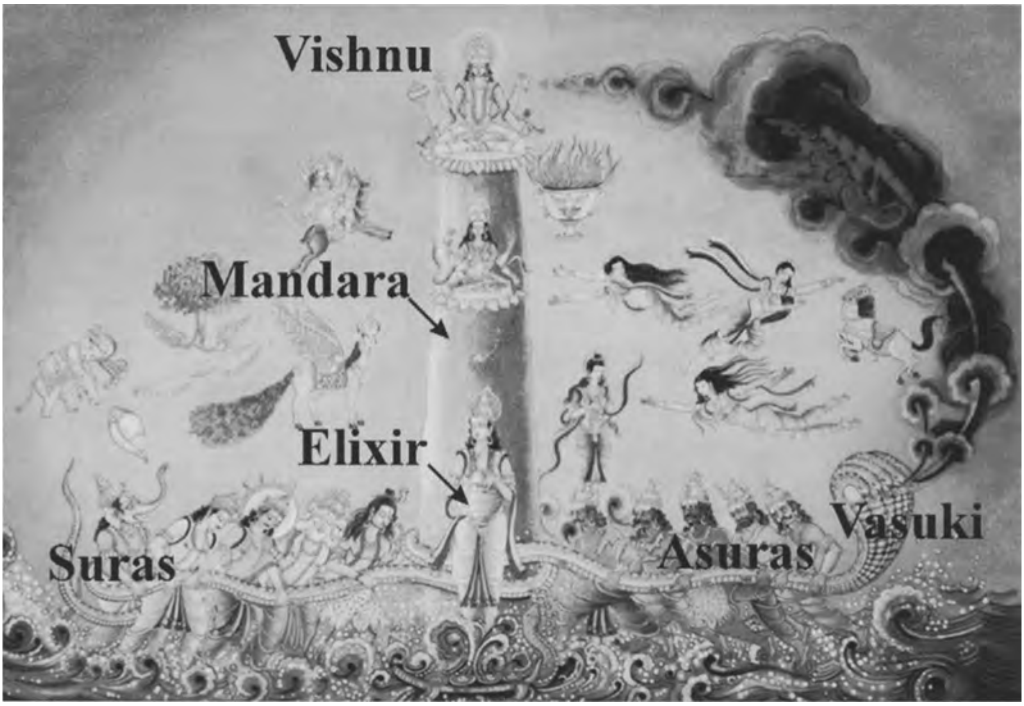

Fig. 2. Churning the sea (Samudramanthan) by Suras and Asuras. Vasuki (name of the serpent) is the churning rope and Mandara (name of the mountain) is the churning rod.

emerge through this rift system (Chandrasekharam & Antu 1995; Subramnya Sastri 1989). Hindu mythology mentions such a rift zone through which Lord Shiva (known as Mahakaleswar) emerged to save his devotees in Ujjain by killing the demon Dushana who was living in Ratnamala hills (Dave 1991*a*). Though there are no hill ranges around Ujjain, the Ratnamala hills may be the Vindhyans that form part of the Narmada rift system. Geographically, Ujjain attained importance for nurturing great Hindu astronomers and because the Tropic of Cancer passes through it. Ujjain was considered the 'Greenwich' of Hindu astronomers (Dave 1991*a*).

Vishnu, Shiva and marine fossils

Fossils are considered divine and are thought to represent Hindu gods. For Indians, ammonites and echinoderm fossils are sacred and are known as '*saligrams*' or '*saligramas*' (the actual name or term in Sanskrit is '*Salagraman*' and is one of the names of Vishnu; Swami Nityananda 1998). In Hindu mythology, ammonites are considered as Vishnu Chakra and the echinoderms and cephalopods (belemnites) as Shiva (in his phallic form, Linga). The ammonite fossil with circular shape and radiating ribs look very similar to Vishnu Chakra (Fig. 3) with radiating spikes. All types of ammonite fossils (e.g. *Meekoceras varaha; Promicroceras planicosta; Almatheus margaritatus;*

Fig. 3. Vishnu, the Hindu deity, holding the Vishnu chakra (also known as Sudarshan chakra) and the Serpent, Vasuki, sheltering Vishnu.

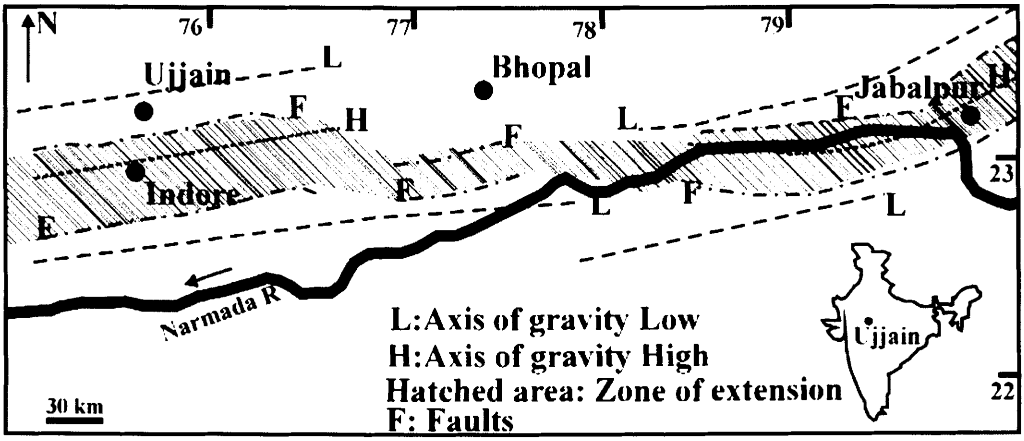

Fig. 4. Mahakaleswar and Mahakal crustal extensions zone (modified after Venkata Rao & Nayak 1995).

Eoderoceras bispinigerum; Cardioceras; Discoscaphites nebrascensis; Acanthoscaphites nodosus: Krishnan 1968) are given different names indicating different manifestations of Vishnu (Swami Nityananda 1998). The ammonite fossil *Meekoceras varaha* found in the Triassic formation of the Central Himalayas (Krishnan 1968) resembles the Vishnu Chakra. *Varaha* is one of Vishnu's avatars. It is not clear whether this name is given to the fossil because of its resemblance to Vishnu Chakra or it attained this name accidentally. Indian geology textbooks mention of the '*saligram*' (Krishnan 1968; Wadia 1978); some of the echinoderm and cephalopod fossils look like a phallus, symbolizing Shiva. In India, these Jurassic and Cretaceous fossils are extensively found in Spiti Shale Formations of upper Himalayas and brought to Nepal by Gandak River (Krishnan 1968), which joins the Ganges in the Gangetic plain in India. Vishnu became incarnate in the form of Saligram to save the demons and semi-gods alike. These fossils are kept in temples and households as natural symbols of Vishnu (Fig. 5).

Stalagmites and Amarnath cave

Shiva is part of life for many Indians and he is worshipped in the form of Linga (phallus) by a large number of Hindus. Some Hindus carry the Shiva Linga (phallus) on their body (especially the echinoderm fossils). A large number of pilgrims travel to Amarnath cave annually to see the Lord. According to Shiva Purana (Subramnya Sastri 1989), Shiva recounted the secret of creation and eternal life to his consort, Parvati, in this cave.

The Amarnath cave is about 145 km NE of Srinagar, at a height of about 4000 m above mean sea level, in the Himalayas (Fig. 6). It is believed that the Shiva Linga in the cave forms every lunar month: during the first half the Linga starts forming and attains full size on the full-moon day (lunar day 15), and during the second half of the month the Linga starts decreasing and disappears on new-moon (Dave 1991*b*). This cave attracts large crowds from all over India and more than 25 000 pilgrims visit this shrine between May and July. In reality this cave is located in limestone-gypsum formation (Krishnan 1968) and the melt-water percolating into the cave from the roof through joints freezes on the ground and grows as a stalagmite (Fig. 7). Due to the heat generated by the pilgrim population visiting the cave, the stalagmite melts by June, thus reducing the size of the Shiva Linga (the stalagmite). White gypsum powder from the cave is distributed to the pilgrims as 'Vibhuti' (sacred powder).

The Kashmir government reportedly is planning to extend the life of the stalagmite artificially.

Sea level change and Dwaraka

In Mahabharata, Lord Krishna was the chief advisor to the Pandavas (worriers and sons of King Pandu). Mathura was the abode of Krishna. Due to constant hostility between '*Suras*' and '*Asuras*', Kamsa, the demon, waged a war against Krishna. Kamsa had a curse on his head that he would be killed by Krishna. In the ensuing battle, Kamsa was indeed killed. Krishna, who actually belongs to the Yadavas (a Hindu sect and disciples of Krishna), found it impossible to continue his stay in Mathura and shifted his abode to Dwaraka along the Saurashtra coast in Gujarat (Kamala 1977; Dave 1991*b*). According to the legend, Krishna's disciples perished from infighting. Since the main task of killing Kamsa had been accomplished, Krishna decided to leave Dwaraka and in one of the texts it was told that Krishna knew about the fate of Dwaraka and hence left for his heavenly

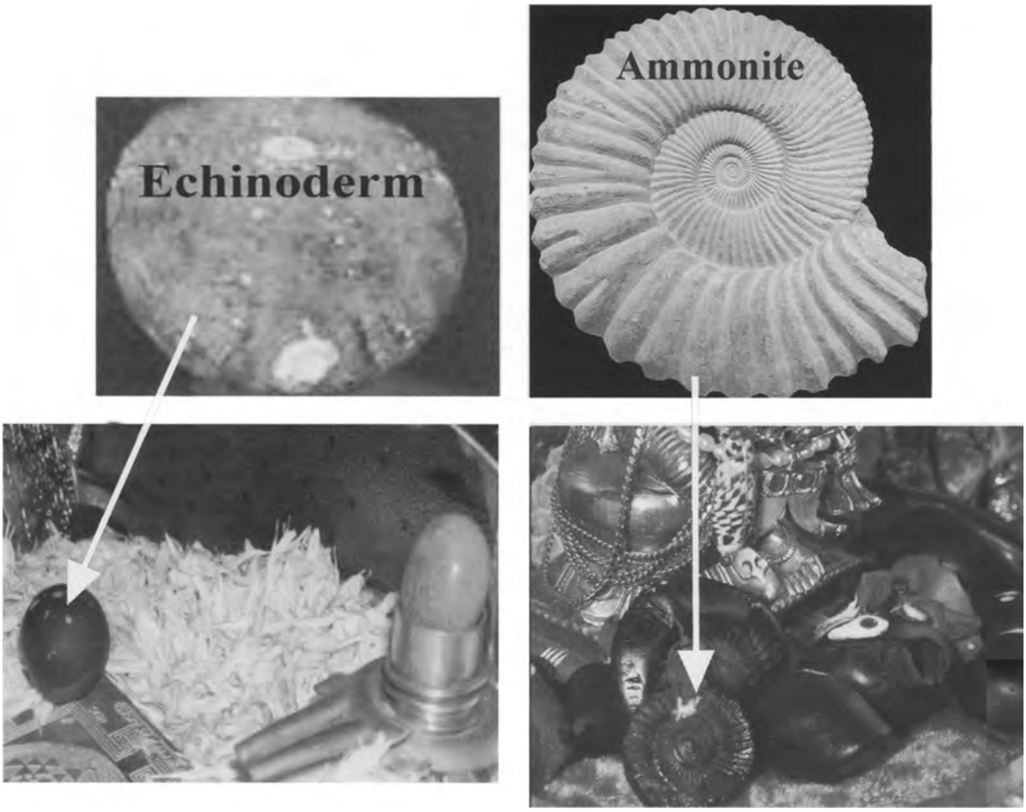

Fig. 5. Ammonites, echinoderms worshipped as Saligrams by Hindus.

abode. The town of Dwaraka was inundated by the Arabian Sea and subsequently submerged.

Recent marine archaeological investigation discovered the mythological Dwaraka town intact, under the sea along Saurashtra coast (Gaur *et al.* 2000) (Fig. 8a,b). The sinking of Dwaraka was due to tectonic activity accompanied by sea level rise; sea level was about 150 m below the present level. Signatures of Late Quaternary coastal tectonics and sea-level changes are well recorded along the cliffy coastline of Saurashtra. A succession of raised terraces and wave-cut notches have resulted from changes in sea level whereas tectonogenic features are represented by steep vertical cliff faces, distorted morphology of wave-cut notches and staircase platforms (Pant & Juyal 1993*a*,*b*). This discovery gives an idea about the lay out of Dwaraka and the forts believed to have been inhabited by the Yadavas of the mythological Mahabharata (Rao 1999; Gaur *et al.* 2000; Vora *et al.* 2002). Further the entire Saurashtra coast has been subject to major tectonic events since Jurassic times (Mishra *et al.* 2001).

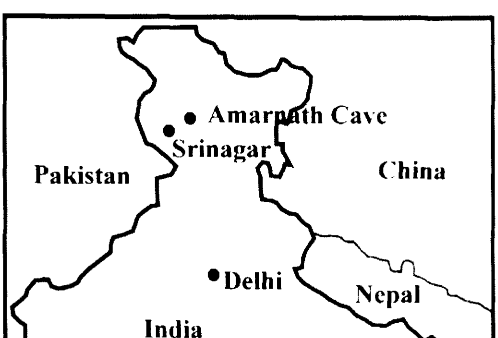

Fig. 6. Map showing the location of Amarnath Cave.

Coral reefs and Ramayana

Rama, the great hero of the Hindu epic Ramayana, was the seventh avatar of Vishnu. The epic Ramayana was written by Valmiki several centuries after Rama's reign, which according to the

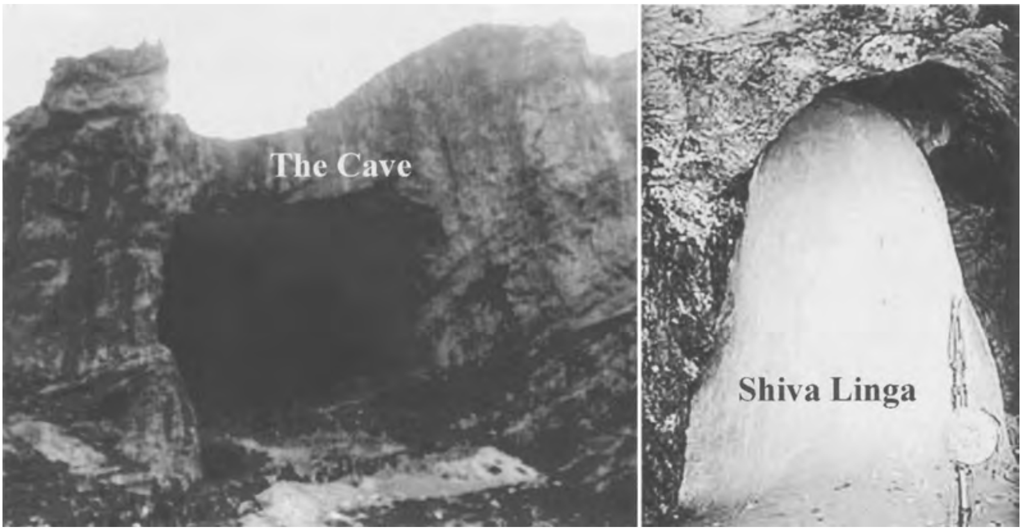

Fig. 7. Amarnath Cave and the Shiva Linga. The Stalagmite (on the right) attains the shape of a phallus after full growth and represents Shiva Linga.

astronomical data was around 2012 BC (Srinivasa 1955). Rama, Sita (his consort), and Laxmana (his brother) were in exile for fourteen years due to the wicked plan of his stepmother Keikeyi. While he was in the Dandakaranya forest, Surpanaka, sister of Ravana, the king of Sri Lanka, expressed her desire to marry Rama. Laxmana cut her nose and ears as a punishment for this desire (Srinivasa 1955; Rajagopalachari 1958; Lakshmi Narasimha 1984; Ganapati Sastry 1986; Dave 1991*c*). Ravana

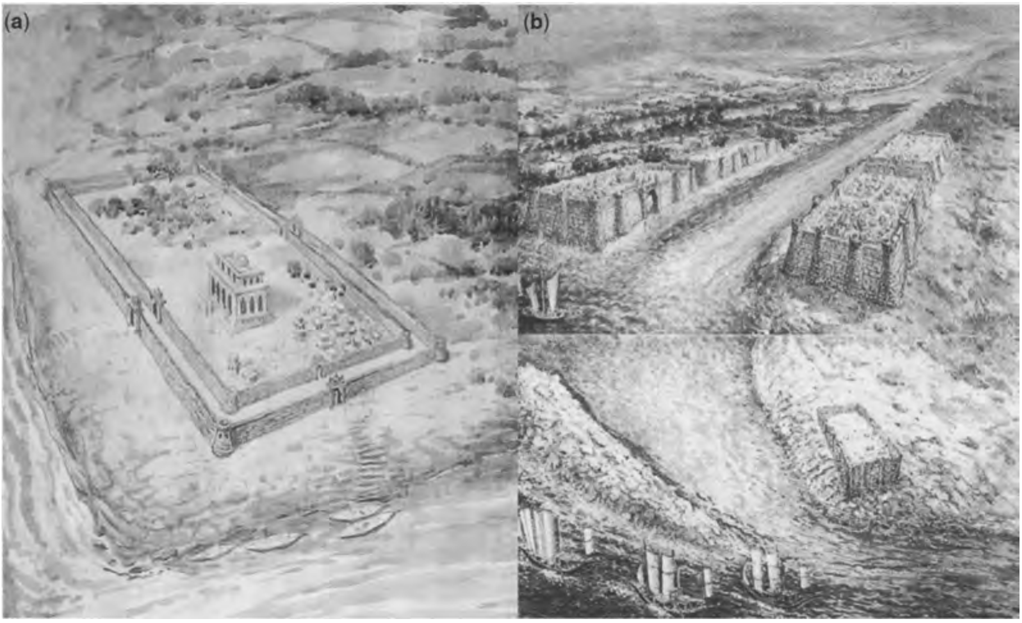

Fig. 8. (**a**) Pictorial view of Dwaraka off Saurashtra coast. (**b**) Harbour of ancient Dwaraka (pictures courtesy Gaur 2004 pers. comm.).

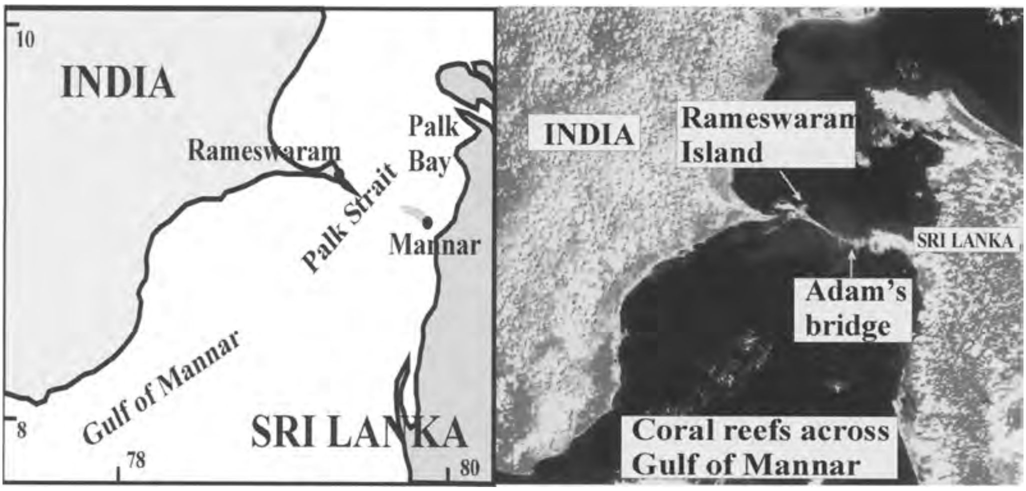

Fig. 9. Park strait and the IRS picture showing the coral reefs between India and Sri Lanka (IRS picture from Bahuguna *et al.* 2003).

took revenge by kidnapping Sita to his kingdom. Rama decided to wage a war against Ravana. The main hurdle was to cross the sea between Rameswaram and Sri Lanka (Fig. 9). Rama's disciples helped him to construct a bridge between Rameswaram and Sri Lanka. This is the legendary Rama's bridge across Palk Strait.

In reality this bridge is a coral reef extending between these two land masses. A recent Indian remote sensing satellite picture clearly shows the presence of coral reefs, sand bars and clay deposits between these two countries (Fig. 9) which are separated at this point by a distance of 32 km (Bahuguna *et al.* 2003). These coral reefs must have been exposed due to a change in sea level, near Sri Lanka, during that period described in the myth. Sea-level changes are not uncommon globally, and about 18 000 years BP the sea level was 100–150 m below the current level (IPCC 2001; Purnachandra Rao *et al.* 2003). These coral reefs must have been exposed to the surface—like those of Lakshadweep islands in the recent historical past—enabling Rama's army to cross over to Sri Lanka. With sea levels rising at the rate of 2.5 cm per year (it has risen by about 10–20 cm in the 20th century; IPCC 2001), this bridge may never again be exposed.

Myths about thermal springs

Ancient Indian civilization considered all geological phenomena as evidence of divine power and gifts from the gods (Rajendranath Seal 1958). This is evident when one visits all the geothermal provinces in India where thermal waters with temperatures from 47–98 °C issue through various geological formations associated with major tectonic structures. A detailed account of the relationship between the thermal springs and Hindu mythology was given by Chandrasekharam (1999). These sites are associated with epics such as Ramayana and Mahabharata, and centres around Lord Shiva, the presiding deity at many thermal spring sites. Legends associated with some of the thermal spring sites are outlined below.

Manikaran is situated along Parvati River near Kullu, 80 km north of Shimla. According to the legend, Parvati, lost her earrings in the River Parvati and asked Shiva for help to recover them. Lord Shiva pierced the Earth with his third eye only to get gushing hot water along with the earrings. Manikaran is a famous pilgrim centre for

Fig. 10. Rice (pots) being cooked inside the thermal pool at Manikaran.

Hindus as well as for Sikhs. A Shiva temple and a Gurudwara (Sikhs religious shrine) are located near the emergence of the thermal springs. Devotees offer rice to Lord Shiva cooked in the thermal waters. Rice is cooked in small cloth pouches dipped in the thermal pool. Gurudwara cooks rice on a large scale in copper vessels for devotees. The food is served free to all the devotees (Fig. 10).

Similarly, the Tuwa thermal springs of Gujarat were believed to have been born due to Bhima's (one of the Panchapandavas of Mahabharata) mystical power. Draupadi, the common wife of Panchapandavas, asked Bhima to fetch water to quench her thirst near Tuwa. Bhima, not finding any source of water in this drought prone area, brought hot water to the surface (Chandrasekharam 1999).

In the case of the Agnigundala thermal springs near Bhadrachalam, Andhra Pradesh, hot water flows below the surface on the western bank of the River Godavari (Chandrasekharam *et al.* 1996). According to the legend, Rama and Sita rested in Bhadrachalam during their exile and Sita requested Rama to fetch warm water to beat the cold. Rama pierced the Earth with his arrow and brought hot water to the surface. Bhadrachalam is famous for Rama temple, and during Rama Navami day (the birthday of Rama) thousands of pilgrims congregate at this temple and have a holy bath in the thermal waters.

In general, in all the thermal spring locations, Shiva is the presiding deity. This is because these springs are considered as Ganga (water) which was brought from heaven to Earth by Bhagiratha (Macfie 1992). It was Brahma who gave the boon to Bhagiratha to enable Ganga to flow on Earth. To contain her fall, Shiva allowed Ganga to fall on his head and locked her in his matted hair thus controlling the flow. Ganga became part of Shiva and adorns Shiva's head.

Conclusions

Geological processes or events are an important component of Indian mythology. Whether a major tectonic event, the growth of a stalagmite, formation of coral reefs or coastal submergence, these processes have been considered as manifestations of the gods. The central theme of all the epics is 'God' and His activities on Earth and hence all the Earth's activities/processes form an integral part of these myths and legends. What emerges is that all these geological processes were known to ancient Indian civilization. Since scientific explanation was not available at that time, such processes were embedded in the legends as God's manifestations. In the Hindu faith these myths and legends are passed on to the next generation. This may be the case not only in India but in the entire world (Cataldi *et al.* 1999). What has been described in the present paper is a fraction of what exists in the Indian mythology. A detailed account of the relationship between geology and myths would run to many more pages.

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Genesis Chapter 1 and geological time from Hugo Grotius and Marin Mersenne to William Conybeare and Thomas Chalmers (1620–1825)

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Abstract: In 1550 few questioned the 'biblical' age of the earth, but by the mid-nineteenth century no educated person accepted it. The change is considered to have been a period of conflict between Christianity and science over the age of the earth. In fact, the conflict was small because from the Reformation era most considered the bible to be accommodated to its culture and that at the beginning of time God created a Chaos, which was re-constituted in 'six days'. This was put forward by Grotius and Mersenne, then by the *Theories of the Earth* of Burnet, Whiston and others and then by later writers to allow for geological time. This reached its climax in early nineteenth century Britain with Chalmers, Conybeare and Buckland, thus preventing any major conflict between geology and Genesis. The perceived conflict of these centuries is a matter of retrospective interpretation, which does not do justice to those Christian thinkers, like de Luc, Chalmers and Townsend who accommodated geological time with little conflict, and those like Patrick, Ray and Whiston who opened up the way for this accommodation to geological time in the seventeenth century. The conflict between geology and Genesis is one of retrospective perception rather than historical reality. Only a minority of Christians, as with the anti- or scriptural geologists of the early nineteenth century, considered there to be a conflict.

In the year 1550, no educated person doubted that the earth was only a few thousand years old, but by the year 1860, no educated person doubted that the earth was millions of years old. No better comment of the conservative Anglican view in the 1860s can be found than in Samuel Wilberforce's '*Answers to Essay and Reviews*' where one contributor, the astronomer the Revd Richard Main, wrote 'Some school-books still teach to the ignorant that the earth is 6000 years old .... No well-educated person of the present day shares that delusion'. The way in which this change of perception took place is often the stuff of myth and legend in which the church is perceived as thwarting every advance of science. The discovery by 'geologists' that the earth was millions of years old did not suddenly inundate Western society at the end of the eighteenth century, but rather, the discovery, or series of discoveries, resulted in a slow erosion and metamorphosis of previously held opinions that the earth was young. As we shall see, those who introduced notions of an ancient earth were as likely to be Christian, whether lay or clerical, as not. Too often the story of this change is related in almost mythical terms, with the church opposing every suggestion of geological time because of their adherence to Ussher's date of 4004 BC. Examples of this litter the writing of the history of geology.

There are several reasons why this chapter considers the period from 1620 to 1825. First, at the beginning of this period, the book of Genesis (and all of the Bible) was seen as a reliable historical source and by 1825 most educated Christians regarded the 'events' of Genesis Chapter 1 as relating to a period of millions of years. Secondly, as geology may be considered to have started with the work of Steno in the 1660s, theologians in the 1620s could have no notion of geological time and cannot have been influenced by new notions of deep[ening] time. Thirdly, by considering numbers of writers, Christian or not, over the following two hundred years, the way they related 'deepening' time to the book of Genesis can be traced (though this is not a linear progression). My single focus is on Genesis Chapter 1 and time and I have ignored the question of Noah's Flood (superbly discussed by Young 1995), the 'fall' of Genesis Chapter 3 and the vast longevity of the early patriarchs.

I also attempt to consider the book of Genesis in the terms it was understood at a given period and not retrospectively to judge writers by recent understandings of Genesis as myth or any other genre. This is unapologetically anti-Whiggish and allows one to put all writers discussed into their historical context and how they related to wider spheres of thought of their day. Seventeenth century writers had neither the benefit of the *Epic of Gilgamesh* nor radiometric age-dating. To fail to understand this would result in a history of the interaction of geology and the book of Genesis which is a myth

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in the pejorative sense. None of the writers I discuss, with the possible exception of Buffon, considered the book of Genesis as myth in the other sense. To most it was reliable history, albeit it accommodated to the thought of the ancient Near East.

The most significant period in the history of geology as regards the age of the Earth is from 1760 to 1830; before 1760 few accepted the age of the earth to be measured in millions of years and after 1830, if not before, no geologist could deny it. Recently, this has been superbly charted by Rudwick (2005). These seventy years were a period of transition, both in geological understanding and how the Christian church understood the implications of deep time for their theology. These interpretations centre on the first chapter of Genesis, but it is too easily assumed that before the rise of geology the calculations of Archbishop Ussher were in some way the official view of the church. However, until about 1750 there was little questioning of a young earth some thousands of years old, whether six or sixty millennia. Since before 1760 there was little in the way of evidence for an ancient earth it is as absurd to cavil at Ussher, Calvin or Aquinas for not dating the earth at 4.6 billion years as to cavil at Darwin for not knowing about genetics.

Historical background

Before 1650, the first chapter of the book of Genesis could not be interpreted in the light of scientific evidence on the possible age of the earth, but there was a great diversity in how theologians interpreted Genesis. The Church Fathers of the first five Christian centuries demonstrate this diversity. The anonymous *Epistle of Barnabas*, which was written between AD 70 and 135, states in Chapter 15 that the earth will last only six thousand years. A century later, Theophilus of Antioch in about AD 180 interpreted Genesis Chapter 1 somewhat literally and calculated the creation at 5515 BC (Theophilus 1970, pp. xxiii–xxv). Augustine of Hippo was ambivalent, seemingly both holding a figurative sense of day and a literal one. Other Church Fathers were clearly figurative and allegorical in their biblical interpretation (Van Till 1996).

The period of the Reformation resulted in a more rigorous biblical interpretation with an emphasis on the literal, or plain, rather than allegorical, meaning of scripture. This inclined most theologians and savants to understand the 'day' of Genesis Chapter 1 as of twenty-four hours and thus the earth to have been created in about 4000 BC, be they Luther, Calvin, Mercator, Raleigh or Columbus. Despite the emphasis of both Roman Catholic and Protestant exegetes on the 'literal' meaning of Scripture, this 'literalism' never went to the extreme of insisting on a flat earth, which is demanded by a literal reading of Genesis 1:6–8, and Exodus 20:4. In fact, very few Christian theologians had ever considered the earth to be flat, a myth demolished by Russell (Russell 1991). Literalism was tempered by 'accommodation'. This refusal to adopt a slavish literalism can be seen clearly in Calvin's understanding of the accommodation of Scripture. In 1554, eleven years after Copernicus published *De revolutionibus*, Calvin published his commentary on Genesis in Latin. Calvin made no reference here, nor probably anywhere else, to the Copernican theory, but he stressed that Genesis was not written to teach astronomy. As he dealt with the Mosaic description of the firmament of Genesis 1 he wrote, 'He, who would learn astronomy and other recondite arts, let him go elsewhere' (Calvin 1847, p. 79). He considered the firmament of Genesis 1:6–8, not to be the solid crystalline dome, which is implied by Egyptian astronomy, but a representation of rain clouds, because 'nothing is here treated of but the visible form of the world' (Calvin 1847, pp. 69–88). Calvin was wrong at this point as most ancients considered the firmament to be a solid dome. But he considered that Moses accommodated himself to the limitations of human thought and as Calvin commented on Genesis 1:15, 'For as it became a theologian, he had respect to *us* rather than the stars'. Calvin approached his task with Ptolemean assumptions of a spherical rather than a flat earth. He also did not question a 6000-year-old earth nor a universal flood. Calvin's accommodating interpretation eased the path for many Calvinists to accept Copernicanism, with the result that some Roman Catholics referred to the 'Calvino–Copernican' theory. In the following centuries Calvin's doctrine of accommodation allowed devout Protestants to accept the findings of science, whether astronomy or geology, without the rejection of the authority or the teaching of scripture (Hooykaas 1972, pp. 114–130).

Alongside the rather literal exegesis of the Reformation era, many writers considered the earth being created 'without form and void' as described in Genesis 1:2 to be paralleled by many classical writers, such as Ovid (5th Book of Metamorphosis) and Hesiod, who wrote of the formation of an original chaos. Thus Genesis Chapter 1 was interpreted as God first creating chaos (i.e. without form and void), which lasted for an unspecified period, and then reordering this chaos in six days. This chaos-restitution interpretation of Genesis, in fact, opened up the way for a longer timespan of creation, as the duration of chaos was undefined. The duration of chaos varied from a mere twelve hours with Ussher in 1650 to millions of years with Chalmers in 1803.

Over the next 300 years, the wrestling of theologians with the implications of the sciences of space and time was almost an interplay of literalism, accommodation and chaos. The apparent literalism commonly obscures an openness to science, which may be lost by an emphasis on the alleged warfare of science and religion over a flat earth, geocentricity, the age of the earth and, finally, evolution. This reached its canonical form in the Victorian works of Draper and White (White 1955), and is still frequently re-iterated in more popular works on science.

The seventeenth century

One of the features of the Renaissance as understood by the churches was that all knowledge was part of a unified whole and thus 'biblical history' was related to other spheres of knowledge, both classical and modern. Thus the book of Genesis was not considered in isolation but with reference to those classical writers who spoke about chaos and creation. Hesiod and Ovid, among others, reckoned that chaos was created first, followed by its ordering. Many commentators quoted the opening lines of Ovid's Metamorphoses, which describes the 'rude and undigested heap', which preceded the creation of the sea, land and sky (Williams 1948, p. 49). The undigested heap of chaos was regarded as the equivalent of the world being 'without form and void' (*tohu va bohu*) in Genesis 1:2. This equating of chaos with 'without form and void' with a significant passing of time between the initial creation and the ordering in six days is held by four important writers of the early seventeenth century; Grotius, Mersenne, Bacon and Descartes. Hugo Grotius, a Dutch Protestant, in *The Truth of the Christian Faith in Six Books* argued that 'the most antient tradition among all Nations [Phoenician and Greek] is exactly agreeable to the Revelation of Moses' (Grotius 1719, section XVI) and his work was later translated and widely available and used throughout Europe. Many later writers, for example Thomas Chalmers, cited Grotius in support of a chaos of undefined duration, opening the door for geological time (Chalmers 1838–1842, Vol. 1, p. 181). Mersenne, Roman Catholic priest-mathematician, wrote a massive commentary of early Genesis adding much mathematics to his exegesis which included many references to classical writers, supporting his somewhat mathematical version of the chaos-restitution interpretation (Mersenne 1623, pp. 718–719).

A few decades later Ussher (1650–1654) published *Annales Veteris et Novi Testamenti* which gave the date of creation as the evening before '*vigesimum tertium diem Octobris ... in anno periodi Julianae 710*'(Ussher n.d. Vol. VIII, p. 13), which translates to 4004 BC. Ussher only allowed the initial creation which was '*inanis et vacua*' (without form and void; Genesis 1:2) to last until the first morning. Humans were created six days later (Ussher n.d., Vol. VIII, pp. 14–15). Many other writers of the sixteenth and early seventeenth century also favoured a date of about 4000 BC (Fuller 2001, 2005), though some allowed an indefinite duration of chaos. Although his chronology from the first humans in 4004 BC to the time of Christ was widely accepted until the 1830s, his strict understanding of six days and a twelve hour 'chaos' was not, and was a minority opinion over the next 150 years. Ussher's work is, in fact, a fine piece of serious chronology of its day. His chronology from the beginning of the Hebrew monarchy from about 1100 BC to the end of the exile in the late sixth century BC more or less stands, but only a strict fundamentalist would accept his chronology before King Saul. His influence on the churches is grossly exaggerated and many writers passed over him in silence. Though his date of 4004 BC for creation is to be found in many English bibles after 1701, that notorious date was never official doctrine.

Towards the end of the seventeenth century a large number of theories of the Earth were published, mostly in Britain by writers such as Burnet, Whiston, Woodward, Ray and Hobbes (Roberts 2002, pp. 144–150). These were an attempt to rationalize the early history of the earth into six days to uphold the text of Genesis. The authors allowed an indefinite time for chaos and combined Genesis, classical writings, scientific observation and speculation into a fascinating mélange of ideas. Burnet wrote of the indefinite chaos, 'so it is understood by the general consent of commentators' (Burnet 1681, chap IV, p. 30) and the commentator Bishop Patrick wrote of the duration of chaos that '(I)t might be a great while' (Patrick 1854, Vol. 1, pp. 1–3). Exactly how long chaos lasted was never made explicit. Most accepted that the 'days' of Genesis 1 were of twenty-four hours duration, but Burnett and Whiston argued that each day of creation could have been a year in duration and the obscure William Hobbs suggested an even longer time basing his ideas on 2 Peter 3:8; 'one day is as a thousand years' and 'I say, why may not one such day, be equall to many years' (Hobbs 1979, p. 110). Writing about Whiston (Whiston 1696), who extended each day to a year, Stephen Gould said that this 'was a big step in the right direction' (Gould 1991, p. 372).

The chaos-restitution interpretation was adopted by most commentators in the eighteenth century—and to mention a few 'conservatives'—Calmet, Wesley, Gill, Pantycelyn (writer of *Guide me O thou Great Redeemer*) and Horsley as well as poets such as Milton, Traherne and Pope (Roberts 2002, pp. 150–155). This interpretation formed the basis for a libretto for a planned oratorio by Handel, which was acquired by Haydn in 1792 and used in *The Creation*. Secular writers, for example Maupertuis (1751) and Kant (1755), who made no reference to Genesis, also referred to the original formation of chaos before the ordering of the universe. The whole schemata of original chaos followed by development was an essential part of the eighteenth century worldview, whether Christian or not. The way was open for a longer time-scale.

The eighteenth century

Scientifically, Newton dominated the eighteenth century and the major advances in geology by de Luc, de Saussure, Hutton, Smith, Soulavie, Cuvier and Werner took place in the closing decades of the century. Simply, in 1700 the age of the earth was reckoned to be well in excess of 6000 years and by 1800 to be numbered in millions, except by de Luc and some others. Among theologians there was no uniform approach; however, most in the first half of the century were more flexible than Ussher. Though most commentators accepted the initiation of chaos followed by six days of creation, as the century wore on an increasing number allowed even more time. A mid-century example is the Anglican clergyman Thomas Stackhouse (1677–1752), who developed ideas of Patrick, Ray and Derham; '... this planetary world, ... was not immediately created out of nothing ... but out of some such pre-existent matter ... chaos. ... This seems to be part of God's original Creation, but why he suffer'd it to continue so long before he transform'd it ... is only answerable to divine pleasure' (Stackhouse 1744, pp. 2–3). Very few argued dogmatically for a rigid six days, though a significant minority, e.g. another Anglican, William Wall (Wall 1734), undogmatically accepted it. It is essential to distinguish between an eighteenth century theologian accepting a young Earth because they were unaware of geological evidence of antiquity and those who, like George Bugg, Granville Penn and Fairholme in the 1820s (Lynch 2002; Mortenson 2004) and modern young Earth creationists, were aware of the evidence but equated it with infidelity.

After mid-century an increasing number of savants became convinced of a vast geological time, and the theological accommodation to this kept in step with the developing ideas of geological time rather than reacting against it. Few theologians actually opposed geology and then only in a mild way as in the case of William Jones of Nayland. Most 'literalists', like Thomas Scott (Scott 1788–1792), Kidder (1694) and Blair (1802) were apparently oblivious of geologists. Most of these were strictly biblical commentators, who did not refer to any kind of science. The most significant of 'old Earth' theologians are discussed below but there were several who do not fit into any of those groups. Thus in 1785 the Revd James Douglas presented *A dissertation on the Antiquity of the Earth* to the Royal Society. As well as geological observations (including those of William Hamilton on Vesuvius), he cited Grotius on the ancient writers and concluded that 'Many well-informed persons have therefore been inclined to suppose that the earth was created in six expanses of time instead of six days' (Douglas 1785, p. 40). He did not name the 'many', who probably would have included Whiston, Whitehurst, Buffon and de Luc.

Buffon and the French connection

One of the leading French commentators was Fr Calmet, whose exegesis of the book of Genesis in 1724 was similar to that of Bishop Patrick, but was far more guarded on the duration of the chaos, possibly restricting it to hours (Calmet 1724). Despite the Protestant/Catholic divide it is remarkable how similar exegetes were in both traditions.

The person who made the greatest impact on a changing understanding of Genesis was George-Louis Leclerc, Comte de Buffon, whose new interpretations are variously understood as a devout attempt by a not very devout man to respect revelation or as a counter-theology, ultimately to reject Christian theology. I favour the former. In 1749 Buffon published the first volume of *Histoire naturelle* in which he discussed the theories of the Earth of Whiston and others at length, as well as that of Scheuchzer. These he rejected in no uncertain terms and wrote of Whiston, 'Whenever they allow themselves to interpret the sacred text by views purely human; ... they must necessarily involve themselves in obscurity' (Buffon 1812, Vol. 1, p. 109). Yet, despite his dismissal of the *Theories of the Earth*, he absorbed much from them, especially notions of a longer time-scale than Ussher and others would have allowed. However, he scarcely touched on Genesis Chapter 1 and concentrated on pointing out how fallacious it was to use the deluge to explain the origin of all strata. It was his rejection of the deluge as a major geological cause rather than time that seems to have precipitated the conflict with the Sorbonne, though details of his dealings with the Sorbonne theologians are unclear (Roger 1997, pp. 186–190).

In the middle decades of the eighteenth century Buffon met and corresponded with Fr Joseph Needham, an English Roman Catholic priest and scientist. Needham was a skilled microscopist and the first Roman Catholic priest to be elected to the Royal Society. His *Nouvelles Recherches*, which were mostly on microscopy also outlined his understanding of Genesis (Needham 1769). Needham was happy to extend the understanding of 'day' to signify periods of different times and that the 'day' described by Moses probably represented periods of more than 24 hours, pointing out that even 60 millions of years are merely '*une partie infinitesimal de l'eternitie*'(Needham 1769, p. 54). Almost with echoes of Calvin, he wrote that '[e]*n effet Moise ecrie pour tout le genre human, et non pas pour les astronomies ou les philosophes*' (Needham 1769, p. 62) and cited Augustine in support. This demonstrates that accommodation was common to both Roman Catholic and Protestant.

Buffon returned to and lengthened his time-scale in *Époques* in 1778. His suggestions of 74 000 years and seven epochs are well-known, along with his unpublished estimate of the age of the earth of 2 million years. Buffon sought to bring his extended time-scale into line with Genesis in a manner that could be perceived as devout or undevout. Though he was hardly the most disciplined of Catholics, he cannot be aligned with *les philosophes* and their infidelity. His scientific and speculative arguments do not concern us but his theology does. In the *Premier Discours* Buffon devoted some dozen pages to the interpretation of Genesis (Buffon 1778, pp. 28–31). Compared to sixteenth century exegetes and Ussher (and the associated mythology) this is radical indeed, but compared to seventeenth century exegetes, Roman Catholic and Protestant, it is a moderate development and no more. It was also well within the bounds of contemporary orthodoxy as Buffon was no more radical than Needham. Roger considers Buffon to have based his ideas on Calmet, but there is only a general likeness, as Buffon gives no citation of Calmet. Further, Calmet, though writing fifty years earlier, gives no indication a long duration of time. Buffon's ideas of the creation of an initial chaos followed by six lengthened days are similar to those of Needham and Whiston, both of whom were devout believers. Buffon had merely extended the conventional exegesis of Genesis. Whereas in his *Natural History* Buffon omitted all reference to Genesis Chapter 1 and criticized interpretations of the deluge, in the *Époques* he omitted any reference to the deluge and concentrated on a 'stretched' time-scale in Genesis. This may have been to forestall major criticism. It was difficult to condemn Buffon, without condemning Needham as well. Buffon had kept to as literalist a position as possible and emphasized the generally accepted understanding of accommodation.

The reactions in France were mixed; the theologians at the Sorbonne and some other clergy were slightly uneasy (Roger 1997, pp. 422–423), Abbé Soulavie was favourable but Abbé Barruel less so. Barruel rejected the idea of chaos and held to a literal six-day creation in a forceful manner (Barruel 1823, Vol. 1, p. 373). The French Revolution interrupted possible later developments and when the church was restored a decade later its ethos was far more reactionary. This was the case for François-René de Chateaubriand (1768–1848) of Combourg in Brittany, who published the *Génie du Christianisme*, a Catholic literary *tour-de-force* reacting against the French Revolution. He rejected Buffon's long time-scale commenting, '*Dieu a dû creér, et sans doute créér le monde avec toutes les marques de vétusté*' (Chateaubriand 1966, Vol. 1, p. 147, 472). This can be translated 'created the world with all the marks of antiquity and decay', thus the world may appear ancient but is actually a recent creation. But he also wrote, '*Voyez l'admirable commentaire de la Genèse. par M. de Luc, et les Lettres du savant Euler*' (Chateaubriand 1966, Vol. 1, p. 472).

De Luc and his letters to Queen Charlotte and Blumenbach

The Swiss-born geologist Jean Andre de Luc, who came to England in 1773 to be Reader to George III's Queen Charlotte, was a friend of both de Saussure and Voltaire. He was also friendly with members of the Lunar Society. From 1776 he wrote many letters to the Queen, which were published in 1779. These letters were almost entirely on geology and its relation to the Christian faith. As these fill many volumes only a few highlights can be mentioned. Like Buffon he discussed Whiston and other Theorists at length and stressed that '*Moyse n'a donc voulu nous apprendre, ni la durée ni la manière de la création. Il nous a indiqué l'ordre sucessif de l'existence de parties distinctif de l'Universe*'(de Luc 1778, Vol. 5, p. 639), thus reiterating an accommodationist view of scripture and here he concurred with Buffon, and, of course, with Calvin and many others.

From 1793–1795 de Luc wrote another series of letters to the German geologist Blumenbach, which was later republished in English in *The British Critic*. The Germans were more than amenable to a long time-scale in Genesis as in 1776 J. G. Rosenmüller had published a commentary in Latin allowing a long time for the creation. De Luc's letters were wide-ranging in their discussion of geology and claimed that both Buffon and

Hutton had grossly overestimated geological time. De Luc was a Swiss Protestant and was at pains to reconcile Genesis and geology. He believed that geological time was far shorter than Buffon had suggested and that the world's continents had been formed only some 10 000 years ago. However, as Rudwick (2001) has recently pointed out, de Luc was instrumental in enabling geological time to be accepted as agreeable to Christian orthodoxy throughout Europe which was particularly significant for England. The publication of his *Trait Elementaire de Geologie* in English in 1809 (de Luc 1809) gave a good account of geology just after 1800 incorporating a relatively short geological time-scale. The importance of de Luc is often under-recognized, due to his controversy over geological time with Hutton, who has often been given heroic status to the detriment of de Luc.

England and geological time

In 1701 the Stationers' Company inserted the date 4004 BC in an edition of the Bible for the date of creation, which was later included in many other editions (Fuller 2005). It has commonly been assumed that this was the Church's official or semiofficial date for creation, and thus there was considerable ecclesiastical opposition to geology and its time-scale. This became one of the themes of Chapter 6 in Andrew White's *A History of the Warfare of Science with Theology* (White 1955), which has informed or misinformed many historical perspectives on geology and Genesis. A wide range of commentaries on Genesis does not support such ecclesiastical opposition in Britain, as most make no reference to Ussher and adopt some chaos–restitution interpretation. Only a handful of theologians adopted a strict six twenty-four hour day chronology for Genesis Chapter 1. Up to mid-century few if any writers adopted a long time-scale but after 1760 more and more did so. Those who did so were not exclusively from the liberal or latitudinarian wing of the church but included Evangelical and High Church Tories, and could have been as reactionary as was Chateaubriand across the Channel a few decades later. Thus three particular streams within the English religious scene will be considered, one radical and two conservative.

The radical stream is the Unitarian dissenting tradition, which could claim allegiance of several members of the Lunar Society, like the Wedgwoods. During the early eighteenth century a proportion of English Presbyterians began to question the Trinity and some local congregations left the Presbyterian Church to set up a Unitarian Church, as happened with the Darwins' family chapel in Shrewsbury. One Unitarian minister, the Revd John Taylor, a tutor in theology at the Warrington Academy from 1757 (just before Joseph Priestley who went there in 1761) wrote in *A Scheme of Scripture Divinity* that 'God may still be creating new worlds in ... space' and continued by giving the Mosaic 'account of the formation of the earth' beginning with chaos, but gave no indication of the duration of chaos (Taylor 1762, pp. 18–19).

From Warrington, interest moved to the Lunar Society with first John Whitehurst and then, less orthodoxly, Erasmus Darwin. Many members of the Lunar Society were interested in geology and were friendly with both Hutton and his opponent de Luc (Uglow 2002, p. 145). In 1778, John Whitehurst published *An Inquiry into the original state and formation of the Earth*: his approach to Genesis was similar to that of Buffon and to de Luc, though there is no evidence that they communicated with each other. His acceptance of vast time was tempered with caution as he wrote, 'The number of ages elapsed, since the Deity created, ... will not, I presume, of a philosophical investigation' (Whitehurst 1778, p. 1) but in the second edition (1786) he was far more confident 'a few more ages will pass away before a satisfactory solution can be given' (Whitehurst 1786, p. 1). He wrote on the original chaotic state of the earth that 'This idea ... not only coincides with the Mosaic account of creation, but also the opinions of most ancient poets and historians' (Whitehurst 1778, p. 11). Like Buffon, Whitehurst had slightly modified the previous consensus of Whiston and Patrick in the late seventeenth century.

In 1790 Erasmus Darwin published *The Botanic Garden*. Most was on aspects of botany but one section dealt with the original formation of the earth and reflects current understandings of creation and chaos:

—Let there be light!' proclaimed the Almighty Lord.
Astonished Chaos heard the potent word:
Through all his realms the kindling Ether runs,
And the mass starts into a million suns;

These ideas are similar to those of Whitehurst, which is not surprising as they were associates. Darwin repeated his reference to chaos in *The Temple of Nature* of 1802. This is an exposition in poetry of the chaos–restitution interpretation and clearly supports a long timescale. Darwin was less orthodox than Buffon, but it is significant that he of all people incorporated Genesis and chaos in an otherwise secular poem.

Most would expect the Lunar Society to be progressive on the age of the earth but not the following two groups. The High Church Tories of the Church of England were often Hutchinsonian, who followed John Hutchinson's anti-Newtonian *Moses Principia* (1724) and thus inclined to literalism.

It is commonly assumed that evangelicals were hostile to science because of their biblicism. The High Church Tories came to the fore in George IIIs reign and were close to saying 'No King, No Church'. Though only a small group, they were very influential and included the Hackney Phalanx and clergy like William Jones of Nayland and Bishop Richard Watson; a few even because Bishops, including Horsley of St Asaph and van Mildert of Durham (Sack 1993).

Their main organ was *The British Critic*, which was founded in the 1790s by Archdeacon Robert Nares, William Jones and others 'to combat revolutionary tendencies and to defend the Church' (Altholz 1989, p. 24). Despite, or in spite of, the common Hutchinsonianism, articles in the journal were largely favourable to geology. From 1793 they published de Luc's letters to Blumenbach, possibly because his earlier letters to Queen Caroline meant that geology was acceptable in St James Palace if not Lambeth Palace. His influence with the Royal Family also enabled de Luc to influence the High Church wing, some of whose members inclined to Hutchinsonianism and a young Earth. Jones of Nayland (died 1800) is a case in point; in the 1780s, in a fine article on geological formations, he inclined to a young Earth in a non-contentious manner, but wrote that 'the drift of this [notions of antiquity] being to weaken the authority of the Bible' (Jones 1801, Vol. VII, p. 350). It is difficult to assess the influence of de Luc's views on the Church of England, but *The British Critic* had a circulation of 3500 in 1800, which means that a sizeable minority of the 10 000 or so Anglican clergy would have read of such ideas in a strongly orthodox High Church publication. In the early nineteenth century the Bampton Lecturer, Nares (1805, p. 314ff), as well as William Smith's (1769–1830) friend Joseph Townsend (Townsend 1813, p. 337ff) both referred approvingly to de Luc to support a moderate geological time-scale in accordance with Genesis. This is particularly significant at a time when Channing could dismiss Darwin's evolutionary opinions as Jacobin in the *Anti-Jacobin* (King-Hele 1999, p. 315). De Luc's letters give the strong message that geology and deepish time was acceptable to the Church of England but evolution was not. Richard Watson, Bishop of Llandaff, writing in 1788 accepted a high age of the Earth and in 1806 argued, like Playfair, that scripture merely fixed the age of man's existence. Yet Watson's theological writings were conservative.

There seems to have been little opposition to geology in the years before Trafalgar (1805), though Richard Kirwan and some contributors to *The British Critic* strongly criticized Hutton's geological ideas, which demanded far more geological time than did de Luc. In his Bampton Lectures of 1805, Edward Nares, cousin of Robert Nares, presented a strong case for accepting the geology of de Luc, but in 1834 he found even the limited time-span of de Luc unacceptable and strongly opposed all modern geology (Nares 1834). Possibly the origin of the story of the churches' alleged opposition to geology at the end of the eighteenth century is the opposition to the very long time-scales of Hutton. On this, most Christian writers, except Playfair, aligned themselves with de Luc and his shortish time-scale of tens of thousands of years. Opposition to Hutton, who has heroic status, has been perhaps seen to be opposition to all geology. In 1800, the Earth was considered to be vastly older than a few thousand years, but whether it was many tens of thousands or millions was an open question. The choice was between Hutton and de Luc, not Hutton and Ussher. If a mark of orthodoxy was a commitment to a chronology limited to a few thousand years, then a very high proportion of churchmen, usually deemed orthodox in every other way, were well and truly heretical! The openness of churchmen in Britain of all stripes from radical dissenters through Roman Catholics to conservative Royalist Highchurchmen and Evangelicals does not sit well with Simon Winchester's recent claim that,

> The hunch that God might not have done precisely as Bishop Ussher had suggested ... was beginning to be tested by real thinkers, by rationalists, by radically inclined scientists who were bold enough to challenge both the dogma and the law, the clerics and the courts (Winchester 2001, p. 29).

The evangelicals

It is almost an axiom that early evangelicals were literalist and opposed to all geological findings, though this has more to do with the flowering of young Earth creationism than historical events. The evangelical revival began in the American colonies and Britain in about 1730 and grew slowly until the 1790s when number of evangelical christians expanded rapidly on both sides of the Atlantic (Noll 2004). Largely because of their paucity of numbers they made little contribution until after 1800 and even then they were no more 'literalist' than their non-evangelical counterparts. In 1764 the Welsh hymnwriter and theologian William Williams (Pantycelyn) wrote an epic poem based on Genesis entitled *Golwg ar Deryrnas Grist* (A View of Christ's Kingdom). In an almost Miltonic manner Williams wove contemporary science and physico-theology into the Genesis text, beginning with the creation of chaos. Though he did not discuss time, the poem is best read if Williams considered the duration of the earth to be more than 6000 years. Williams' work is similar to many of his contemporaries and not that different from Buffon and Whitehurst. In 1761 John Wesley produced a commentary on Genesis following the common chaos–restitution theme, as did the Baptist Calvinist John Gill (1748–1763).

In the late eighteenth century several evangelicals took a considerable interest in science, especially the chemists Farish, Milner and Francis Wollaston (brother of William) at Cambridge. In Bath, three local Anglican clergy, Joseph Townsend, Richard Warner and William Richardson, were encouraging William Smith in his geological work (Torrens 2001). Townsend was one of the second-generation evangelicals and for a time had been associated with the Countess of Huntingdon (Noll 2004) and seems to have retained his evangelicalism after returning fully to the Anglican fold, when he obtained a parish in Bath. Warner's and Richardson's attitude to Evangelicalism is unknown. All were aware of Smith's longish time-scale and in his volume *The Character of Moses Established for Veracity as an Historian* published in 1813 Townsend followed a chaos–restitution interpretation and, like de Luc, accepted a limited geological timespan (Townsend 1813).

The most significant evangelical contribution must surely be in Thomas Chalmers' Gap theory. Chalmers modified the traditional chaos–restitution exegesis by holding that the first period of creation i.e. of the chaos had existed for the whole of geological time and that all geological events occurred in this 'Gap'. After that God reordered the earth in six twenty-four hour days and humans were created some six thousand years ago. This had the attraction of both holding to a literal (almost) interpretation of scripture and an acceptance of geology. Chalmers first put this forward in some chemistry lectures at St Andrews in the winter of 1803–4 (Hanna 1852, p. 86, 381) and reiterated it in the 1810s. In 1802, Chalmers was a moderate Presbyterian minister, who later converted to evangelicalism, and probably developed his ideas in response to his fellow Scotsmen, Hutton and Playfair. Hutton and Playfair had raised issues of geological age in previous decades. Hutton was no Christian but Playfair was an ordained Presbyterian minister who dealt briefly with theological implications of geology in the *Huttonian Theory of the Earth.* Playfair parried objections to Hutton on the alleged inconsistency of high antiquity with the sacred writings by stating that the Bible 'seems to be but little interested in what regards the mere antiquity of the earth itself; nor does it appear that their language is to be understood literally concerning the *age* of that body, any more than concerning its *figure* or *motion*' (Playfair 1802, p. 126). In 1816 John Bird Sumner, who was Archbishop of Canterbury from 1848 to 1862, presented a similar view in *A Treatise on the Records of Creation* (Sumner 1833). However another leading evangelical, G. S. Faber, favoured a day–age approach but was in a minority (Faber 1823). In *Outlines of Geology* Conybeare, an Anglican clergyman and later Dean of Llandaff, and Phillips discussed the theological interpretations of Genesis at length. They gently dismissed a literal view and clearly favoured the Gap theory over the day–age interpretation (Conybeare & Phillips 1822). The Oxford geologist, William Buckland, adopted a similar approach in his inaugural lecture of 1818 *Vindiciae geologicae* (Buckland 1820) in which he argued for a chaos–restitution interpretation. This he considered to be a continuation of the understandings of Townsend, Chalmers and Sumner and also the two old adversaries de Luc and Buffon (Buckland 1820, pp. 17, 22, 25–28). Buckland was propounding nothing novel and represents the culmination of two centuries of reconciling geology and Genesis.

For the next fifty years Chalmers' Gap theory became the commonest reconciliation of geology and Genesis only to be replaced by the day–age theory of Hugh Miller and others for conservatives and by a mythological view, forcefully put forward by Baden Powell in *Essays and Reviews* in 1860, for 'liberals' (Roberts 1998, 2002, pp. 159–161). After the Gap theory was rejected by more intellectual Christians after 1860, most conservative evangelicals and fundamentalists in Britain and America held a form of the Gap theory until it was eclipsed by young Earth creationism in the 1970s (Numbers 1992). This enabled most fundamentalists in the early twentieth century to accept the vast ages of geology, even if they rejected evolution.

It is irrelevant whether or not Chalmers' Gap theory was sound exegesis. Hardly any Christian accepts it in the twenty-first century and it has been vilified by young Earth creationists like Fields (1976) and Sarfati (2004). However, for a century it enabled even the most conservative Christians to accept the implications of geological findings and also prevented a serious conflict between geology and Genesis from 1800 to the 1960s when young Earth creationism came to the fore. However, from 1820 to 1850 there were major skirmishes from scriptural geologists like Bugg and Cockburn who insisted on a strict six-day creation. (Lynch 2002; Mortenson 2004). Apart from George Young none of these scriptural geologists had any geological competence, despite the special pleading of Mortenson. Even within the churches their influence was minimal. By the 1850s, hardly any educated Christians held to a 6000-year-old Earth, and recent studies on the

Christian response to Darwin demonstrates that few opposed Darwin on the grounds of defending a literal Genesis (Moore 1979; Livingstone 1987; Numbers 1998).

A problem of perception

In his fine volume on *The Secularization of the European Mind*, Chadwick wrote of the 'two hypostatized entities of the later nineteenth century ... a mysterious undefined ghost called Science against a mysterious indefinable ghost called Religion' (Chadwick 1975, p. 161). The parallel entities of the eighteenth century may be seen as the ever increasing duration of geological time of Enlightenment science and the hide-bound orthodoxy of both the Protestant and Roman church which clung to Ussher's precise and brief chronology. Thus if a professing Christian writer, or even a Buffon, happily accepts the evidence for long (or even moderate as with de Luc) geological ages and that chaos or the days of Genesis must have had a long duration, then, at that point, Enlightenment thought had taken precedence over their orthodoxy (Mortenson 2004) and probably gave rise to inner tension. Recently Uglow has expressed this,

> ... Whitehurst faced a terrible dilemma as a careful observer, he should have been content to make deductions from the 'facts' he had collected, but these conflicted with his deeply held religious beliefs, which had taught him allegiance to the Mosaic story of creation and the Deluge .... The theological and the scientific fought each other within him (Uglow 2002, p. 151).

However she provided no evidence for this battle in Whitehurst's soul. It is too facile to assume conflict between 'orthodoxy' and science without giving any evidence, as does Winchester on numerous occasions in his book on William Smith (Winchester 2001). This assumption is similar to the claims of Cannon (1978), Morrell & Thackray (1981, pp. 225–245) and Herbert (2005, p. 184) that the Anglican geologists, such as Sedgwick and Buckland, were liberal or broadchurch Anglicans and heirs to the latitudinarians, rather than orthodox. That was not the case. Sedgwick was an evangelical (Clark & Hughes 1890) and Buckland, Whewell, Henslow and Conybeare were close to being such. Buckland was encouraged by the evangelical theologians Sumner and Faber and the ultra-conservative Bishop Shute Barrrington of Durham (Rupke 1983, p. 14), whereas Conybeare contributed to the evangelical Anglican journal, the *Christian Observer*, on matters geological. In England, as in Scotland, geology was acceptable to most evangelicals, despite their adherence to the Bible (Roberts 1998). The finest example of evangelical geological writing is Hugh Miller's *The Testimony of the Rocks* (Miller 1857).

If it can be demonstrated, as it is frequently asserted (Blocher 1984, p. 41), that Christians only lengthened the Genesis day or the duration of chaos under duress from the weight of geological evidence then it would be reasonable to conclude that they had succumbed to, or compromised, Enlightenment thought. This is the implication of many writers, Andrew Dickson White, Gillispie, and, more recently, popular writers of history of geology like Cadbury and Winchester, and even young Earth creationist writers like Mortenson (2004) and Sarfati (2004), who wish to show that geological ages are the result of an 'infidel' Enlightenment. They have little credence for several reasons. First, there is a matter of chronology. Theological arguments for accepting a long, or rather a moderate, chronology preceded rather than followed geological findings, although the example of Chalmers is often wrongly presented as simply reacting to geological time. Secondly, Christian thinkers were open to a slightly longer time-scale long before geological evidence was apparent, as may be evidenced by Grotius, Mersenne, Burnett, Bishop Patrick and myriad others in the seventeenth century, who accepted a long duration of chaos and thus 'deepish' time, before there was any geological evidence for a great duration of time. And that is without going further back to the broader interpretations of Genesis of the church Fathers such as Augustine.

It is probably only the Hutchinsonians, Chateaubriand, Cowper, Barruel, the 'scriptural geologists' and a few others on one side and some *philosophes* on the other who fit neatly into such hypostatized entities of orthodoxy and Enlightenment. Most of those discussed in earlier sections accepted the science of their day and saw this in harmony with 'traditional' theology without very much internal or external conflict.

Conclusion

Throughout the three centuries from 1550 the churches' changing understanding of geological time did not proceed in a gradual evolutionary manner, but was an erratic and muddled process like all human activity and thought. However, neither was it bigoted resistance to the irrefutable claims of science. It is probably better to say that the churches' and geologists' understanding of time co-evolved with a certain amount of 'competition', but proceeding at a variable rate and, at times, the geologist and churchman were one and the same person.

Certain conclusions can be made. Despite the date of 4004 BC being found in many English bibles a strict six-day creation was never the dominant view and was the official position of no church in Europe or America (until the late twentieth century). The chaos–restitution interpretation promulgated first by Hugo Grotius, if not earlier, and then in the *Theories of the Earth*, in tandem with the understanding that the Bible was accommodated to the 'rude and unlearned', in fact opened the door for the churches' acceptance of geological time. That door was first opened wide by Buffon, then gently opened by de Luc for Queen Charlotte and the High Church divines and, finally, with protestations of biblical literalism, by the evangelicals Chalmers and Sumner. Christians of whatever theological persuasion seemed happy in their method of 'stretching the Bible like an elastic band' (an expression used by Adam Sedgwick to criticise Hugh Miller's biblical exegesis in a letter to Francis Close [27 March 1857], cited Roberts 2002, p. 160) without any major worries of being considered unorthodox. It did not matter whether they were High Church 'Church and King' Anglicans, evangelicals of all shapes and sizes, Roman Catholics or radical dissenters associated with the Lunar Society and republicanism.

To most Trinitarians and Unitarians the vast aeons of geological time were to be welcomed, even if tinged with a little caution. That caution was greater in Britain than in Europe, largely due to the biblicist influence of the evangelical revival. It is remarkable that so little caution was shown in the reactionary 1790s by the British Church to the findings of geology which are so often perceived as a result of what they opposed—the Enlightenment and its bitter fruit the French Revolution.

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Environment and natural hazards in Roman and Medieval texts: presentation of the CLEMENS database project

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Abstract: CLEMENS, acronym for *Corpus Latinorum Et Mediaevalium Naturae Scriptorum*, is a new electronic archive of *excerpta* reporting environment-related data contained in the literary and epigraphic sources of classical Roman and Medieval age. The aim is to fill a gap in information about environmental disruptions or memorabilia that occurred in ancient times within the Mediterranean basin, and to verify whether any useful information has eluded our knowledge. One of the main purposes of the systematic gathering and cataloguing carried out by CLEMENS is to become an extensive easy-to-search tool, offering the scientific community complete annotated documentation of what is available inside ancient sources about the natural environment in the Mediterranean. This information, currently dispersed in a variety of publications that may be difficult to access, has often proven essential for hazard assessment in several areas of the former Roman empire. It also contributes significantly to the understanding of changes caused by environmental events over the centuries, and of their incidence on natural habitats and on cultural heritage. The analysis of such interconnections may lead to a much improved understanding of either natural environment, hazards and cultural setting, as shown by interdisciplinary investigations merging together science, archaeology and history or even myth.

Considering the vast amount of documentation, the work is still far from completion. However, the encouraging preliminary results will soon be available on the web.

multaque praeterea ceciderunt moenia magnis motibus in terris et multae per mare pessum subsedere suis pariter cum civibus urbes.

Lucretius, *De Rerum Natura, liber VI*

and many a walled town, besides hath fall'n by such omnipotent convulsions on the land and in the sea engulfed hath sunken many a city down with all its populace.

(translation by Leonard 2004)

When dealing with recursive natural phenomena, a question comes to mind: how far back in time can we go to find evidence of similar occurrences? Answering such a question would help us to estimate, for example the return period of such events, to see if larger (and how much larger) events have taken place in the past, to find out the incidence of phenomena now unknown in a given area, to reconstruct climate changes, and to verify astronomical calculations.

People's interest in natural forces, often seen as manifestations of divinity, has prompted many written records about the most powerful or mysterious natural phenomena, since the very beginning of civilization. Scientists and historians have spent entire lives trying to interpret citations in the Bible: a typical example is the deluge, described in the Sumerian epic of Gilgamesh and in other codes. Astronomers have found confirmations of their calculations of eclipses and discovered passages of comets, falls of asteroids, even explosions of supernovae. Geologists have found data on earthquakes, eruptions—Pliny's description of the AD 79 eruption of Vesuvius is renowned—and floods; climatologists on climate evolution, and so on. However, still in the sixteenth century many natural events were *prodigia*, as made evident in the famous book by Konrad Wolffhart, better known as Lycosthenes, entitled *Prodigiorum ac ostentorum chronicon* (Chronicle of Omens and Portents), published in 1557 (Fig. 1, available at: www.propheties.it/nostradamus/prodigiorum/prodigiorum1.html). Some drawings from the Lycosthenes' book are reproduced here to illustrate the most common phenomena (Fig. 2).

At present, a wide knowledge on the environment and hazard information reported in most of the ancient written sources has been developed. However, this information is largely subject-specific and specialized, hence only accessible to specialists in humanities. As an example, we report a passage

From: PICCARDI, L. & MASSE, W. B. (eds) *Myth and Geology*.
Geological Society, London, Special Publications, **273**, 51–59.
0305-8719/07/$15.00

PRODIGI
ORVM AC
OSTENTORVM
CHRONICON,

Quæ præter naturæ ordinem, motum,
ET OPERATIONEM, ET IN SVPERIO-
ribus & his inferioribus mundi regionibus, ab exordio mundi uſque ad hæc
noſtra tempora, acciderunt. Quod portentorum genus non temere euenire
ſolet, ſed humano generi exhibitum, ſeueritatem iramque Dei aduerſus ſcele-
ra, atque magnas in mundo uiciſsitudines portendit. Partim ex probatis fideque
dignis authoribus Gręcis, atque Latinis: partim etiam ex multorum
annorum propria obſeruatione, ſumma fide, ſtudio, ac ſe-
dulitate, adiectis etiam rerum omnium ueris ima-
ginibus, conſcriptum per
CONRADVM LYCOSTHENEM
RVBEAQVENSEM.

Cum Cæſareæ Maieſt. gratia & priuilegio.
BASILEAE, PER HENRI-
CVM PETRI.

Fig. 1. First page of Konrad Lycosthenes' *Prodigiorum ac ostentorum chronicon* (Chronicle of Omens and Portents), published in 1557 in Basel (Switzerland). Accessible online at: www.propheties.it/nostradamus/prodigiorum/prodigiorum1.html.

from a work of the famous archaeologist and engineer Rodolfo Lanciani (Lanciani 1892):

It seems probable that at that time all the lowlands surrounding the Alban volcanoes, as, for instance, the Pontine, the Volscian, and the Latin districts, were comparatively healthy, on account of the purifying action of telluric fires, of sulphuric emanations, and of many kinds of healing mineral springs. In the deadly calm of nature which has succeeded the extinction of the Latin volcanoes, we find it difficult to conceive an idea of the subterranean activity which prevailed at the time. All along the valley of the Roman Forum, which valley corresponds to a fissure or rent of the soil between the Palatine and the Quirinal hills, volcanic phenomena continued to appear even in historic times. The chasm under the northeast spur of the Palatine, into which Marcus Curtius is said to have leaped, seems to have been the crater of a kind of geyser. Near the Janus Quadrifrons there were hot sulphur springs, described by Varro (ll. V. 32). In the fourth century before Christ powerful jets of water sprang up suddenly in a street called Insteia or Insteiana. Julius Obsequens speaks of other jets of reddish water, near the Senate Hall, which he compares to blood (*sanguine fluxit*). A district of the Campus Martius is called *campus ignifer* by Livy, *fumans solum* by Valerius Maximus, *to/puro/feron pedi/on* by Zosimus, on account of volcanic smokes and emanations which for centuries had been noticed there.

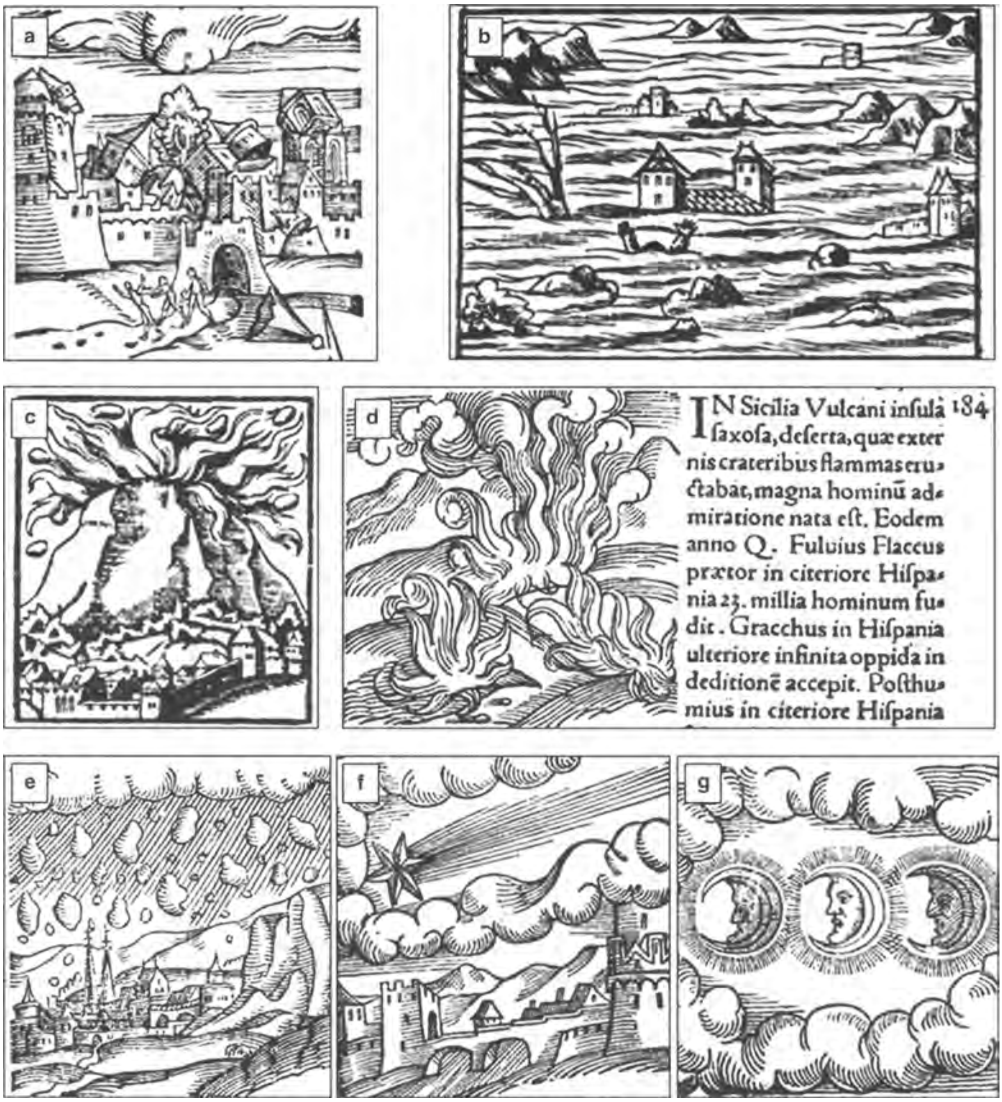

Fig. 2. Drawings symbolizing natural prodigies in Konrad Lycosthenes' *Prodigiorum ac ostentorum chronicon.* All images in Lycosthenes' *opus* are stereotypes not portraying real situations. (**a**) earthquake; (**b**) flood; (**c**) volcanic eruption; (**d**) gas/flame emission from the ground or birth of a volcanic island. In text, an event occurring in the Aeolian archipelago in 184 BC is remembered: *In Sicilia Vulcani insula saxosa, deserta, quae externis crateribus flammas eructabat, magna hominum admiratione nata est* (In Sicily near Vulcano, a deserted stony island was born with great surprise of the people, which erupted flames—lava—outside its craters); (**e**) rain of stones (sometimes related to volcanic eruption?). Rain of 'blood' and 'milk' are reported also in modern times, interpreted as contamination of rain drops by windblown dust or vegetation particles (e.g. spores and pollen); (**f**) comet or meteorite; (**g**) multiple moons (also frequent are three suns).

This interpretation, independently on its scientific soundness, is based on the deep knowledge of sources, hardly accessible to scientists without difficult research. In this case, the valuable website *LacusCurtius* (http://penelope.uchicago.edu/Thayer/E/Roman/home.html) has easily enabled the discovery of the the text above.

This short note is intended to introduce a new collection of *excerpta*, in the form of a searchable database, reporting environment-related data contained in the sources of the classical Roman and Medieval age, to enable a better understanding of how natural disasters have changed people's awareness and therefore the cultural attitude to these occurrences over the centuries. The name of the data base is CLEMENS, acronym for *Corpus Latinorum Et Mediaevalium Naturae Scriptorum*, an interdisciplinary working-programme, which involves earth science and archaeology, focusing on the analysis of environmental disruptions or memorabilia which occurred in ancient times in Italy. However, the database also considers events occurring elsewhere in the general Mediterranean area.

The Database CLEMENS

The CLEMENS archive aims at collecting and cataloguing all direct or indirect information about natural world, especially regarding the environment and related hazards in the Mediterranean basin, provided by ancient Latin and Medieval secondary sources. To best comply with the demand of search possibilities and data management, the architecture of the system has been built up with the most advanced technologies, taking advantage wherever possible of open source software. The input system has been kept relatively simple and flexible, based on a single form with two main sections: humanities and science. The output, on screen or printed, can be customized through an advanced query system. The structure of the catalogue is as follows:

1 Humanities section:
   a data concerning the author and the literary work from which the excerpt is taken;
   b the source excerpt (*excerptum*) in its original language—commonly Latin, sometimes Greek—with a translation into Italian and English, an explanation of technical or poetic terms included in the source if needed, as well as a commentary.
2 Scientific section:
   a The identification of the natural phenomenon analysed according to scientific standards, its reliability, the period and place of occurrence including geographic coordinates, and finally, explanations and comments with pertinent bibliographic references.

Environment and birth of myth and historiography

In its primitive cultural expressions, mankind had difficulties in understanding and classifying natural phenomena and related disasters. Therefore, tribal culture invented patterns to find explanations for current events and to establish them initially in oral traditions—subsequently, during the evolution of social systems, in religion—and finally, with the improvement of technology, in science (e.g. de Santilliana & Von Dechend 1969; Kirk 1973). In the Greek world the term *mythos* is associated with different meanings: narration, tale and history (see Vivaliano 2007). A myth also trades definite and conclusive statements concerning a true state of the case, which are founded on real events. These sentences are transmitted through time in order to confirm life continuance, becoming a permanent structure which simultaneously refers to past, present and future.

Myths and ancient historiography, beginning with the oldest sources (Egypt, about 3200 BC), passing through the Acadian and Sumerian cultures, the Hittites, the Jews, and finally reaching the Greeks and Romans, mostly concern traditions and thoughts that form the milestones of the western world's culture. Although historiography, in the sense of the modern term, was developed during the seventh century BC in ionic Greece, the topics of every ancient culture deal mostly with the activities of kings, wars, politics and economics. However, these sources also contain important narrations and often detailed information describing environmental changes and disruptions that have caused the decline or rise of many cultures.

For a long period, humanity availed itself for these intents of myth, religion and only later of historiography. This means that history has become intertwined with and has always been a subjective way of reporting events, commonly near to the truth but never reaching it in its wholeness or completeness. The ancient historiographers, not having all the answers to every possible question, solved this problem by introducing narration statements belonging to divine actions, fate and myth. To paraphrase an important axiom of the philosopher Xenophon (fifth–fourth century BC), who influenced Cicero and Sallustius, the gods did not reveal everything to humanity, but rather it is man's duty to seek after the truth. It has been a great Greek achievement to develop new empirical methods in contemplation of nature and sciences—philosophy, mathematics, astronomy—in order to set the bases for a better comprehension of the world, the environment and the hazards. These accomplishments reached Rome after the second century BC, with the annexation of Greece. In that period many important Greek philosophers and historians, such as Poseidonius of Apamea (135–50 BC) or Polybius of Megalopolis (203–120 BC), successfully spread their doctrines and knowledge in the higher circles of Roman society. And, last but not least, several important Hellenistic libraries were transferred to the capital, e.g. after the defeat of Pydna (168 BC), P. Emilius took possession of the great library of the Macedonian king Perseus, introducing unknown scientific and historical works into Rome.

Results

Although the work is still in progress, it is worthwhile discussing the present results of CLEMENS. After a thorough analysis of the existing classical Latin literature, nearly 70 texts—from the third century BC to the fifth century AD—have been identified, which may include information about the subject of natural phenomena, with the intent of widening the spectrum of the *excerpta*. Up to now five famous works of Roman authors between the second half of the first century BC and the first century AD have been analysed in detail. The genres are: architectural/technical, historical, philosophical/scientific and poetical. At the moment of writing this note, a total of 279 *excerpta* relating to environmental disruptions and natural calamities have been catalogued:

a Titus Livius (59 BC–AD 17), *Ab Urbe condita* (27–25 BC), genre: history, with 170 citations;
b M. Anneus Lucanus (39–65 AD), *Bellum Civile—Pharsaglia* (*c.* AD 60), genre: history/poetry, with 16 citations;
c T. Lucretius Carus (98–55 BC), *De rerum natura* (*c.* 50–55 BC), genre: science/philosophy, with 69 citations;
d C. Sallustius Crispus (86–35/34 BC), *Bellum Iugurthinum* (43–42 BC), genre: history, with only 3 citations.
e M. Vitruvius Pollio (first century BC), *De architectura* (27–23 BC), genre: architecture/environmental sciences, with 21 citations.

The works of other authors, Tacitus, Pliny the Younger, Julius Obsequens, and Strabo, have already been sieved, and are included in the database. Others, e.g. Ovidius, Horatius, Seneca, and Pliny the Elder, are now under scrutiny. The environmental effects identified fall in the following primary genres, ordered by frequency: history, science, astronomy, geography, myth, war, climate, medicine, ritual, technology, tale, poetry, nature (Fig. 3).

Thrity-seven types of environmental effects have been classified, specifically: whirlwind (only three cases in Lucretius' *opus*), weather anomaly, volcanic eruption, tide, thermal spring, temperature anomaly in water and spring, salt pit, physical phenomenon, pestilence, marsh, marsh draining, magnetism, lightning, landslide, landscape, geological and geographical information, gas emission with ignition, flood, fire, faulting, famine, falling stars, eclipse, earthquake, earth moving/excavation, drought, comet, changing of the seasons, change of the moon, climatic conditions, environmental information, meteorite, subsidence and unidentified anomaly (14 cases). The latter are cases of controversial interpretation that need more investigation. Also famines and pestilences have been included, because of their frequent link to environmental events.

These *excerpta* focus on phenomena ranging from earthquakes to floods, landslides, rockslides, tides, solar eclipses, etc. Furthermore, there are many geographical descriptions of sites and geological information about changing environments, like the existence of a great cavern in Umbria (Livy, **X**,1), the description of the origin of Capo Peloro, the ridge in Sicily (Lucanus, **II**, 435–438) or Livys' beautiful description of the territory in which one day the Urbs will rise (Livy, **5**, 54), and many others. These events are independently interpreted as mythical, scientific or historical occurrences. Although the authors' intents are different, they accept without prejudice the

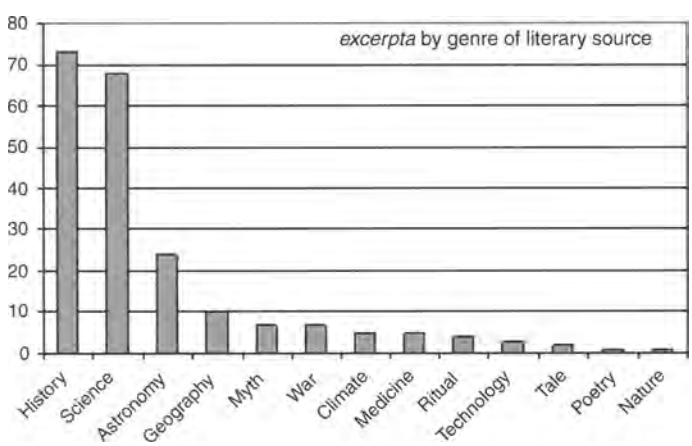

Fig. 3. Number of *excerpta* by genre already catalogued in the CLEMENS archive. History and science genres are the most frequent source of information.

various attitudes of their time, reporting mythological interpretations of phenomena as well as scientific, technical, poetic and historical points of view.

Anneus Lucanus, for example, uses phenomena to describe the tough personality of Caesar and Pompeius as rivals, comparing them to the strength of weather anomalies or lightning. On the other hand he also tells us about a volcanic eruption occurred in *c.* 49 BC: 'In Sicily fierce Mulciber opened wide the mouth of Etna; nor did he lift its flames skyward, but the fire bowed its crest and fell on the Italian shore. Black Charybdis churned up waves of blood from the bottom of the sea ...' (Lucanus, *Bellum Civile*, **1**, 545–548). With the aid of mythology, which states how in the bowels of Etna lives the god Volcano—also named *Mulciber*, 'who moulds the iron'—with his Cyclops, producing volcanic phenomena, Lucanus describes with poetical elegance an eruption connected with an extreme activity of the Charibdis' sea vortex.

On the other hand, Lucretius Carus uses a more scientific approach when he deals with disruptions and natural phenomena. He describes the origin of many anomalies, for example: 'We must believe that thunderbolts are produced from clouds thick and piled up high, since they are never emitted in a serene sky nor when the clouds are lightly packed' (Lucretius, *De Rerum Natura*, **6**, 246–248) or 'Since therefore she [the Earth] has these things attached beneath her and ranged beneath, the upper earth trembles under the shock of some great collapse when time undermines those huge caverns beneath; for whole mountains fall, and with the great shock the tremblings in an instant creep abroad from the place far and wide' (Lucretius, **6**, 543–547).

Moreover, the author gives also concrete examples of events, when he reports with great feeling the volcanic eruption that destroyed Catania in 122 BC:

> For there was no common devastation that attended the fiery storm which arose and held supreme dominance over the fields of Sicily, drawing upon itself the eyes of neighbouring nations, when perceiving all the regions of heaven to smoke and sparkle, they filled their hearts with panic fear, whether nature was in travail to work some universal disaster (Lucretius, **6**, 640–646).

Lucretius mentions also phenomena then well known within the Mediterranean area, such as the annual floods of the Nile (Lucretius, **6**, 714–728), gas emissions in Athens (Lucretius, **6**, 749–755), in Cumae (Lucretius, **6**, 747–49), and in Tracia on the isle of Skapté Hyle (Lucretius, **6**, 806–810), anomaly in a spring in Arados (Lucretius, **6**, 890–894), magnetism in Magnesia in Lydia (**6**, 910–916) and Samothrace: 'I have seen Samothracian iron dance, and at the same time iron filings go mad in a bronze bowl, when this magnet stone was applied underneath: so eager seems the iron to escape from the stone' (Lucretius, **6**, 1044–1047). As influenced by the philosophical ionic school, Lucretius manuscript is characterized by a strong rational way of scientific thought, which is very familiar to us, and *De Rerum Natura*, has been one of the most influential works of our western culture through the centuries. Besides, studies about environmental science also exist that explain how to plan the foundation of cities, how to build the edifices, etc. The military surveyor and architect Vitruvius Pollio (first century BC) gives professional indications in order to prevent hazards:

> For fortified towns the following general principles are to be observed. First comes the choice of a very healthy site. Such a site will be high, neither misty nor frosty, and in a climate neither hot nor cold, but temperate; further, without marshes in the neighbourhood. For when the morning breezes blow toward the town at sunrise, if they bring with them mists from marshes and, mingled with the mist, the poisonous breath of the creatures of the marshes to be wafted into the bodies of the inhabitants, they will make the site unhealthy. Again, if the town is on the coast with a southern or western exposure, it will not be healthy, because in summer the southern sky grows hot at sunrise and is fiery at noon, while a western exposure grows warm after sunrise, is hot at noon, and at evening all aglow (Vitruvius, *Praefatio*, 4).

Vitruvius' tractate has been a fundamental milestone for the western world in construction science until the Renaissance.

Livy, the first great Roman historiographer, who cleverly summarized the massive, now lost, work of the annalists, had an original approach to the environmental events. Since, the main intent of his work *Ab Urbe Condita* is to glorify the origin and rise of Rome, the phenomena explain legendary events which are transformed in myths, such as the death of Romulus, about 721–718 BC:

> When these deathless deeds had been done, as the king was holding a muster in the campus Martius, near the swamp of Capra, for the purpose of reviewing the army, suddenly a storm came up, with loud claps of thunder, and enveloped him in a cloud so thick as to hide him from the sight of the assembly; and from that moment Romulus was no more on Earth (Livy, **4**, 21).

He also reports real events that are mainly characterized by a strong superstition (398 BC):

> One incident, however, caused universal anxiety. The Alban lake rose to an unusual height, without any rainfall or other cause which could prevent the phenomenon from appearing supernatural. Envoys were sent to the oracle of Delphi to ascertain why the gods sent the portent (Livy, **5**, 15).

The Romans followed the indication given by the Phytia, the priestess of Delphi, and smartly drilled a tunnel to control the water level: so the gods were appeased. The existence of such an ancient tunnel, still in operation two decades ago (!) is there to testify that some trust can be placed in Livy.

Many phenomena were still interpreted in various sources as portents (see stereotyped examples in Fig. 2), like:

- appearance or disappearance of islands (obviously volcanic or seismic activity);
- fall of stones (volcanic or meteoritic activity?);
- showers of milk, blood, flesh, iron, wool, and baked tiles (Pliny, **2**), likely aerolites—e.g. '*Lucanis lacte, Lunae sanguine pluit*' (Obsequens, *Liber Prodigiorum*, fourth century AD, a *compendium* of Livy's *oeuvre*);
- flying objects, e.g. '*clypei ardentes*' (Pliny): burning shields, likely meteorites (but taken as evidence of extraterrestrial visits by ufologists!), or '*sol noctu visus*', '*In Gallia tres soles et tres lunae visae sunt*' (Obsequens), frequently reported portents of unclear origin, together with eclipses and falling stars;
- blood in rivers and lakes, e.g. '*Carseolis torrens sanguinis fluxit*' (Obsequens): likely *Planktothrix rubescens* or other phytoplankton.

The database also helps to analyse how the Roman society dealt rationally with the principal types of phenomena recorded by the historiographers. The famous scientist Gaius Plinius the Elder (AD 23–79) in his *Naturalis Historia* (AD 77–78), the encyclopaedic *oeuvre* that mostly influenced the western world, investigated the causes of earthquakes:

The earth is shaken in various ways, and wonderful effects are produced; in one place the walls of cities being thrown down, and in others swallowed up by a deep cleft; sometimes great masses of earth are heaped up, and rivers forced out, sometimes even flame and hot springs, and at others the course of rivers is turned. A terrible noise precedes and accompanies the shock; sometimes a murmuring, like the lowing of cattle, or like human voices, or the clashing of arms. This depends on ... the shape of the caverns or crevices through which it issues ... Nor is it a simple motion, but one that is tremulous and vibratory. The cleft sometimes remains, displaying what it has swallowed up; sometimes concealing it, the mouth being closed and the soil being brought over it, so that no vestige is left; the city being, as it were, devoured, and the tract of country engulfed.

He also explains that:

Maritime districts are more especially subject to shocks. Nor are mountainous tracts exempt from them; I have found, by my inquiries, that the Alps and the Apennines are frequently shaken. The shocks happen more frequently in the autumn and in the spring, as is the case also with thunder. There are seldom shocks in Gaul and in Egypt; in the latter it depends on the prevalence of summer, in the former, of winter (Pliny the Elder, ch. 82, Of clefts of the Earth).

Pliny tries to define characteristic situations in which an earthquake occurs:

'There is no doubt that earthquakes are felt by persons on shipboard, as they are struck by a sudden motion of the waves, without these being raised by any gust of wind. And things in the vessels shake as they do in houses, and give notice by their creaking; also the birds, when they settle upon the vessels, are not without their alarms' (Pliny the Elder, ch. 83, Signs of an approaching earthquake).

Some ingenuities in interpreting the causes of earthquakes endured for millennia. In the eighteenth century the great philosopher Immanuel Kant (1724–1804), in a dissertation inspired by the Lisbon disaster of 1755 (Kant 1756), basically follows Aristotle's (384–322 BC) and Lucretius' interpretation:

'Earthquakes have revealed to us that the Earth surface is made of vaults and caverns and that under our feet hidden galleries and an infinite number of labyrinths extend everywhere. The 'time-history' of the earthquake [the 1755 event] will clarify this point leaving absolutely no doubts about it',

or

'There are many examples in the history of earthquakes and volcanic eruptions showing that they occur more frequently in autumn'.

In this second passage Kant supposes, according to the philosopher Aristotle and Pliny, that one of the causes of earthquakes is heavy rainfall.

The flooding from the Tiber was one of the most dangerous phenomena for Rome; a problem solved only at the end of the nineteenth century with the building of the great embankments that protect the centre of the city. Livy describes several floods, causing considerable damage, and subsequent pestilences: 'There was an enormous rainfall that year and the low-lying parts of the City were inundated by the Tiber. Near the Porta Flumentana some buildings collapsed' (Livy, XXV, **9**, 192, 214 BC); 'The flooded Tiber made a more serious attack upon the City than in the previous year and destroyed two bridges and numerous buildings, most of them in the neighbourhood of the Porta Flumentana' (Livy, XXXV, **21**, 3, 200 BC); 'There were very heavy floods this year; on twelve other occasions the Tiber inundated the Campus Martius and the low-lying parts of the City' (Livy, XXXVIII, **28**, 198 BC).

The Romans made many attempts to mitigate the flood risk, with poor results. During a large part of the Republican period (509–27 BC) most people—organized in static tribes—lived on the seven hills, hence safe from the huge floods of the river. Following victory over the Punics, Rome began to develop on the low land near the Tiber. As the city reached one million inhabitants, Augustus (27 BC–AD 14) encouraged the urbanization of Campus Martius, initiated by Julius Caesar, even building his mausoleum there. With the great political and administrative accomplishment of Italy and Rome and due to the frequent floods, Augustus started maintenance works in the river bed and appointed the '*curatores alvei*

Tiberis et riparum' (Suetonius, *Augustus*). After a disastrous flood in AD 15, two magistrates commissioned by Tiberius (AD 14–27) proposed, without success, to divert the courses of two tributaries of Tiber (Chiana and Nera). A few decades later, Claudius (emperor in AD 41–54) opened a new channel near the river mouth, to facilitate the flow and to serve the new port of Rome at Ostia. In the same period, the highly variable Lacus Fucinus, for example the exceptional rise in 137 BC remembered by Julius Obsequens, was drained with a 4.5 km long tunnel, mostly cut in hard limestone, which represents one of the greatest engineering achievements of Roman technology.

Although Romans interpreted natural calamities as gods' signs, for which specific rites, such as *nouendiales*, were required to regain their benevolence, the Roman craftsmen developed appropriate engineering solutions to reduce the hazard, e.g. artificial channels to ease the river flow, better masonry to resist the seismic shaking, and restrictions on urban occupation. Various emperors and consuls financed the restoration of monuments and towns destroyed by earthquakes and floods. In Rome the hazard rose enormously with the town expansion in the low-lying areas along the Tiber, following the wealth of the imperial age; risk remained very high after the fall of the empire. In fact, even when the population dropped dramatically, the remaining citizens preferred to live in the unhealthy areas periodically flooded near the river, which was the only source of water after the aqueducts were destroyed in the sixth century, during the Gothic–Greek war (535–553), to be rebuilt only a millennium later, in the fifteenth–sixteenth centuries.

The Romans developed a wise mixture of praise to gods and preventive actions based on the acquired experience. After that, the only shelter was God, or more commonly the Virgin Mary and the saints, up to the Modern era and beyond.

Final remarks

The comprehensive and systematic gathering and cataloguing of environmental information carried out by CLEMENS has never been undertaken before. The available lists and publications, even though of high quality, are the result of profound studies. They are mainly summaries (e.g. Bustany 2001) and/or of sectoral typology, especially focused on earthquakes (e.g. Guidoboni 1994), floods (e.g. Le Gall 1953), astronomy (e.g. for eclipses, Stephenson 1997; for meteorites, D'Orazio 2007). Only part of the classical period literary works describe natural phenomena. Nevertheless, in order not to miss any important piece of information, it is necessary to read every single page, which may be dreadfully boring for a scientist! For example, Pliny the Younger, apart from his essential and vivid description of 79 AD eruption of Vesuvius, almost never cites in his wide opus any *naturalia*, which interested his uncle Pliny the Elder so much (*Naturalis Historia*) and his contemporary Seneca (*Naturales Quaestiones*).

As stated before, one of the main purposes of the CLEMENS project is to become an extensive easy-to-search tool, offering the scientific community a complete documentation of what is available within ancient sources about the natural environment in the Mediterranean. Although these sources are never coupled with modern, scientific criteria, such information is essential for hazard assessment in several areas of the former Roman empire. It also contributes to a better understanding of changes caused by environmental events over the centuries, and of their incidence on the natural habitats and on the cultural heritage. In fact, natural disasters have often led to abrupt deviations of the course of history, prompting economic crises and famine, sometimes followed by pestilence. They have also caused migration and colonization of new sites, hence sometimes leading to fierce wars, and foundation of new cities and destruction of others, social regress followed by progress, decline and birth of cultures.

At a more local scale, geological events of various kinds have often induced a strong cultural imprint. The analysis of such interconnections may lead to a much improved understanding of natural environment (and hazards) and cultural setting, as proven by interdisciplinary investigations merging together science, archaeology and history or even myth (e.g. Piccardi 2000, 2005).

Despite their undisputable cleverness and open minds, our ancestors found it hard or impossible to explain many natural phenomena scientifically, which were often taken as omens by the common and sometimes also cultured people, or offered to them as such for political reasons. Even now, some phenomena reported by ancient sources lack a sound explanation, especially the astronomical ones to the delight of ufologists.

A significant spectrum of authors and *naturae memorabilia* have already been catalogued. However, this is a work in progress, still far from its completion and not yet on the web, which will be its natural location in the near future. Nevertheless, it has achieved a success: to make us read with new eyes some masterpieces of literature from the Roman age, allowing us to discover once again the natural wisdom of our ancestors.

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From myth to Earth education and science communication

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Abstract: There is a longstanding and intimate relationship between myths and the Earth. Myths represent human beings in childhood when a primitive language made of symbols transmitted the wisdom necessary to live in harmony with nature. Today science uses mainly the language of data. Nevertheless, myths and legends are still popular and part of our culture, and the Earth sciences remain confined mostly to the world of scientists. This paper is an attempt, from the perspective of science communication, to provide a theory that uses myths and legends to stimulate the curiosity of the man in the street about the planet we live on. Recent studies have demonstrated that fictional stories can be used to convey science to the general public in an accurate, memorable and enjoyable way. Following these ideas, we believe that myths can be a useful tool for Earth science studies, learning and popularization.

From ancient times, natural forces have been portrayed as mythological figures. The behaviour of these figures resembled that of humans and the Earth phenomena were familiar to its inhabitants. In many cultures, giants and demons are the cause of volcanic eruptions. In Greek mythology, Poseidon was the 'earth shaker' and the king of floods. Earthquakes and floods were sent to Earth as a punishment. Lakes have inspired ancient legends, becoming homes of spirits and ancestors. Today, geologists can benefit from myths because they are often a source of relevant information for their studies (e.g. historical records). A recent study shows that Homer's Iliad is not just a tale but also is an accurate account of the geography of ancient Troy (Kraft *et al.* 2003). Similarly, excerpts from Diodorus Siculus, from the Epic of Gilgamesh and from the Bible (Genesis 7:11) are referred to, in a footnote of a scientific article, to support the hypothesis of a methane-driven oceanic eruption as the basis of some catastrophic events, even at a smaller scale, such as the biblical flood (Ryskin 2003).

On the other hand, there are studies aimed at giving scientific support to biblical accounts or to the birth of some classical myths. For instance, two Russian scientists, N. E. Voltzinger and A. A. Androsov, have explained the Red Sea parting during the Jewish exodus with scientific data. They determined that a reef runs from Egypt to the north side of the Red Sea and that during biblical time (1500 BC) it used to be much closer to the surface. Their interest was in studying the speed of the wind and the strength of a storm needed to leave the reef high and dry at low tide (Voltzinger & Androsov 2003). As another example, geologists and toxicologists have published their data to demonstrate that the trance-like state of the Priestess (the Pythia), the Oracle at Delphi, was not just a piece of fantasy. Piccardi (2000) has shown that Delphi is directly above one of the main antithetic active faults of the Gulf of Corinth Rift. The presence of an active fault directly below the temple of the oldest sanctuary suggests that the mythological oracular chasm might well have been an ancient tectonic surface rupture. Other scientists support the hypothesis showing that the trance-like state of the Pythia during her mantic session could have been produced by inhaling ethylene gas or a mixture of ethylene and ethane coming from a naturally occurring vent of geological origin (Spiller *et al.* 2002). The idea that the degassing activity from the soil or from the sea can affect the human mind is not new. Even Strabo, quoting Posidonio, reported that the sea was swelling up off the coast of the Aeolian Islands. Some ships came very close to the site where the natural phenomenon was taking place. Dead fish were observed and some men died as well, while the survivors experienced something similar to epileptic attacks, and were very near to madness (H. L. Jones ed. 1970).

Are the geological origins of myths enough to explain their existence or do myths have an autonomous meaning that should also be considered and used for other purposes? The term 'geomythology' indicates a new discipline based on the idea that some myths and legends can be explained in terms of actual geological events witnessed by various groups of people. The term was originally conceived as the geological application of the term 'euhemerism', from the Sicilian philosopher, Euhemerus (300 BC), who held the belief that the

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Table 1. *Number of items from one-week survey on different issues carried out in September 2003 on prime time European TV news (data from Leon 2004).*

	Science	Environment	Health	Crime	Sports	Politics	Total items
France	12	11	32	49	25	49	383
Germany	6	3	2	22	23	46	186
Spain	10	7	6	51	81	52	372
UK	4	1	9	27	19	35	153
Italy	0	3	5	20	15	44	252
Total	32	25	54	169	163	226	1346

gods of mythology were simply deified mortals (Vitaliano 1973). When Vitaliano (1973) collected various examples in a single volume describing how geological events could have inspired myths, legends and folk tales all over the world, she hoped that it might aid in bridging the communication gap between scientists and the non-scientists. She hoped to stimulate the curiosity of non-geologists sufficiently to persuade them to seek further information about the Earth we live on. We concur, it is a duty of scientists to explain scientific subjects in terms that non-scientists can understand, especially in times when the results of man's tampering with the natural environment are rapidly approaching crisis proportion, as Vitaliano has already pointed out. In particular, Earth sciences should be considered as part of the basic scientific knowledge that any educated citizen requires to understand contemporary issues such as global warming and natural hazards and also to take an active part in the problem solving.

The importance of sharing knowledge about Earth

Geoscientists sometimes lament the lack of popular interest in what they consider to be of pivotal importance in the well being of people. In truth, it is the general custom of science neither to seek the attention of the public nor to promote coverage by the media, as recent research in a number of European countries shows (see Table 1). If we consider TV programmes as a reliable mirror of what people like to watch, we can conclude with the author that science and technology are marginal topics within European prime time television news (Leon 2004). If we go into detail, as in a recent study performed in Spain, we may be surprised by some results. The graph in Figure 1 is related to a Spanish science TV programme called *Redes*, and shows results drawn from a nine-year-long survey. The authors were answering the question 'What scientific issues do people prefer to watch on TV?' According to this study, the answer is that physics and cosmology have the biggest audience. In the survey, Earth sciences were in the same category as biology or with the topic 'environment'. But even 'environment' has a disappointingly modest audience in this study. It is interesting to note with the authors that 'hard' topics such as the laws of physics and quantum particles were greatly appreciated by the public even though these are subjects less related to everyday life (Estupinya *et al.* 2004). Do people prefer to look at the sky or to invisible worlds rather than gaze at what is under their feet? Similarly, sea-explorers sometimes lament that twelve humans have already been on the moon whereas only two have explored the Mariana submarine trench (almost 40 years ago) which is the deepest location on Earth, the planet we live on.

Nevertheless, an accurate Earth science education and effective communication can really

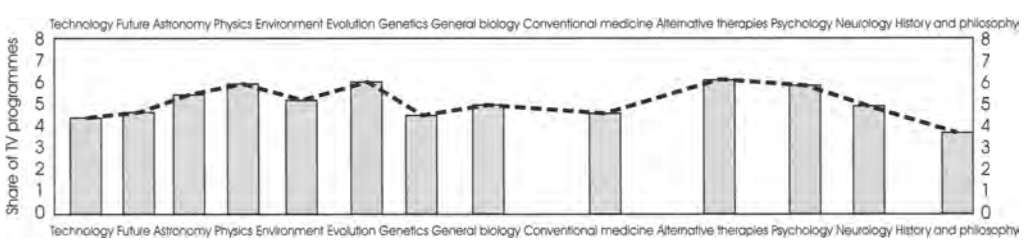

Fig. 1. Histogram showing the share of TV programmes for different scientific topics. The plot refers to a nine-year long survey of the Spanish science TV programme *Redes*. Earth sciences are included in general biology and in environment (modified from Estupinya *et al.* 2004).

make a difference. It can help geoscientists to raise funds for their studies, it can facilitate emergency procedures during a crisis, and above all, it can save lives as the 26 December 2004 tsunami disaster that occurred in the Indian Ocean shows. The disaster has been considered the world's biggest failure of science communication (Dickson 2005). It is also a clear example of the difficulties that scientists face in explaining the potential hazard of some regions of the Earth. A few days before the disaster, American scientist Kerry Sieh (Sieh *et al.* 2004) presented some results obtained by investigating the outer-arc islands of western Sumatra at the AGU fall meeting. Palaeoseismic studies together with GPS measurements and palaeogeodetic observations suggested that the next giant earthquake in the area would occur soon. In collaboration with the Indonesian Institute of Science (LIPI) he was already implementing an education programme distributing posters and brochures to the population in Sumatra. After the disaster, in an article posted to *Time Asia*, talking about his experience with the islanders, he was underlining the complexity of convincing people of the need to be worried about big, powerful geological processes that might happen in the near future on in ten generations' time (Sieh 2005).

One may concur with Sieh that it is hard to convince people in poor countries because they have a tough enough job finding time to get their daily chores done. In truth, despite a long list of very successful commercial movies that have made the hazards of our planet familiar, the reaction of people to natural hazardous events in developed countries can also be inadequate. In Italy, people sleep quietly on the flanks of one of the most dangerous volcanoes in the world, Mount Vesuvius. The last significant seismic event in Italy, the 1997 Umbria–Marche earthquake, shows that the experience of an earthquake can be transformed by the media, in the absence of public education relating to a natural hazard. The consequences can be dramatic especially when the scientific community is not accustomed to interact with the complex world of the media (Lanza 2001).

Another example is that of Cameroon, during the 1986 explosion of Lake Nyos. On that occasion almost 1700 people were killed. Among them, the ethnic groups living in the area survived because they were following local mythology. Referring to the legends documented by anthropologist Eugenia Shanklin, science journalist Kevin Krajick reported in an article that according to Cameroonian myths, lakes are the homes of ancestors and spirits and can be a source of death (Shanklin 2007). A lake may rise, sink, explode or even change location. Certain ethnic groups decree that houses near lakes should be erected on high ground, perhaps, in the collective memory, as a defence against disaster (Krajick 2003). They did it and they survived. The above observations raise two questions. What makes myths and legends worth following? And why are myths potentially interesting?

A common human heritage—meaningful today?

Today, people use the terms 'myths' and 'legends' to indicate something irrational that causes misinformation. If, for instance, we type the words 'tsunami myths' into the Google search engine, the first scores we obtain are related to 'myths' as opposed to 'facts'. Facts are explained and supported by science. Are we sure that scientific facts have replaced myths? Should we consider myths and legends as a treasure belonging to the past and to pre-modern societies? Or should we still consider them meaningful in the twenty-first century?

In his beautiful essay *The Impact of Science on Myth*, J. Campbell (1993) affirms that J. G. Frazer, in his monumental work *The Golden Bough*, was convinced that the superstitions contained in myths would have been discarded by science. Campbell comments that Frazer was a typical nineteenth century author and believed that myths were based on magic, and magic on psychology. But the psychology he relied on was positivistic and ignored the deep and irrational instinct of human nature. Frazer was then convinced that showing the irrationality of a belief was a way to make it disappear. In another book, Campbell (1990) asserts that myths have been the living inspiration of whatever else may have arisen from the activities of the human body and mind, including the prime discoveries in science and technologies.

On the contrary, modern science has contributed to making our inner world silent. It was mythology that consolidated the inner world, gave human form to its experiences, and connected man to life (Hughes 1988). Even if reduced to silence, our inner world has not ceased to exist. Eliade (1991) affirms that symbols, myths and images belong to our spiritual life. We can mask them, mutilate them, denigrate them but we will never eradicate them. In the same vein, Campbell (1993) appreciated the interpretation of Freud and Jung, according to which myths are the product of our psyche and are strictly related to dreams. Freud maintained that dreams are private myths and myths are public dreams, whereas Jung recognized that myths are a precious 'link' to our inner life and for this reason they can never be replaced by scientific discoveries. Jung explained the birth of similar myths all over the world in terms of identical psychic structure common to all, the archetypes that give rise to similar thoughts, images and mythologems (recurring themes of myths). If we accept the results of Jung's studies we can consider myths as a common human heritage, meaningful also for the modern societies. The dialogue we maintain with our inner world through the study of our dreams and myths is therefore of great importance. Nowadays scientists highlight the importance of our inner world when they investigate the role of sleep in scientific discoveries concluding that sleep facilitates extraction of explicit knowledge and insightful behaviour (Ullrich *et al.* 2004).

At the same time, since myths are a type of narrative (such as fairytales, short stories, anecdotes and jokes), they can be potentially charming. The word 'myth' comes from a Greek word that can be translated with terms such as 'word', 'speech' or 'tale'. In this study, myths are taken as type of narrative that uses a symbolic language, takes place outside history and time and includes characters (mainly gods and heroes). In this sense they constitute a structure (schema) familiar to most of the general public. Besides being enjoyable, as any other form of narrative they are also an alternative way to represent reality.

Narrative knowledge as a legitimate form of reasoned knowing

Narrative knowledge is more than emotive expression. It is rather a legitimate form of reasoned knowing. Bruner (1990) denoted as paradigmatic cognition the familiar logical–scientific mode of knowing, and storied knowing as narrative cognition. Traditionally, paradigmatic cognition is the only cognitive mode for the generation and transmission of valid and reliable knowledge. However, although the idea that there is more than one mode of rationality has long been ignored, it has in fact been part of human culture for centuries (Polkinghorne 1988). Today, it is widely accepted that both paradigmatic and narrative cognition generate useful and valid knowledge and that they are part of the human cognitive repertoire for reasoning and making sense of reality (Gardner 1983).

Classic work by Bartlett (1932) proposed the idea that schemas, or mental frameworks, constructed from prior knowledge and experience, are influential in determining and shaping the memory of a story. People (the general public) already have knowledge (schemas) for narrative information that guides understanding and assists the individual in constructing meaning. This means that when an individual is reading a story, he/she has certain knowledge about the structure of a story. For example most classical stories contain a beginning, middle and outcome; characters (normally a villain and a hero); there is a denouement or twist to the story and something to pursue. All these previously known elements assist the reader in reading and understanding the story.

Added to the schemas (previous knowledge of the structure of a story), narratives include several characteristics that make them memorable, understandable and enjoyable. Apart from their aesthetic value, narrative resources (such as tropes) can work as mnemonic devices (elements that help to remember). They can aid understanding by organizing information and also serve as models to make sense of reality (Negrete & Lartigue 2004).

Towards a new mythology of the Earth

Recent research in science education and communication suggests that science can be learned through literary stories or fictional narratives and that this represents an important means for science communicators to transmit information in an accurate, memorable and enjoyable way (Negrete 2002). Myths can be used in the classroom to attract pupils' attention, raising discussion of how science today explains what myths tried to without scientific knowledge. We have already seen how Cameroonian myths were transmitting the hazard of Lake Nyos. That is a tale that the ethnic population knows very well. When science journalist Kevin Krajick was there to write his article about killer lakes, Che, an inhabitant of the area, was happy to retell him the story he had learned from his grandfather. The journalist was happy to listen to it and to repeat it.

> Long ago, a group of villagers decided to cross Lake Nyos. One man parted the waters, much as God parted the Red Sea for the Israelites, but a mosquito bit the man on a testicle; when he swatted the insect, he lost his grip on the water and every villager was drowned.

We quote also Krajick reporting Che's concluding words 'They're between those two rocks', he said, referring matter-of-factly to the ghosts of that catastrophe. 'You hear them talking sometimes, but you do not see them' (Krajick 2003).

So what does science say about the Lake Nyos explosion? We know that the accident was due to carbon dioxide and its behaviour in the lake's water. Experiments have shown that decompression of carbon dioxide saturated water is able to power explosive eruptions (Zhang 1996). Both science and myth transmit the truth that Lake Nyos is a hazardous place. Science is able to explain the reasons of the hazard. Myth adds some values to the truth. Never lose attention being in a hazardous situation as when crossing a lake. That man was absorbed by the mosquito and became responsible for the villagers drowning. Che respects his grandfather teaching.

Today, many authors agree on the fact that re-establishing myths could help man again to have a healthy relation with nature. Gough (1993) writes that prior to the modern age humans sustained their sense of interdependence and relatedness with the Earth through metaphors of kinship. An example is a recurring theme in Australian Aboriginal stories: 'Earth just like mother and father and brother of you' (Neidjie 1990). But in the language of modern science, as reported by Gough, nature was represented via such degrading metaphors as Bacon's reference to it as a 'common harlot'. It was rendered lifeless, as in Isaac Newton's 'world machine'. So, Gough concludes, even if the narrative strategies of modern science have helped to raise our awareness of the origin and the extent of numerous environmental problems, at the same time these problems may themselves have resulted from modern science's construction of stories in which the story-maker or story-teller is 'detached' from the Earth. In them subject and object, 'culture' and 'nature', are categorically distinct. In this sense, the myths of pre-modern culture can help acknowledge that modern science has failed to transmit the view that the creation of meaning in this world is a communal human responsibility.

Blades (2001) suggests that the deep insight provided by the myths of ancient people and the collective wisdom of societies can be part of the conversation concerning the relationship of human kind to reality. Instead of delegating myth to the impoverished status of superstition, science education can introduce these important stories into the classroom in order to help children realize that there are many facets to the representation of reality, each with an insight to contribute to human understanding.

Even if ancient myths are no longer suitable for us, Gough (1993) suggests that the re-enchantment of the world requires our participation in a creative reconstruction of a language that emphasizes our kinship with nature. We need new myths and new metaphors that can help us to perform and represent our interrelationships with the Earth as a living planet in the conditions of urban and late industrial lifestyle. Campbell & Moyers (1989) affirm that we have to learn again to be in harmony with nature, experiencing a feeling of brotherhood with the animals, the water and the sea. It can help us to consider the Earth as a whole, and not subdivided into towns, regions or nations. Even if we do not know which myths the future reserves for us, the 'renewed Gaia myth' shows the contemporary need for an Earth education not based merely on dry scientific facts but accompanied by an emotional content. In the ancient myth, Gea was both a goddess and Mother Earth. She gave birth to the human race and she deserved respect. A good starting point for Earth education would be comparing the ancient myth with the newborn Gaia theory as expressed by the British scientist James Lovelock. According to this theory the planet behaves as a living organism. In the words of Lovelock (1988), if we see the world as a super organism of which we are part—not the owner, nor the tenant, not even a passenger—we could have a long time ahead of us. It is not surprising that people around the world have embraced the Gaia theory, and that it has become very popular. The new scientific theory reminds us of the wisdom of ancient myths and legends that taught people how to live.

Even if in scientific terms, the Gaia theory encourages us to imagine Earth as an organism where the equatorial rainforests function as lungs, the atmosphere, the rivers and the streams as a respiratory and a circulatory system and so on. The Earth in this way is not an inanimate entity detached from us, but an organism similar to us. Gaia is a name that comes from Greek mythology and represents Mother Earth, and reminds us that our planet is a living organism, to which we belong, not the reverse.

Conclusion

Some studies encourage us to believe that scientific discoveries cannot replace myths and legends. Their symbolic language still constitutes a common human heritage that, other than being relegated to superstition, can add value to our interpretation of reality. Early human civilizations used myths to organize and convey information for transmitting the wisdom necessary to live in harmony with and survive in nature. Since myths are a type of narrative, they have a structure familiar to most people. Today the narrative mode is considered to be a reliable way to express and transmit information, complementary to paradigmatic cognition. Thus, it is possible to consider myths as charming tales and useful tools capable of representing information, creating meaning and enriching the knowledge developed by Earth scientists about the planet.

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psychology *vis-à-vis* the violent forces of nature, and other aspects of society and culture. This lore can also shed useful light on the geological record, sometimes even to the extent of suggesting major geological events that remain undiscovered by conventional scientific approaches. Common themes appear in stories from different cultures, and may help identify stories with geological information.

In this paper, we examine two types of earthquake lore from Cascadia and Japan. First, we discuss figurative stories from the Pacific Northwest coast of North America that appear to refer to earthquakes, tsunamis, permanent land level changes, or landslides. Geographically these stories describe events along two major fault zones: the Cascadia subduction zone (CSZ), which produced a magnitude 9+ earthquake in 1700 (Satake *et al.* 2003), and the Seattle fault in Puget Sound which produced an earthquake of estimated magnitude 7.4 in approximately 900 AD (Bucknam *et al.* 1992). Secondly, we discuss non-geological evidence from Cascadia and Japan that researchers have used to date the CSZ earthquake of 1700. Next, we examine figurative conceptions of earthquake causality in Japanese folk culture, both circa 1700 and, in greater detail, during the period following the Edo (present-day Tokyo) earthquake of 1855. This earthquake produced an outpouring of figurative *namazu-e* (catfish picture prints), which expressed a wide range of popular views on earthquake-related phenomena, both geological and social. Data from both Cascadia and Japan support our general argument that symbolic language can usefully describe geological events.

In addition to demonstrating a linkage between local earthquake lore and geological events in these two parts of the world, we propose some observations about similarities in this lore, with reference to other regions of the world. At a deep level, which we call the 'archetypical level', many apparently unconnected societies throughout the premodern world conceived of earthquakes in similar ways.

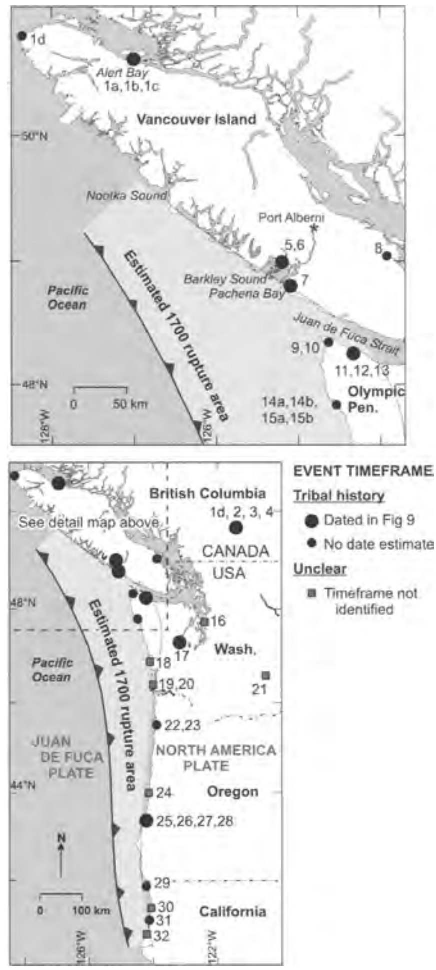


Fig. 1. Estimated 1700 rupture of the Cascadia Subduction zone, from Wang *et al.* (2003). Numbers indicate locales of Native stories with descriptions of shaking and/or flooding. Story elements are tabulated in Figure 9. Story references: **1.** Boas 1935, **1a** *33*; **1b** *92*; **1c** *122*; **1d** *27–31*; **2.** Teit 1912, *273–274*; **3.** Jenness 1955, *11, 12, 72, 91, 92*; **4.** Duff 1955, 9, *123–126*; **5.** Roberts & Swadesh 1955, *315*; **6.** Sproat 1987, *124–125*; **7.** Arima *et al.* 1991, *230–231*; **8.** Hill-Tout 1978, *157–158*; **9**. McCurdy 1961, *109–112*. **10.** Swan 1870, *57*; **11.** Gunther 1925, *119*; **12.** Clark 1953, *44–45*; **13.** Eels 1878; **14.** Reagan and Walters 1933, **14a** *320–321*, **14b** *322*; **15.** Reagan 1934, **15a** *33–34, 36–37*; **16.** Jefferson 2001, *69–70*; **17.** Elmendorf 1961, *133–139*; **18.** Van Winkle Palmer 1925, *99–102*; **19.** Clark 1955, *321*; **20.** Boas 1894, *144–148*; **21.** Kuykendall 1889, *67*; **22. 22a** Boas 1898; *23–27* (similar story identified as historical in the following reference), **22b** *30–34*, **22c** *140*; **23.** Jacobs 1959, *176*; **24.** Jacobs 2003, *187*; **25.** Frachtenberg 1920, *67–91*; **26.** Frachtenberg 1913, *14–19*; **27.** Jacobs 1939, *58*; **28.** Ward 1986, 27; **29.** Dubois 1932, *261*; **30.** Spott & Kroeber 1942, *224–227*; **31.** Kroeber 1976, **31a** *174–177*; **31b** *460–465*; **32.** Warburton and Endert 1966, *58–60*.

Stories of earthquakes and related events from native societies in the Cascadia subduction zone

Geological knowledge of the Cascadia subduction zone

The plate-boundary fault at the Cascadia subduction zone (CSZ) separates the oceanic Juan de Fuca plate from the continental North America plate (Fig. 1). It lies about 80 km offshore and extends roughly parallel to the coast from the middle of Vancouver Island to northern California. Although recognized as early as the mid-1960s, seismologists initially assumed that the CSZ was incapable of producing great (megathrust) earthquakes. It is seismically quiet, and no sizable earthquake has occurred on it since European settlement began. As the theory of plate tectonics matured, studies of subduction zones worldwide identified characteristics associated with megathrust earthquakes. These earthquakes are most common in areas where hot, young, buoyant crust is rapidly subducted (Heaton & Kanamori 1984). Although the rate of subduction in Cascadia is relatively slow, the subducted crust is among the youngest and hottest anywhere.

Field investigations in the 1980s of the coastal margins along the CSZ located geological evidence of abrupt land-level changes characteristic of megathrust earthquakes in 'ghost forests' of dead cedar trees in coastal estuaries in Washington and Oregon (e.g. Nelson *et al.* 1995). The cedars, originally above the limit of the tides, were killed when their roots were suddenly plunged into salt water. Beneath the surface of these same estuaries, soil cores reveal layered deposits showing a repeated cycle of slow uplift and rapid submergence. Preliminary age estimates based on radiocarbon dating (Nelson *et al.* 1995) and tree-ring studies suggested that the most recent earthquake happened about 300 years ago. A precise date, 26 January, 1700, was determined from Japanese historical documents (Satake *et al.* 2003), and confirmed by a close study of tree-ring patterns of ghost cedar roots (Yamaguchi *et al.* 1997). The magnitude estimate of 9.0, derived from the amplitude of the tsunami that reached Japan, implies rupture along the entire length of the CSZ (Satake *et al.* 2003). Figure 1 shows the geographic extent of the likely rupture area.

Native folklore from the Cascadia subduction zone

This section examines Native stories from along the Cascadia margin that are figurative and folkloric in style, and not amenable to dating with any precision. Some of these stories appear to be of fairly recent origin and possibly linked to the 1700 earthquake; others are apparently much older.

Native peoples have lived on the Cascadia coast for thousands of years, transferring knowledge from generation to generation through storytelling. These Native groups spoke more than a dozen distinct languages (Thompson & Kinkade 1990), and lived in a complex social landscape with both similarities and differences between groups. Collection and recording of Native stories began in the 1860s, almost 100 years after initial European contact in Cascadia, resulting in losses of Native oral traditions as high as 95% (Jacobs 1962). Therefore, available records may not be a representative sampling of the original material. Nevertheless, the hundreds of extant sources include numerous stories that describe shaking or marine flooding.

Throughout the Cascadia coast, figurative stories with no direct mention of earthquakes nevertheless describe earth shaking and tsunami effects. At the southern end of the region, many stories explicitly mention both earthquakes and tsunamis. At the northern end, there are explicit earthquake stories and explicit flood stories, but only a few stories including both phenomena. In the middle portion of the CSZ, along the coast of Oregon and Washington, direct mention of earthquakes is rare and stories of marine floods are common. The differences in the content of these stories may in part be the result of different methods or priorities in their collection and preservation. In any case, differences in Native cultures and lifestyles along the Cascadia coast or variations in earthquake effects are also a likely factor in the variable content of these stories.

Native oral traditions are sometimes structured as stories about the acts and personalities of supernatural beings, often in the guise of animals. Throughout Cascadia, stories were part of broader cultural contexts that also conveyed information through artifacts, dances, songs, and ceremonies, and personal and place names. Shaking imagery appears in stories about a variety of supernatural beings (McMillan & Hutchinson 2002), not surprising in an area with multiple cultures and multiple earthquake sources. Some stories are local, whereas others appear over a wider geographic range. Some stories have generic descriptions of shaking that could occur in any earthquake whereas others appear to describe specific effects, such as tsunamis or permanent ground level change along the coast, that might suggest a great subduction zone earthquake. We sought stories with widespread distribution along the Cascadia coast and imagery or descriptions of the effects that might be expected from a subduction zone earthquake.

The struggle between the Thunderbird and Whale is a story told by many groups from western Vancouver Island and northern Washington. One version, story 15b (see Fig. 1), includes a side comment that explicitly links earthquake and tsunami-like effects to the struggle and suggests an historical context:

> My father (father of the medicine man who related this story to the writer) also told me that following the killing of this destroyer ... there was a great storm and hail and flashes of lightning in the darkened, blackened sky and a great and crashing 'thunder-noise' everywhere. He further stated that there were also a shaking, jumping up and trembling of the earth beneath, and a rolling up of the great waters. (Reagan 1934).

Thunderbird and Whale are beings of supernatural size and power. A story from Vancouver Island says that Thunderbird causes thunder by moving even a feather, and that he carries a large lake on his back from which water pours during thunderstorms (Carmichael 1922). The same story says that all creation rests on the back of a mammoth whale and tells of an occasion when Thunderbird drove his talons deep into the quivering flesh of Whale's back, and Whale dived and dragged the struggling Thunderbird to the bottom of the ocean; imagery suggestive of ground shaking and ocean surges. In this story, three of the four original thunderbirds were drowned in this manner, and one remains alive. Other stories also have multiple whales or thunderbirds (Fig. 1, stories 1d, 15b, 22b; Reagan 1934, p. 25; Spott & Kroeber 1942, p. 227–232) that may refer to aftershocks.

Stories 5, 9, 14a and b, and 15a (see Fig. 1) further tie the story of a supernatural battle to the flood, with imagery that implies shaking—Thunderbird lifts the massive Whale into the air and drops it on the land surface. The flood description in story 15a is strikingly similar to story 10, which hints at a historic framwork by placing the event 'A long time ago ... but not at a very remote period'.

The struggle between Thunderbird and Whale is unique to the Cascadia coast, and appears in stories from Vancouver Island to northern Oregon. From central Oregon south, Thunder or Whale figures appear individually in stories describing earthquake or tsunami themes. The central figures variously appear in the form of Thunder, Thunderbird or bird, and Whale, fish, or sea monster. In northern California, the Yurok tribe has an 'Earthquake' figure with 'Thunder' as his companion. Stories from Puget Sound and eastern Washington also use similar motifs in conjunction with descriptions of earthquake effects. Story 16, of the battle between the double-headed eagle and the water-monster, is about the creation of Agate Pass, a Puget Sound waterway far from the outer coast, but adjacent to the Seattle Fault, where a magnitude 7.4 earthquake caused a Puget Sound tsunami (Moore & Mohrig 1994) about 1100 years ago (Bucknam *et al.* 1992).

Although none of the Thunderbird/Whale stories are dateable, a few have vaguely historical timeframes. In addition to describing earthquake effects, Thunderbird and/or Whale stories have a general association with landscape-forming events, such as glacial moraines (Fig. 1, story 15b), icefalls (Reagan & Walters 1933), and landslides (Barbeau & Melvin 1943). Thunderbird also appears in stories about thunder, lightning, and rain. Thunderbird and Whale stories are part of a systematic oral tradition that used symbolism and mnemonic keys to condense and present information in a format that could be remembered and retold for generations. Native populations witnessed multiple cycles of CSZ earthquakes; geological evidence indicates at least seven in the last 3500 years (Atwater & Hemphill-Haley 1997). Artifacts depicting Thunderbird and Whale that long predate the 1700 earthquake have been recovered from coastal archeological sites (McMillan 2000). Knowledge of a repeating earthquake cycle may be implied in a story where the Thunderbird becomes a man and sends his Thunderbird costume back to the sky saying: 'You will not keep on thundering, only sometimes you will sound when my later generations will go (die). You will speak once at a time when those who will change places with me will go (die)' (Boas 1935, p. 65).

The Thunderbird/Whale motif is the central theme in carved and painted art of the outer coast and coastal fjords of Vancouver Island (Malin 1999) (Figs 2 & 3), where broad ocean openings

Fig. 2. Two interior ceremonial screens from Port Alberni, dating from the late nineteenth century. The screens depict the Thunderbird, accompanied by the lighting serpent and wolf, carrying the Whale in its talons. Collection of American Museum of Natural History; 16.1/1892 AB. The screens are said to commemorate a 'chief's encounter with the supernatural while checking his sockeye traps at Sproat Falls' (Kirk 1986). Sproat Falls is just above the modelled extent of the 1700 tsunami (Clague *et al.* 2000).

Fig. 3. Nootka Sound Memorial, erected 1902–1903 to honour Chief Maquinna, who died in 1902. Thunderbird and Whale are shown as similar in size to Conuma Peak. Photo PN11478-A, taken by C.H. French and reproduced with the permission of the Royal British Columbia Museum.

Fig. 4. Alert Bay; a Thunderbird and Whale painted on the front of the house of Kwakwaka'wakw Chief Tlah go glas (Malin 1999). Photo taken by Richard Maynard, 1873, print available from Vancouver Museum, 23.

funnel water into narrow waterways that run far inland. Port Alberni, at the landward terminus of Barkley Sound, 40 km from the ocean, experienced tsunami run-up about six times larger than sites on the open coast following the 1964 Alaska earthquake (Sokolowski Alaska Tsunami Warning Centre). Clague *et al.* (2000) have documented tsunami deposits from both the 1964 and 1700 earthquakes in Port Alberni and other fjord-like inlets on Vancouver Island. Alert Bay, between the northern end of Vancouver Island and the mainland, also has prominent Thunderbird and Whale artworks (Fig. 4) and story themes linking Thunderbird and flooding (Fig. 1, story 1a), and placing flooding at the time of the winter ceremonial (Fig. 1, story 1b).

Native stories, art, ceremonies, and naming preserve memories of Cascadia subduction zone earthquakes. Ancient, recurring imagery describes earthquake and tsunami effects and suggests awareness of repetitive cycles of world-altering events. Likewise, similarities in symbols and imagery along the length of Cascadia suggest commonly experienced events. We now take a closer look at earthquake-related lore from the Puget Sound area.

A'yahos, the AD *900 Seattle earthquake and earthquake lore from the Puget Sound area along the Seattle fault*

The Seattle fault is a multi-stranded east–west striking reverse fault cutting across Puget Sound, through downtown Seattle, and across Lake Washington. Although geophysical evidence has long indicated a substantial offset in basement rocks beneath Puget Sound (Danes *et al.* 1965), no clear pattern of recent earthquake activity defining the fault has been observed. However, geological evidence of an earthquake around AD 900 (estimated magnitude 7.4) came to light in the early 1990s (Bucknam *et al.* 1992) and the Seattle fault is now recognized as a substantial hazard to the Seattle urban area.

The circa AD 900 earthquake caused 7 m of vertical uplift on the southern side, sent massive block landslides tumbling into Lake Washington, and created a tsunami in Puget Sound that left sand deposits on Southern Whidbey Island (Atwater & Moore 1992).

Two archaeological sites near Seattle attest to the effects of such events on local indigenous communities. Excavations at West Point, a promontory jutting out into Puget Sound north of downtown that was used as a fish- and shellfish-processing site since at least 4000 years before the present, show that the area dropped at least a metre during the quake. The point's marshes were flooded with saltwater and a layer of sand covered the entire site. Over time, people returned to West Point and began using it as they had before the quake (Larson & Lewarch 1995). The earthquake also permanently transformed some areas. At the Duwamish No. 1 archaeological site, excavations show that the quake lifted up a low, wet area that had only been a minor camping and food-processing site and turned it into a higher, drier spot that eventually became home to a major permanent settlement with several longhouses (Campbell 1981;

Blukis Onat 1987). Natives passed down knowledge of these events in their oral tradition using descriptive metaphors based on their cultural concepts, often ascribing earth shaking to actions of supernatural beings.

In 1985, prior to published evidence of the AD 900 earthquake on the Seattle fault, an article in the Seattle Weekly (Buerge 1985) mentioned a Native American 'spirit boulder' associated with earthquakes and landslides located near the Fauntleroy ferry dock in west Seattle. The proximity of this location to the Seattle fault invited investigation and we discovered that the Fauntleroy Spirit boulder is associated with a supernatural being called a'yahos. Native stories often describe a'yahos in a way that could refer to earthquake effects, especially landslides. A'yahos is a shape-shifter, often appearing as an enormous serpent, sometimes double headed with blazing eyes and horns, or as a composite monster having the fore-quarters and head of a deer and the tail of a snake (Mohling 1957). A'yahos is a 'Doctor' spirit power; reserved for shamans. It is one of the most powerful personal spirit powers; malevolent and dangerous to encounter. A'yahos is associated with shaking and rushes of turbid water and comes simultaneously from land and sea (Smith unpublished notes). 'At the spot where a'yahos came to a person the very earth was torn, landslides occurred and the trees became twisted and warped. Such spots were recognizable for years afterward.' (Smith 1940)

Stories about a'yahos mention a number of specific places in the central Puget Sound, along the Hood Canal, and on the Strait of Juan de Fuca as far west as the Elwha River. A total of 13 a'yahos sites are mentioned in various stories (Fig. 5a, b), and these locales coincide with shallow faults around Puget Sound, including the Little River fault along the strait of Juan de Fuca, the Tacoma fault, and the Price Lake scarps (Haugerud *et al.* 2003). Five of the a'yahos story sites are located very close to the trace of the Seattle Fault (Fig. 5b). Four of the Seattle locales can be associated with landslides or reports of land-level changes that might have been caused by the AD 900 Seattle earthquake. Additional Native stories related to shaking, landsliding, or land-level change are associated with three of these sites.

A'yahos stories along the Seattle fault

The west Seattle a'yahos spirit boulder mentioned by Buerge (1985) is located on the beach immediately south of Fauntleroy Ferry Dock (Fig. 5b:1),

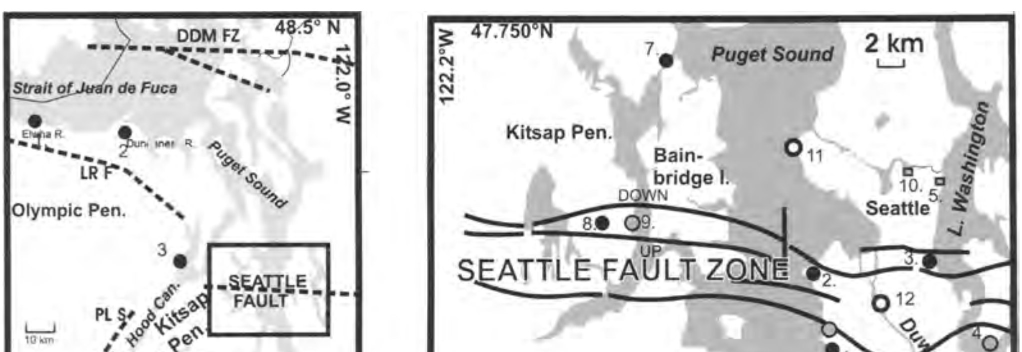


Fig. 5. (**a**) Map of Puget Sound and eastern Olympic Peninsula. Boxed area indicates location of larger-scale map shown in Figure 5b. Dashed lines show locations of some shallow faults (after Haugerud *et al.* 2003): LR F, Little River fault; T F, Tacoma Fault; DDM FZ Darrington Devil's Mtn fault zone; PL S, Price Lake Scarps; FC S Frigid Creek Scarps. Numbers in Figure 5a indicate sites outside the Seattle fault area associated with a'yahous stories. 1, Elwha River; 2, Dungeness River; 3, Dabob Bay; 4, Bald Point also known as Ayers Point; 5, Tahuya River; 6, Medicine Creek (Nisqually Delta); 7, American Lake; 8, Black Diamond Lake (1–5 from Elmendorf, 1993; 6 and 8 from Waterman 2001; 7 from Smith, 1940). (**b**) Larger-scale map showing the Seattle fault zone, a'yahos story localities (indicated by black circles), other stories that have apparent connection to earth shaking or landsliding (indicated by grey circles), and archaeological sites (white circles). 1, Fauntleroy; 2, Alki Point; 3, Lake Washington a'yahos site; 4, South Point, Mercer Island; 5, Madison Park; 6, Three Tree Point; 7, Agate Passage; 8, Bremerton; 9. Moore Point; 10, Portage Bay; 11, West Point; 12, Duwamish Site No. 1. LIDAR images of Fauntleroy (1) and Three Tree Point (6) are shown in Figure 6.

below what appears to be a very large landslide of undetermined age clearly visible in LIDAR images (Fig. 6a) but not shown on existing geological maps. Long term local residents Mory Skaret and Judy Pickens pointed out the boulder; Waterman (2001) indicated a location further south, near Brace Point. Stories of a'yahos spirit power are told about both the Fauntleroy boulder (Waterman 2001) and Alki Point (Smith unpublished notes), immediately to the north and uplifted during the AD 900 quake. Stories about Alki Point speak of shaking, rocks exploding, and the power coming from sea and land simultaneously (Smith unpublished notes).

The second place in Seattle associated with a'yahos is by the shore of Lake Washington (Fig. 5b: 3). According to elders who worked with T.T. Waterman, 'On the lake shore opposite the north end of Mercer Island ... an enormous supernatural monster ... lived' (Waterman 2001, p. 102). Large block landslides dated to AD 900 slid into Lake Washington from the southern end of Mercer Island and at Madison Park (Karlin & Abella 1992), about 2 km south and north, respectively, of the a'yahos site. In addition to the massive slides of AD 900 that bracket this site, a close-by landslide during the 1890s is said to have damaged buildings (McDonald 1956). It is possible that the 1890s landslide entered into the identification of this site with a'yahos. Landslides occur in many locations along the bluffs and steep slopes that line portions of the shores of Lake Washington and Puget Sound.

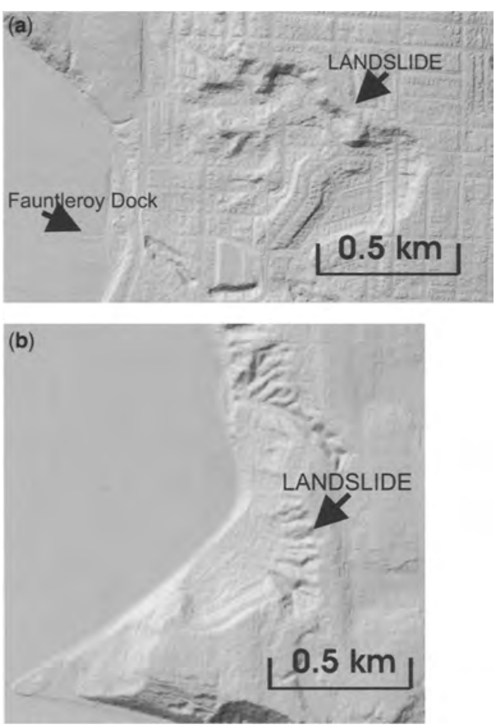


Fig. 6. LIDAR images (from the Puget Sound LIDAR Consortium 2000) showing apparent landslides at localities said to be a'yahos dwelling places; (**a**) Fauntleroy Cove in West Seattle (**b**) Three tree point in Burien.

The large blocks of land that slid into Lake Washington from Mercer Island's South Point in AD 900 submerged intact with upright trees. As the lake rose and fell several feet during the course of the year owing to seasonal run-off in the lake basin, the trunks of these drowned trees were exposed. Native people avoided this place, which they called 'stripping someone's clothes off'. A man who came to strip the bark off the drowned trees protruding above the lake surface reportedly became crazy, because stripping the bark from the submerged trees was thought to be like stripping the clothes off the supernatural 'earth beings' who lived in the stumps of the drowned trees (Waterman 2001, pp. 108–110).

A third locality in greater Seattle is on the shore of Puget Sound, near Three Tree Point in Burien (Fig. 5b: 6), at a bluff where 'a great snake lived inside, shoving the sand down when people disturbed him' (Waterman 2001). James Rasmussen, of the Duwamish Tribe, identifies this snake as a'yahos. As at Fauntleroy, the locale at Three Tree Point features what appears to be a large, undated, and previously unmapped landslide, which is visible in LIDAR (Fig. 6b).

The fourth story comes from the Suquamish Tribe on the western side of Puget Sound (Fig. 5b: 7; Fig. 1:16). Oral traditions handed down by elders tell of the creation of Agate Passage (the waterway between the northern end of Bainbridge Island and the Kitsap Peninsula; located on the down-thrown side of the Seattle fault) following an underwater battle between a water serpent (not specifically identified as a'yahos) and a mythic bird. The battle resulted in ground shaking, churning of the waters, and widening of the channel.

Long ago, when this land was new, the area we know as Agate Pass was much smaller than today .... There lived in this ... body of water a ... Giant Serpent.

The Double Headed Eagle flew over the pass and the Giant Serpent came up very angry. The two began to fight, and the earth shook and the water boiled ... the people began to scream and cry until it was as loud as thunder.

Then, as if the earth was going to be swallowed by the waters, they began to boil and churn. Then, the Double Headed Eagle exploded out of the water and up into the sky with the body of the Giant Serpent in its claws. The Double Headed Eagle flew back into the mountain and behind him was left the wide pass ... (Jefferson 2001).

The description of the widened channel could reflect permanent ground level change, and the sense of ground motion suggested by the story is accurate; Agate Passage is on the down-thrown northern side of the Seattle fault. However, geological evidence suggests that the AD 900 earthquake produced mainly uplift on the southern side, with the north side down only slightly; the correspondence between the story and reality is approximate rather than exact. We note, however, that some 'drift' seems reasonable in a story that may be a thousand years old and has been preserved through extreme cultural destruction. This story, set in an undated 'long ago', is strikingly similar to the stories from the outer coast of Cascadia that use the struggle of a supernatural bird and water-beast to refer to earthquakes on the Cascadia subduction zone (Ludwin *et al.* 2005*a*). The 'long ago' time frame suggests an origin more ancient than 1700.

A fifth place, on the Kitsap Peninsula near Bremerton (Fig. 5b: 8), is said to be another spot where shamanistic spirit-power could be acquired (Waterman 2001, pp. 206–207; Smith unpublished notes). Sam Wilson, born in 1861, and grandson of Chief Seattle told Marian Smith, 'it comes from land and sea at same time' (Smith unpublished notes). No obvious geological features were noted at this site, though it is situated between several strands of the Seattle fault. On the Puget Sound shore of Kitsap Peninsula just east of this locality, at Moore Point near Illahee State Park (Fig. 5b: 9), is a spot named 'to have a chill' or 'to feel a tremor' (Waterman 2001, pp. 206–207). A comparison of earth tremors to feverish chills was made by Aristotle (Leet 1948) and it is possible that the Natives of Puget Sound drew a similar connection. Although the origin of the name 'to feel a tremor' is uncertain, shaking was a central element in Puget Sound Native medical practices and ceremonials, and a'yahos was a potent source of shamanistic 'Doctor' power, as discussed below.

Native 'Doctor' or shaman power was a particularly strong form of spirit power. Throughout the region, individuals sought personal spirit powers to guide their lives and bring them luck and skill. A'yahos was one of the most powerful of these personal spirit powers, though it was also malevolent, dangerous, and possibly fatal to encounter (Smith 1940). A'yahos 'Doctor' spirit power was one of only two powers (a'yahos and stáduk^{w}'a) reserved exclusively for shaman, and descriptions of both these shamanistic powers include shaking or landsliding imagery (Elmendorf 1993; Smith unpublished notes; Smith 1940; Waterman 2001). Shaman were believed to hold the power to cure certain illnesses, and also the power to cause illness and even death (Suttles & Lane 1990). The name of James Zackuse, a Duwamish Indian Doctor who lived in Seattle on Lake Union's Portage Bay during the late nineteenth and early twentieth centuries, translates to 'trembling face'; rooted in 'dzakw', the Puget Lowland Native word for earthquake (Miller & Blukas Onat 2004, pp. 78–85).

Shaking also appeared as an important element in Puget Sound Salish ceremony, when ritual objects filled with spirit power and became self-animated (Miller 1999, p. 133; Elmendorf 1993, p. 192–198; Haeberlin & Gunther 1930, p. 79). An early white settler noted a specific connection between ceremony and earthquake shaking as early as 1893:

> During the past thirty-three years I have on many occasions endeavored to gather from the oldest and most intelligent Indians something of their earlier recollections; for instance, as to when the heaviest earthquake occurred. They said that one was said to have occurred a great many years before any white man had ever been seen here, when mam-ook ta-mah-na-wis was carried on by hundreds. This is the same performance they go through when they are making medicine men, and consists of shouting, singing, beating on drums and sticks and apparently trying to make as much noise as they can. (Seattle Post-Intelligencer 1893)

Salish earthquake stories from outside Puget Sound also draw a connection between ceremony and shaking (Fig. 1, stories 8 and 22b; Ludwin *et al.* 2005*b*).

Earthquake lore from Puget Sound in the context of regional earthquake motifs

Although the a'yahos name appears to be specific to central Puget Sound, the double-headed serpent is widely known and depicted in NW cultures, and may have been similarly linked to earth changes. The Quileute, a non-Salish group living on the NW Washington Coast, have artifacts depicting a two-headed horned snake with the forelegs of a deer. Although not clearly linked to a'yahos, stories describe it as a vicious guardian spirit (Powell & Jensen 1976). Another two-headed snake, the Sisiutl, is a figure well known from stories and ceremonial artifacts of northern Vancouver Island.

Whales or water-monsters (which may represent the subterranean world in the same way that snakes do) appear in many Pacific Northwest coastal stories that describe ground shaking and/or tsunami-like floods, probably related to earthquakes on the Cascadia subduction zone (Ludwin *et al.* 2005*a*). Whales *per se* are not prominent in stories from the Seattle fault area, though the water-serpent of Agate Pass is analogous to a whale. However, in southern Puget Sound where damaging earthquakes centred deep underground are relatively common (occurring in 1949, 1965, and 2001), several stories mention whales trapped inland and thrashing their way out, sometimes through underground channels (Ballard 1929). Thunder, also common in coastal stories of shaking and flooding, appears occasionally in stories from Puget Sound (Ludwin *et al.* 2005*b*).

Figure 7 shows two versions of a Salish ceremonial dance mask and costume linked to earthquakes (Lévi-Strauss 1979), whirlwind (American Museum of Natural History catalog), and thunder (Jenness 1955). The Sxwayxwey (also Swai'xwe and many alternate spellings) masks sometimes include a two-headed snake (Jenness 1955). The mask's origin is relatively recent, probably sometime after 1500 (Ludwin *et al.* 2005*a*), and is described in a number of Salish stories that use shaking imagery and/or descriptions, though often quite figurative (Lévi-Strauss 1979). The Sxwayxwey has been incorporated into the ceremonies and oral traditions of non-Salish groups living at the north end of Vancouver Island (Lévi-Strauss 1979), where mythic-style stories of its origin explicitly relate the mask to earthquakes.

Fig. 7. Salish Swai'xwe masks associated with shaking, whirlwind, thunder and the two-headed snake (Jenness 1955). The two open-mouthed protuberances above the forehead likely represent snakes. (**a**) Mask from mainland British Columbia, collection of American Museum of Natural History; 16/9222A. (**b**) Mask from Vancouver Island, photo by Edward Curtis (2001).

In a northern Vancouver Island ritual (Boas 1897) the Sxwayxwey represents earth shaking. A mythic story (Fig. 1, story 1d) tells of the Sxwayxwey mask obtained at night in the winter ceremonial house of Red Cod, where rumbling sounds and earth shaking are caused by fish thrashing about on the floor. Additional sources identify the Sxwayxwey as originating in recent historical time and place its geographical origin near the town of Hope (Codere 1948; Duff 1955; Carlson 2006; Lévi-Strauss 1979) on the British Columbia mainland. The Sxwayxwey is related to earthquakes over its entire geographic range (Lévi-Strauss 1979), although the shaking element is not prominent in mainland stories. Mention of the Sxwayxwey also occurs in connection with thunder and whirlwind (American Museum of Natural History Catalog; Jenness 1955; Fig. 1, story 2).

One striking story from the northern end of Vancouver Island (*Head-Winter-Dancer*: Boas & Hunt 1905) mentions the acquisition of the Sxwayxwey mask in combination with earthquake- and landslide-related figures and imagery from multiple northwest cultures in an epic tale about the founding of the great houses of the Kwakwaka'wakw (Kwakiutl) people. In *Head-Winter-Dancer*, Thunderbird and his wife descend from the sky at a mountain called Split-in-Two. They become human, taking the names Head-Winter Dancer and Winter Dance Woman, and bear sons who travel around Vancouver Island gathering crests and founding great houses. When their youngest son is born, they hear a sound like rocks rolling down and find a double-headed serpent in their salmon-trap (Fig. 8). They wash the new baby in the blood of the double-headed serpent and he is transformed into Stone-Body, a name similar to Stone-Ribs—an earthquake-related being in Haida stories from British Columbia's Queen Charlotte Islands (Swanton 1905, pp. 190–210). Stone-Body cries out in the voice of the Dzonoqwa (a supernatural being linked to earthquakes and to the Sxwayxwey (Levi-Strauss 1979) and it is divulged that Dzonoqwa had come to Winter Dance Woman and Stone-Body is his son. Stone-Body grows up rapidly and travels in a self-propelled death-bringing, double-headed serpent canoe, acquiring crests from the communities he visits. He obtains the earthquake-related Sxwayxwey mask from the Salish to the sound of thunder. Stone-Body gives his older brother

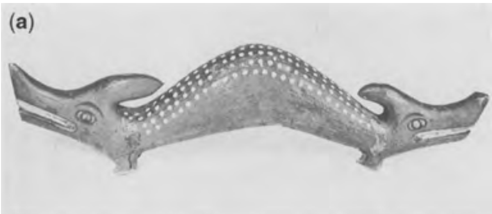


Fig. 8. Non-Salish Cascadia Native representations of two-headed snakes. Neither of these figures has yet been explicitly linked to earthquakes, but they likely represent the same spirit power as a'yahous. Both have horns, representing spirit power. (**a**) Quileute ceremonial representation of t'abale, a vicious guardian spirit on the northwestern Washington coast (Powell & Jensen 1976). (**b**) Kwakwaka'wakw Sisiutl mask, from the northern end of Vancouver Island, photo by Edward Curtis (2001).

Cannibal the additional names Rolling-Down, Great-Mountain, Rock-Slide and Coming Down.

The two-headed Sisutl of the Kwakwaka'wakw is similar in form to the two-headed supernatural serpent a'yahos of Puget Sound, and its blood transforms the child of the Thunderbird/Dzonoqwa into the earthquake-related figure Stone-Body. The inclusion of multiple earthquake-related mythic figures (Thunderbird, Dzonoqwa, Stone-Body, Sxwayxwey, Sisiutl) in a story about the foundation of the great houses of the Kwakwaka'wakw suggests that earthquakes deeply affected their culture. The use of earthquake imagery from the adjoining Salish and Haida cultures suggests earthquake events that were felt across tribal boundaries.

Non-geological evidence for the Cascadia subduction zone earthquake of 1700 from Cascadia and Japan

The precise dating of the Cascadia subduction zone earthquake of 1700 is an example of how local lore and other non-geological evidence can enhance conventional geological knowledge. The 1700 earthquake was initially dated through Japanese historical documents, and the date was confirmed independently through Native American oral traditions and dendrochronology.

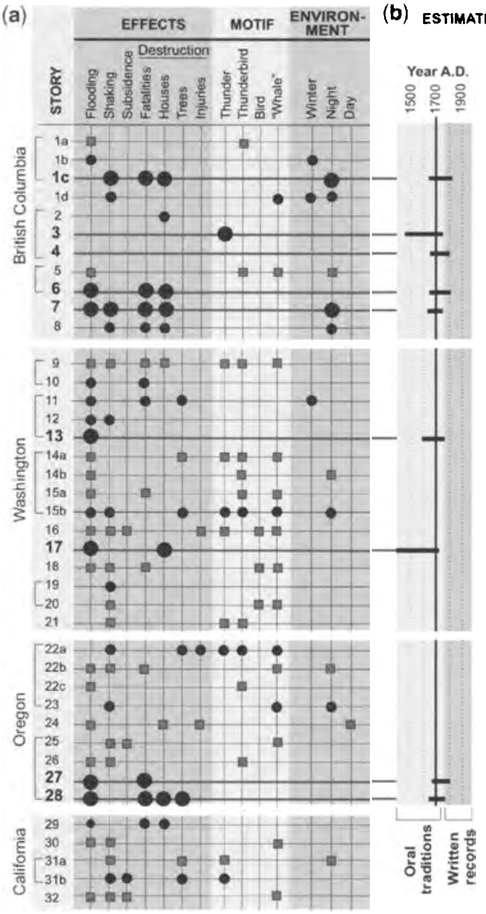
Nine Native stories from the Cascadia coast (Fig. 1, stories 1c, 3, 4, 6, 7, 13, 17, 27 and 28) have sufficient information for estimating a date range since an event associated with shaking and/or flooding (two stories with both, three with shaking only, and four with flooding only). Two stories, told between 1860 and 1964, tell of a grandparent who saw a survivor of the flood, and one of a great-grandparent who survived it. Figure 9 tabulates the accounts, and gives date ranges. Date range minima and maxima are 1400 and 1825. All estimates span the interval between 1690 and 1715, and the average value of the midpoints of the date ranges is 1690. Discarding the earliest and latest midpoints yields an average midpoint date of 1701. This finding is remarkably consistent with the 1700 date of the most recent CSZ earthquake determined from Japanese historical documents.

The date estimates based solely on descriptions of floods could possibly be reports of tele-tsunamis (i.e. those arriving from distant earthquakes). Alaskan and South American earthquakes produced notable tsunamis on the Cascadia coast in the twentieth century (Lander *et al.* 1993). Although we do not know the history of Alaskan earthquakes around 1700, tsunamis from South American earthquakes were recorded in Japan in 1730, 1751 and 1780 (Watanabe 1998). Japanese earthquakes have not produced significant tsunamis in Cascadia since at least 1806 (Lander *et al.* 1993), but locally generated tsunamis damaged the Japanese coast in 1611, 1707, and 1771 (Watanabe 1998).

Cascadia Native stories that can be used to date the 1700 earthquake are mostly straightforward descriptions of flooding and/or shaking. Of these stories, the clearest and most complete is from the outer coast of Vancouver Island, recorded by Chief Louis Nookmis following the 1964 Alaskan earthquake. It describes a night-time earthquake quickly followed by a tsunami that destroyed the Pachena Bay people:

> They had practically no way or time to try to save themselves. I think it was at nighttime that the land shook .... I think a big wave smashed into the beach. The Pachena Bay people were lost .... But they who lived at Ma:lts'a:s, 'House-Up-Against-Hill' the wave did not reach because they were on high ground ... Because of that they came out alive. They did not drift out to sea with the others. (Fig. 1, story 7, Arima *et al.* 1991)

Robert Dennis, Chief Councilor of the Huu-ay-aht First Nation and descendent of Chief



(b) ESTIMATED DATE RANGE AND BASIS FOR ESTIMATE

1650-1825 (1c) "This is not a myth ... my tale is seven generations old ... there was a great earthquake and all the houses of the Kwakiutl collapsed." — *La'bid in 1930*

1456-1756 (3) "The masked dance ... originated with a man ... who lived about 12 generations ago." — *Unidentified informant in 1936*

1670-1795 (4) "... the mask was first obtained five generations before her own ..." — *Mrs. Robert Joe, age >80 in 1950*

1655-1814 (6) "The tide ... rushed up at fearful speed. ... The Clayoquot who thus became a chief was the great-grandfather of Hy-yu-penuel, the present chief of the Sheshaht ..." — *Unidentified informant in 1860*

1640-1740 (7) "These are stories from my grandfather's father (born c. 1800), about events that took place four generations before his time ... over 200 years ago" "... the land shook ... a big wave smashed into the beach." — *Chief Louis Nookmis, age 84 in 1964*

1600-1775 (13) "One old man says that his grandfather saw the man who was saved from the flood ... " — *Unidentified informant c. 1875*

1400-1715 (17) "...eight or nine generations from my grandfather there was a flood" — *Frank Allen, age 60 in 1940*

1690-1805 (27) "My grandfather saw one of the old women (survivors) who had been left alive. She had been hung up on a tree, and the limbs of that three were too high up. So she took her pack line and tied it to a limb, and then when she wanted to go down by means of that, she fell, she was just a girl when she fell from it. Her back was broken from it (she had a humpback thereafter). That is what she told about the raised water." — *Annie Miner Petersen, age 73 in 1933*

1657-1777 (28) "...there was a big flood shortly before the white man's time, ... a huge tidal wave that struck the Oregon Coast not too far back in time ... the ocean rose up and huge waves swept and surged across the land. Trees were up-rooted and villages were swept away. Indians said they tied their canoes to the top of the trees, and some canoes were torn loose and swept away ... After the tidal wave, the Indians told of tree tops filled with limbs and trash and of finding strange canoes in the woods. The Indians said the big flood and tidal wave tore up the land and changed the rivers. Nobody knows how many Indians died." — *Beverly Ward, recounting stories told to her around 1930 by Susan Ned, born in 1842*

Fig. 9. (**a**) Tabulation of story elements for stories listed in Figure 1; effects, figurative motifs, and environmental setting. Brackets by story numbers group stories from a common geographic locale. Symbols are as in Figure 1. The 'Whale' motif is enclosed in quotes to cover a variety of sea-monsters appearing in the stories. (**b**) Date range estimates and quotes used to calculate date range estimates. Date range estimates used the following assumptions: a 'generation' is no fewer than 15 and no more than 40 years, events before age 5 are not remembered, the maximum lifespan is 100 years, flood survivors were 'old' when seen, and an 'old' person is at least 40.

Louis Nookmis, has discovered previously unpublished information that allows us to estimate a date at between 1640 and 1740. This new information comes from a comprehensive transcription and translation of the 1964 recordings undertaken by the Huu-ay-aht First Nation.

A second datable story that includes flooding and shaking elements is from the northern margin of the Olympic Peninsula in northwestern Washington. It combines information from three independent sources (Fig. 1, stories 11–13) to yield a tale indicating winter flooding with accompanying strong shaking. A tradition that cannot be dated but vividly describes strong night-time shaking, from a group on the inner coast of Vancouver Island, supplements the datable stories:

> In the days before the white man there was a great earthquake. It began about the middle of one night . . . threw down . . . houses and brought great masses of rock down from the mountains. One village was completely buried beneath a landslide. It was a very terrible experience; the people could neither stand not sit for the extreme motion of the earth. (Fig. 1, story 8, Hill-Tout 1978).

The remaining stories that can be dated describe saltwater flooding events. Archaeological evidence indicates that some Native villages on the British Columbia, Washington, and Oregon coasts experienced subsidence, were flooded by tsunamis, and abandoned following the 1700 earthquake and tsunami (Minor & Grant 1996; Hutchinson & McMillan 1997; Losey 2002; Cole *et al.* 1996), supporting the possibility that flooding stories may reflect this event.

As we mentioned earlier, Japanese textual data were instrumental in precisely dating the CSZ earthquake of 1700. The exact date and approximate time of this earthquake (9 pm on 26 January 1700) were determined from a variety of Japanese historical documents such as domain (*han*) records, merchant records, and the records of village headmen that reported the arrival of a tsunami with no reports of associated shaking (Satake *et al.* 2003). In addition to recording the 1700 earthquake, Japan has a rich folklore related to earthquakes and written and graphic documentation that allows us to observe how that folklore developed and interacted with other aspects of Japanese culture. Earthquake imagery in Japanese folklore has distinct similarities to Cascadia imagery, and we explore this, particularly through the example of 1855 Ansei earthquake, which was followed for a few months by a brief but abundant output of *'namazu-e'* (catfish picture-prints) that combined earlier earthquake folklore with incisive observations on both earthquake effects and current events.

Fig. 10. *'Earthquakes and Tsunamis Explained'*, *c.* mid-seventeeth century. On the outer edges of the circled dragon are written the months of the year. What appears to be a small sword is just above and touching the dragon's head. Below this sword is written *'kaname-ishi'*, (foundation stone). Inside the dragon are the 'the 60 plus islands of Japan and the various foreign countries'. The last line of text inside the dragon explains that all of these places should be regarded as existing above the dragon. In other words, the dragon resides under the earth. Normally, it is pinned down and made immobile by the deity of the Kashima Shrine, who presses down on a boulder (the foundation stone), which presses down on the dragon's head. The deity's sword is a substitute for the boulder. Sometimes, however, the deity dozes or is otherwise distracted, and he lets up on the boulder. The dragon is thus able to wiggle around under the earth, which causes earthquakes (from Miyata & Takada 1995, p. 54).

Halfway to the present and halfway around the world—The 1855 Ansei earthquake in Japanese folk images

Japanese documents used to date the 1700 earthquake focus on straightforward descriptions of areas flooded by the 1700 tsunami and resultant damage and do not touch upon the origin of the event. However, Japan lies in an area of especially vigorous seismic activity and it is not surprising that we can find abundant earthquake-related data expressed both as written records describing the effects of specific events and in folk culture ideas about their cause. The long written history available in Japan enables us to track changing conceptions of earthquakes and offers an interesting comparison to the earthquake stories from the oral traditions of Cascadia. For example dragons and other serpent-like creatures associated with water were prominent in Chinese and Japanese folk beliefs concerning earthquakes. Figure 10 shows a broadsheet entitiled 'The cause of earthquakes and tsunamis' published *c.* 1650. In Japan, the serpent figure gradually gave way to that of a giant catfish (*namazu*), a belief that parallels the many shaking-related whale stories found in the Pacific Northwest (Ludwin *et al.* 2005*a*).

The link between earthquakes and giant catfish developed gradually over several centuries from native Japanese folk beliefs with some influence of Chinese ideas. The basic view was that a giant *namazu* lived in the subterranean waters below the Kashima Shrine in Hitachi Province (present-day Ibaraki Prefecture, slightly north of Tokyo). A large boulder called the foundation stone (*kaname-ishi*) pinned the *namazu* down and kept it largely immobile. The weight of the foundation stone itself, however, was insufficient to suppress the *namazu*'s movements, and the system depended on the Kashima deity (*Kashima daimyōjin*, often known simply as Kashima) pressing down on the stone. During the tenth month of each year Kashima had to leave his post and travel south to Ise to attend a meeting of the major Japanese deities. In his absence, Kashima would leave the local deity Ebisu in charge of pressing down on the foundation stone. Whether owing to negligence by Kashima himself or to Ebisu's inability to perform the *namazu* suppression tasks, earthquakes took place when the lack of pressure on the foundation stone allowed the giant *namazu* to wiggle around under the earth. The severity of shaking depended on the extent of the *namazu*'s movements.

This basic understanding of the *namazu*-based cause of earthquakes was subject to many variations because it was enmeshed in the broader network of Japanese folk religion. Cornelis Ouwehand's detailed, structuralist study of *namazu* images situates their themes within the broader matrix of folk religion (Ouwehand 1964). One twist on the basic motif was that Kashima often worked in close association with the thunder deity and sometimes other local deites of Edo. *Namazu-e* sometimes depicted Kashima, Ebisu, and the thunder deity as being jointly responsible for the devastation of a major earthquake. Also, most early nineteenth-century Japanese people associated earthquakes with water. The *namazu*, of course, was a water-dwelling creature and the thunder deity manifests himself in storms. Indeed, most popular newspaper accounts of earthquakes also mention the presence of thunderstorms associated with them (e.g. Kitahara 1999, pp. 32–33, 36–37).

Although the *namazu*-based explanation of earthquakes had become widely known throughout Japan by the early nineteenth century, it was not the only way of describing the mechanism of earthquakes. The *Ansei kenmonroku* (Accounts of the Ansei [1854–1859] era) contains a typical alternative, based on a widely known view of cosmic transformation whereby the five primary agents of yin and yang—fire, metal, wood, earth, water—interacted to create the material world and to embody the forces that govern it. With respect to earthquakes, normally water (purely yin) overcomes fire (purely yang). Furthermore, water is the agent normally holding sway in the subterranean environment. Earthquakes result from the occasions when fire overcomes water underground, thus reversing the normal state of affairs. A broadsheet issued just after the Ansei earthquake of 1855 explained its cause in terms of both yin and yang forces and the movements of *namazu*, but it called the *namazu*-based explanation an 'unsophisticated theory'. (Wakamizu 2003, pp. 16–17). Popular newspapers often started their accounts of earthquakes with a simple, brief statement of yin and yang forces being out of balance. For example, the text of an account of the Ise earthquake (14th day, 6th month, 1854) explains that a clash of yin and yang forces resulted in thunder in the skies and shaking of the earth. An account of an earthquake in Odawara (2nd day, 2nd month, 1853) employs verbatim the same explanation (Kitahara 1999, pp. 32–33).

The key point here is that in nineteenth-century Japan, multiple theories of earthquake causality co-existed. Most of these theories postulated an imbalance in the cosmic forces, expressed in terms of the five agents (*gogyō*) of yin and yang or the subterranean movement of a giant creature. This creature was most commonly a *namazu*, but might also be a dragon, a turtle, a whale or even an oversized worm (*jishin mushi*). Scholars tended to talk about earthquakes in terms of abstract cosmic forces and ordinary people tended to invoke images of giant animals wiggling around under the earth. Despite these differences, the two general modes of conceiving and explaining earthquakes were not necessarily mutually exclusive. Both approaches saw earthquakes as the result of temporary aberrations in the delicate balance of power in and around the earth.

One *namazu-e* explicitly combines these two approaches to understanding earthquakes (Fig. 11). It depicts three members of the construction trades (identified by clothing and tools) around a *namazu* dressed in human clothes. The foundation stone floats in the air and gold coins are scattered around it, about to rain down on the three tradesmen. All seem to be enjoying their newfound good fortune. The redistribution of wealth was a theme in *namazu-e*, as carpenters, plasterers, roofers, and other specialists in the building trades prospered in the wake of the earthquake. On the clothing of each tradesman and the *namazu* are the characters for one of the five agents of yin and yang: wood 木, fire 火, earth 土, and water 水 (the *namazu*). The gold coins function as the final agent, metal 金 (also means gold). In addition to depicting a situation in which the five agents have returned to a state of balance, each agent stands for an important part of the immediate post-earthquake experience. Wood represents the houses and other structures, fire stands for the fires that raged for days, the watery *namazu* caused the earthquake in the first place, which dislodged metal (money) from the coffers of the rich and put it into the hands of labourers. The text accompanying the image reinforces the theme of the five agents. This print combines scholarly explanations of earthquakes and folk explanations in a way that the residents of Edo could have 'read' in either relatively simple or sophisticated manners without contradiction (Wakamizu 2003, pp. 68–70; Miyata & Takada 1995, p. 304).

The precise origins of the link between *namazu* and earthquakes in Japan are unclear. It is possible that the general idea of a giant fish supporting the earth came to Japan from China as part of popular Buddhist beliefs. Kojima points out that several Buddhist temples in China feature an image of the Bodhisattva Guanyin standing atop a giant fish that roughly resembles the Japanese *namazu* (Kojima 1995, pp. 188–189). Some degree of Chinese influence undoubtedly facilitated the development in Japan of both the idea that *namazu* cause earthquakes and the view of earthquakes as resulting from an imbalance or aberration

Fig. 11. Untitled *namazu-e* showing (**1**) the co-existence of two modes of thinking regarding the causes of earthquakes and (**2**) the *namazu* as an agent of world rectification (*yo-naoshi*). Three members of the construction trades, identified by their tools, are celebrating their newfound wealth (the gold coins apparently falling from the sky) by drinking with the *namazu*. The foundation stone appears to be floating in the air. On jacket of the man in the left foreground is the character for earth (土), while the jacket of the man in the right foreground reveals the character for fire (火). The character for water (水) forms the pattern of the *namazu's* robes, and the character for wood (木) does the same for the jacket of the man behind the *namazu*. The airborne gold coins stand for metal (金), whose character also means gold or money. Earth, fire, water, wood, and metal are the five agents of yin and yang, whose imbalance was the cause of earthquakes in many premodern theories throughout East Asia. The shaking of the earthquake rectifies this imbalance, both in an abstract sense and in more specific ways. In this case, the tradesmen are receiving metal (gold, money) from the wealthy members of society. Here the *namazu* can be viewed as a literal cause of earthquakes, as a metaphor for earthquakes, and as a symbol of social rectification (from Wakamizu 2003, p. 69).

in the forces of yin and yang. Nevertheless, the close link between *namazu* (or anything similar) and earthquakes never developed in China.

Perhaps the most significant Chinese influence on Japanese views of earthquakes came from the ancient idea of heaven's mandate (*tianming*). In this view, which could accommodate both abstract and anthropomorphic conceptions of the cosmic forces, heaven (the cosmos) bestows on rulers a mandate to govern based on their moral fitness. Earthquakes, floods, famine, epidemics, and other natural calamities were signs of heaven's displeasure. This idea became the bedrock of classical Chinese political theory. It was also influential in Japan, especially in the notion that the cosmic forces periodically rectify a social order gone awry (*yonaoshi*, 'world rectification'). Earthquakes were a major tool for bringing about such rectification, and in this sense, they were not random occurrences. The print described above in which the earthquake redistributes wealth reflects this way of thinking. Earthquakes, therefore, necessarily had political significance in premodern Japan, and commentary on them could easily become commentary on the state of society and government.

The namazu-e *(catfish picture prints): Japanese responses to the Ansei earthquake*

For Japan, a particularly well documented example of how folk beliefs intersected with contemporary political and social culture is the Ansei earthquake of 1855. On the second day of the tenth month (November 11 in the solar calendar), a magnitude 6.9 earthquake with a shallow focus shook Edo (present-day Tokyo) and a wide surrounding area. Aftershocks continued for the next nine days. Estimates of the number killed in the greater Edo area range from 7000 to 10 000 (4000–5000 for the downtown area), but the precise figure is uncertain. This death toll amounted to roughly 1 in 170 Edo residents, and shaking and subsequent fires destroyed 1 in 3 non-military houses and other structures (Inagaki 1995, p. 64). The injured were especially numerous, and fires burned for days throughout the city.

A remarkable coincidence between geology, geography, and politics magnified the psychological impact of this earthquake in such a way as to make it appear as a direct attack on the heart of the *bakufu*, Japan's military government based in Edo. The distribution and severity of damage was not uniform. Some areas suffered severe devastation and loss of life, whereas other parts of the city came through the ordeal with nearly all buildings and people shaken but intact. The damage was less a function of proximity to the epicentre than it was a function of topography and soil conditions. The Yamanote Tablelands, an extension of the Musashino Plateau, wound their way through parts of the heart of Edo, constituting modest upland areas. These upland areas were not always obvious because of erosion and past filling with soil or debris of low-lying areas. In 1590, when Tokugawa Ieyasu (1542–1616) made the fishing village of Edo his base of operations, human engineers and construction workers began to reclaim the marshy flats around Edo Castle. This process accelerated rapidly during the early seventeenth century, after Edo became the *de facto* political capital of Japan. Edo Castle itself was on natural high ground, but much of the prime land around the castle had been part of a river drainage basin of Edo Bay a mere two or three centuries earlier.

When the earthquake struck, it shook the whole city, but structures on the firm foundation of the uplands generally fared better. The severe damage occurred in low-lying areas, especially areas of land reclaimed from marshes and waterways. As fate would have it, the most prominent neighbourhood of *samurai* residences, home to the *bakufu*'s closest supporters among the domain lords, leading *bakufu* officials, and several key *bakufu* offices, was located at a place that during the sixteenth century had been the Hibiya Inlet of Edo Bay. The earthquake devastated this neighbourhood, as if it had targeted the government for destruction. One residential zone further out from the castle, the area adjacent to the elite neighbourhood, was home to commoners. Built on a firm foundation, it suffered only moderate damage and stood in stark contrast to the elite neighbourhood's collapse. In the eyes of commoners and elite alike, the cosmic forces made a strong statement that night (Noguchi 1997, pp. 73–108).

As if to add insult to injury, there was one more odd twist to the earthquake damage. In the commoner neighbourhood of Kitachi-ku, for example, not one main building collapsed. Nearly all the serious injuries from this neighbourhood were the result of falling roof tiles or eaves from collapsed storehouses, built as separate structures from the main buildings. Many other neighbourhoods reported the same pattern, and all visual evidence points to storehouses sustaining much worse damage than any other type of structure. These rigid, heavy, mud walled, tile-roofed storehouses tended to vibrate at the same frequency as the high-frequency seismic waves generated by the shallow-focus earthquake. The irony is that the *bakufu* ordered this rigid, heavy storehouse design in 1842 as a fire-prevention measure (Noguchi 1997, pp. 118–120). In this way too, the earthquake seemed to be paying especially close attention to the government in its destruction.

Within two days of the initial shaking, printers set up makeshift facilities in the relatively less damaged areas and began to produce *namazu-e* for sale through street vendors. *Namazu-e* sold briskly for approximately two months before government authorities outlawed their production and burned the printing blocks. These symbolically rich prints are a record of the Ansei earthquake, and they served as a medium through which the common people of Edo could interpret the event (Abe 2000, pp. 26–28, 46). Therefore, *namazu-e* are an excellent case study in the use of historical documents and symbolic language to complement conventional geological evidence in reconstructing the history of geological events. These prints also provide insight into the cosmological, social, and political meaning that many nineteenth-century Japanese ascribed to major earthquakes. More generally, the views of earthquakes manifest in *namazu-e* may be part of a global set of local responses to earthquakes that share broad themes in common such as the notion of a chthonic fish/dragon/snake-like creature as the immediate cause of the earthquake or a connection between earthquakes and thunder. The following section examines *namazu-e* with respect to their value as earthquake records, documentation of social responses to earthquakes, and possible commonality of themes with symbolic representations of earthquakes elsewhere in the world.

Correspondence between namazu-e *and earthquake-related events*

The most common types of *namazu-e* to appear immediately after the initial shaking were talismanic prints that people could hang in their houses in the hope of warding off further damage. Aside from the fires, aftershocks were also serious concerns for the residents of Edo. Many of these talismanic *namazu-e* depict the Kashima deity, often with the assistance of the thunder deity or others, decisively pinning down a giant *namazu* with a sword or the foundation stone. In some variations, the *namazu* vigorously apologize, sometimes in writing, for the destruction wrought by their reckless movements. Frequently, groups of smaller *namazu*, usually representing aftershocks, surround a giant *namazu*. The purchase and display of an image depicting the Kashima deity having regained firm control over the various *namazu* was, of course, wishful thinking. Kitani points out that *namazu-e* functioned as a mental health aid for those caught up in severe circumstances largely beyond their control. By dealing with fear, suggesting a degree of reassurance, and expressing emotions such as anger and disgust, often leavened with irreverent humour, popular prints helped residents of Edo cope with what today we might call post traumatic stress disorder (Kitani 1995*b*, 1999).

One of these talismanic images, entitled *Jishin o-mamori* (earthquake protection: Fig. 12) is

Fig. 12. A *namazu-e* talisman to protect against earthquake damage. Notice the dragon-like tail of the *namazu*, probably an iconographic remnant of the older belief that a subterranean dragon caused earthquakes. The thunder god (right) is typically a symbol of unrest, often associated with earthquakes, but here he lends his mallet to the task of helping the Kashima deity (left) suppress the giant *namazu*. At the top left is 'Kashima' written in a special 'spirit writing' script associated with popular Daoism and more commonly found in China than Japan. Directly above it is an iconographic depiction of *Ursa Major* (Great Bear or Big Dipper) constellation, thought to be an especially lucky set of stars. The four small *namazu* each wear human robes with characters for place names on their backs: Ise, Shinshū, Odawara, and Kyoto. These place names correspond to major earthquakes from the relatively recent past and attest to a widespread knowledge of earthquakes that took place even in other regions of the country owing to inter-city news networks (from Miyata & Takada 1995, p. 110).

especially interesting. It features a giant *namazu*—half catfish, half dragon—pinned firmly to the ground by the Kashima deity's sword through its head, which the thunder deity is pounding with his mallet. The upper left corner features an iconographic image of the *Ursa Major* (Great Bear or Big Dipper) constellation and the word 'Kashima' rendered in the peculiar 'spirit writing' of Daoist talismans. The text explains the various problems the *namazu* have caused and ends with a statement of protection for the integrity of houses. There are four smaller *namazu* in front of the giant *namazu*, all bowing down vigorously and abjectly before the quelling power of the two deities. At first glance, these four smaller *namazu* may seem to be aftershocks. Normally, however, aftershocks appear in these prints as a larger group of small *namazu*. In this case, the four small *namazu* each wear robes with characters for place names on their backs: Kyōto, Shinshū, Odawara, and Ise (Wakamizu 2003, pp. 85–86; Miyata & Takada 1995, p. 262). These place names correspond to major earthquakes from the relatively recent past. They attest to a widespread knowledge of recent earthquakes among Japan's urban population, even those that took place in other regions of the country. Indeed, the text of many popular newspaper accounts mentions recent earthquakes, either in passing or comparatively, when discussing the Ansei earthquake in 1855. Let us examine some of the details symbolized by each of these small *namazu*.

The 'Kyōto' *namazu* stands for an 1830 earthquake of about magnitude 6.5 shook the old imperial capital of Kyōto causing about 280 deaths, 1300 injuries, and an unusually large number of aftershocks (Usami 2003, pp. 131–132). Because Kyōto rarely experienced earthquakes of any significance, this otherwise rather modest seismic event became an occasion for worry, especially because it occurred almost in concert with the promulgation of a new era name, Tempō. Matsuzaki Kōdō, for example, a Confucian scholar living near Edo, took anxious notice of both the Kyoto earthquake and the unseasonable blooming of cherry trees. Writing in his diary a day after the Tempō era started, he said that 'Our ruler is virtuous, and our habits upright ... so there should be no reason for any disasters .... All we can do is pray for the Heavenly Protection of yesterday's new era name' (Bolitho 1989, p. 117).

'Shinshū' is another term for Shinano, present-day Nagano Prefecture, which was the site of the magnitude 7.4 Zenkōji earthquake of 1847 that resulted in at least 10 000 deaths by most accounts. According to one newspaper account from the time:

> In the third month of 1847 on the 24th day around 10pm, a large earthquake struck Shinano. Unfortunately, that month the Zenkō Temple (Zenkōji) was displaying a Buddhist statue, and so people from all around had crowded in to see it. A large crowd was milling around, which exacerbated the panic when the earthquake struck. Many of them were pinned down by or crushed beneath collapsing houses. Moreover, fire flew from the collapsed houses in an instant, and before long, the district in front of the temple gate was a sea of flames. Aftershocks sounding like thunder continued without cease, there being more than 80 throughout the night. A fissure appeared in the earth from which flowed mud and sand. A cliff overhanging the north fork of the

Sai River collapsed, which caused massive flooding. Disasters two or three deep caused, it is said, the deaths of 30 000. Prior to the earthquake, the temple put up a notice board of regulations for viewing the Buddhist image in front of its gate. It disappeared in the night, as did a second one. After putting up a third one, a guard was posted around the clock. Reflecting on this matter, people claimed that it must have been a way that the main Buddha of the temple tried to warn the people of an impending earthquake (Nishimaki 1978, p. 126).

Mention of the Zenkōji earthquake was common in popular accounts of subsequent earthquakes and occurred especially frequently in images and documents connected with the Ansei earthquake.

Odawara is a city slightly to the south of Edo, which experienced a major earthquake of unknown magnitude on the 3rd day of the second month, 1853. According to one newspaper account, houses 'collapsed like chess pieces'. A corner of Odawara castle collapsed, and the shaking and subsequent fires killed 3780 (Nishimaki 1978, p. 140; Kitahara 1999, p. 32).

Finally, the 'Ise' *namazu* represents an earthquake that occurred on the 14th day of the 6th month, 1854. It shook Iga-Ueno in present-day Mie Prefecture and the Ise and Konoe areas in present-day Shiga Prefecture. It caused widespread property damage, destroying over 20 000 homes, and was widely reported in the popular press of the major urban areas (Kitahara 1999, p. 33).

There was at least one more talismanic *namazu-e* of similar iconographic design featuring the same four smaller *namazu* representing the same past earthquakes (Miyata & Takada 1995, p. 262). More common were textual references to past earthquakes. *Namazu-e* often mentioned or discussed one or more of these previous earthquakes, thereby linking them with the Ansei earthquake. The popular urban press and inter-city news networks preserved the memory of recent earthquakes in the Japanese islands even among those who did not experience them directly. This point is significant because, as we will see, many urban Japanese came to regard the Ansei earthquake as part of a series of 'world rectification' (*yonaoshi*) events.

The major themes of the *namazu-e* of 1855 and the sequence of the appearance of these themes tracked the physical, psychological, and social courses of the earthquake and its aftermath. Immediately after the initial shaking, the emphasis in *namazu-e* was on the destruction. Commentary on the destruction assumed at least four different forms. One form was a relatively straightforward reporting of the damage via images of collapsing buildings, fires, dead and injured people, and so forth. A second type of early *namazu-e* criticized the Kashima deity and the deities associated with him for their negligence. Some of these prints depict the deity as trying without success to restrain the *namazu* and others are more irreverent, depicting the deity or deities as lazy or negligent (Fig. 13). A few prints even go so far as to demote Kashima and elevate Amaterasu (the solar deity associated with the imperial family) as the main hope for a return of stability (Abe 2000). Nevertheless, because the local deities were the only forces likely to restrain the *namazu* in the future, the most numerous form of *namazu-e* were talismanic images such as the one discussed previously (Fig. 12). In other words, the residents of Edo experienced both anger toward the deities and a desire to beg them for assistance, and early *namazu-e* embodied both attitudes, albeit rarely on a single page. Another variety of early *namazu-e* depicts the residents of Edo themselves as suppressing the *namazu*, often quite violently. In addition to the obvious emotion of anger, these prints also depict the wishful thinking whereby ordinary people might have some control over the raging forces of nature (Fig. 14).

As the fires subsided along with the fear of aftershocks, the work of recovery and rebuilding began. During this phase, a second wave of *namazu-e* began to emerge, many of which featured the theme of world rectification (*yonaoshi*). We have already examined one case of this type of image (Fig. 11). As agents of world rectification, the destructive power of the *namazu* served a worthy end. During the 1850s, many denizens of Edo increasingly came to see the *bakufu* as ineffective and corrupt. The early nineteenth century was a time of frequent crop failures, famine, strange weather patterns, urban riots, and mass religious pilgrimages—often started by rumours of supernatural phenomena—whose participants sometimes developed into unruly mobs. Some of the urban riots were the result of the hoarding of basic commodities by unscrupulous merchants in an effort to create artificially high prices. In short, there were many reasons for ordinary urban dwellers to regard their world as needing radical rectification and thus teetering on the edge of one or more major heaven-sent calamities.

As we have seen, the uneven severity of destruction due to variations in topography, soil conditions, and construction type caused the earthquake to appear as a direct attack on the government. Nevertheless, there was collateral damage in the form of death, injury, and destruction to the innocent. In some examples of the second wave of prints, the *namazu* seem genuinely to regret the damage suffered by the innocent. In prints produced after the extent of devastation had become clear, *namazu* often expressed second thoughts or regret after seeing the effects of their deeds. One way to depict this point was to show smaller *namazu*

Fig. 13. In this *namazu-e*, fires rage and the earth shakes while a tired-looking Ebisu—filling in for the Kashima Deity who is out of town to attend a meeting in Ise—dozes against the foundation stone. Money (large gold coins) is falling from the burning city, which presages the world rectification theme that will become more prominent in *namazu-e* during the rebuilding phase of the earthquake's aftermath. The strange looking man on the left is the thunder deity, a close associate of the Kashima deity. The thunder deity is engaging in a peculiar pastime of some Edo residents, what might call 'extreme farting', or 'thunder farting'. The main object of this sport was to make more noise than your opponents. According to the scholar Hiraga Gennai (1729–1779) in his treatise *Hōhiron* (On farting), thunder farting made its debut in 1774 at the Ryōgoku Bridge, a major site of popular culture displays and spectacles in Edo. Small drums issue from the thunder deity's posterior, emphasizing the thunderous quality of his performance. The man on horseback at right is the Kashima deity, rushing back from his meeting with other major deities in Ise. In the scene depicted here Kashima's temporary replacement, the less capable deity Ebisu, is sleeping on the job, and the thunder deity, who should be working, is off at the Ryōgoku Bridge literally farting around. These incompetent deities have allowed a major disaster to unfold in the form of a fire-ravaged, post-earthquake Edo (interpretation based on Wakamizu 2003, pp. 70–73; image from Miyata & Takada 1995, p. 106).

vigorously criticizing a giant *namazu*, whose movements caused excessive shaking. Another was to depict *namazu* assisting earthquake victims in various ways (Fig. 15). Other prints featured anthropomorphic world-rectifying *namazu*.

The most common depiction of world-rectifying *namazu* shows them re-distributing wealth. For example, they force the rich to vomit or excrete money (Fig. 16). Consider the effects of a major earthquake on different social groups. Of course, the shaking itself and the resulting fires would be dangerous and terrifying for anyone in society regardless of status or circumstances. The aftershocks would probably cause even more damage over the course of the next day or several days. Relief efforts, salvage operations, the hauling away of rubble, and rebuilding would begin soon after the aftershocks subsided. Labour, both skilled and unskilled, would be in great demand during this recovery period. Nearly anyone willing to work would be able to find work at an elevated wage, at least for a while. The wealthy, whose expensive homes and businesses would need repair or rebuilding, would have to pay these high wages to the labourers. Of course, the homes of the labourers, too, might need rebuilding, but they would have been able to afford it. Official wage rates for various types of labourers rose between sixteen and seventy percent in the wake of the earthquake, but actual wages for carpenters, plasterers, and other skilled tradesmen roughly quintupled during the period of peak demand (Noguchi 1997, pp. 202–203).

Most of the population of Edo and other large cities made their living through unskilled labour, through skilled craftwork, or by operating small shops (including street vendors). Many of these occupations would have profited nicely from the post-quake recovery work. Therefore, for many urban dwellers, earthquakes, although terrifying and destructive, were also a boon for personal and family finances. It would have been like money pouring out from the heavens and into their hands—a common image in many second-wave *namazu-e* (e.g. Fig. 16). Not all occupations, however, benefited from the earthquake. Some *namazu-e* criticized the tendency of carpenters, plasterers, and other earthquake profit-makers for a callous neglect of their less fortunate neighbours (Tomisawa 1999, pp. 194–198; Fig. 17).

More broadly, there was a strong sense that earthquakes, as destructive as they are in the short term, provide an impetus for society to regain its social and financial health. The thinking here extrapolates from prevailing theories about human health. For a person to be physically healthy, the most important consideration is that the flow of blood and vital essence (*ki*—the major concern of acupuncture)

Fig. 14. This *namazu-e* shows the courtesans and male workers of the elite brothel district, *Shin-Yoshiwara*, attacking the earthquake *namazu* (and children attacking a child-sized one, right foreground). This district suffered especially devastating damage from the Ansei earthquake because of its location atop reclaimed swamp land. Most of its buildings were destroyed, loss of life was severe, and, although the elite brothel district quickly re-opened in temporary quarters, the earthquake suppressed business for months. Notice the group of five men in the upper left corner. At first glance, they seem to be rushing to join in the attack. Instead, however, they are calling on the crowd to stop its attempt to subdue the *namazu*. Their tools identify these men as construction workers of various types—the element in society that stood most to profit from the earthquake.

be vigorous and unimpeded. Japanese in the early nineteenth century typically regarded disease as the result of a blockage in the flow of these fluids. Economists and social commentators of the time frequently likened the flow of wealth, especially metallic currency, through society to be the major factor in social health. In this sense, the activity of merchants was normally a good thing because they were the main agents of the exchange, and thus circulation, of goods and wealth. Successful merchants, however, often amassed great stores of wealth and sometimes hoarded goods in an effort to raise prices by creating an artificial shortage. Thus, major earthquakes would literally shake things up and put the stagnating goods and wealth back into circulation, especially into the hands of ordinary people. In this sense earthquakes were like medicine for an ailing society (Fig. 18).

The theme of world renewal in the *namazu-e* went beyond economic redistribution. A close reading of the prints reveals a connection with the major political events of those times, specifically the arrival in Edo of Matthew Perry of the United States in 1853 and 1854 to negotiate a formal diplomatic treaty with Japan. Depictions of Perry and the Americans in the popular press were generally unflattering. Some accounts, however, regarded Perry's arrival as a world rectifying event to shake up Japan's complacent rulers in the *bakufu* and the warrior class (*samurai*) in general. The occurrence of major earthquakes (1853, 1854, and 1855) within a short time of Perry's arrival fit perfectly into this world rectification scheme. Some *namazu-e* therefore made veiled connections between Perry and the Ansei earthquake. Because direct commentary on political events of this magnitude would have been dangerous, the printmakers employed plays on words and symbols to conceal political commentary.

In one well-known print, a giant *namazu* appears to have partially morphed into a whale spouting money, but not from a blowhole (Fig. 19).

Fig. 15. 'The sympathy of the world-rectifying *namazu*' (*Yo-naoshi namazu no nasake*). This print is typical of those suggesting that the *namazu* feel remorse for the high levels of damage they have caused in their capacity of agents of world rectification. Here they help rescue earthquake victims. In other prints, they might be dispensing medical care to the wounded.

Fig. 16. 'The outward-bound ship of the wealthy' (*Kane-mochi-tachi no defune*). This *namazu-e* is a typical illustration of the world-rectifying *namazu* helping to return society to economic health by forcing the money horded by the wealthy to return to circulation. From the point of view of workers in the construction trades and many other types of labourers, the higher wages and extra work caused by the earthquake was like money pouring from the heavens.

Instead, the money comes from precisely the place where a smoke stack would be located on the steam ships of the time. Furthermore, the entire appearance of the *namazu* resembles that of one of Perry's 'black ships'. The text of an accompanying song written on the print includes a play on words that links 'great country' with 'big black' and a popular deity of wealth whose name is literally Big Black (Kitani 1995*a*, pp. 56–61). At least some Japanese at the time of the Ansei earthquake explicitly linked prosperity, world rectification, Perry's expedition, and the earthquake. The *namazu-e* functioned as sophisticated commentary on geological, social, and political events.

Discussion

The allegorical tales from Cascadia describing flooding, shaking, and other earthquake-related phenomena and the *namazu-e* of Japan exist at the nexus of social and geological reality. Depending on circumstances, symbolic language of this sort is capable of indicating: 1) the existence of major seismic activity in the past (and thus potentially in the future); 2) the time and location of specific earthquakes and tsunamis; 3) the approximate intensity of specific earthquakes; 4) local understanding of the cause(s) of earthquakes; and 5) the socio-political significance of earthquakes. Non-geological evidence such as local written records, monuments, place names, folklore, and non-Western elite intellectual theories of earthquake mechanisms also have the potential to supplement conventional geological evidence for understanding past seismic activity and its effects. In short, symbolic language and other non-geological evidence deserve the serious attention of Earth scientists. The relative infrequency of extraordinarily damaging earthquakes and their wide social impacts argue for inclusion and study of all relevant records.

Fig. 17. 'The hard-to-figure-out bird' (*Nangitori*). The earthquake made many of Edo's carpenters, plasterers, and other specialized tradesmen quite wealthy, at least in the short term. Here a group of them is in a fancy restaurant, drinking and sitting around a *namazu* they are going to eat. Suddenly a giant bird swoops down and removes their feast. A look at the bird quickly suggests why it is hard to figure out. The bird consists of the various tools from those occupations who have suffered because of the earthquake (e.g. large hairpins of the courtesans, books, dry goods, abacus, tall *geta* shoes, and tea ceremony utensils). It is a statement about and critique of the tendency of the newly-rich to forget about their less fortunate former peers.

Fig. 18. 'Powdered medicine selling *namazu*' (*Furidashi namazu kusuri*). Here a world-rectifying *namazu* sells a type of medicine called '*furidashi*'. During the Tokugawa period, *furidashi* was powdered medicine to be dissolved in hot water and consumed like tea. But the word *furidashi*, then and now, also suggests renewal or making a fresh start. Despite (and because of) the destruction they cause, earthquakes were an opportunity for renewal. More concretely, labourers of all kinds benefited economically from the post-quake reconstruction. Skilled crafts workers such as carpenters, plasterers, roof-tile makers, and so forth did especially well. Sure enough, the *namazu*-man carries doll-like images of these types of workers. In this view, the earthquake was beneficial medicine for many members of society, and for society as a whole. The text of this image explains in detail the efficacy of this medicine for restoring economic health. It restores the flow and circulation of money that has been collecting and stagnating in storehouses. Furthermore, it restores warmth to the cold-hearted and cures poverty. It reduces laziness and the ill effects of luxurious living. Strong medicine indeed!

Although the data from Cascadia and Japan are sufficient to support the contention that non-geological evidence might play a constructive role in creating a complete record of seismic activity, they also suggest intriguing possibilities about human perceptions and understanding of earthquakes. Plate tectonics were not understood to be the cause of earthquakes until the mid-twentieth century, and all prior considerations of earthquake causes were speculative. Human nature demands an explanation for events experienced over extensive areas and that cause damage, fatalities, and permanent land-level changes. Through the ages, people documented earthquake effects and speculated about their causes (all early theories ultimately proving incorrect), both in folklore from seismogenic areas and in the writings of scientific thinkers including Aristotle, DaVinci, Darwin, Lyell, Humboldt, Kant, and Mallet (Oeser 1996–2001). Early attempts at scientific explanation sometimes found it useful to compare earth

Fig. 19. 'The giant *namazu* and Edo's prosperity [shaking]' (*Ō-namazu Edo no furui*). This *namazu-e* abounds in plays on words. A whale-like *namazu* as large as a ship spouts money into Edo Bay. The people on shore vigorously beckon for it to come closer. The small boats appear to contain fishermen who might harpoon the whale-*namazu* in an attempt to pull it closer to shore. The whale-*namazu* looks much like a 'black ship,' that is a steamship. Notice that it is not spouting money from a blowhole, which would be located near its head. Instead, the money pours forth from the place where a smoke stack would typically be located on a steam ship. The small boats resemble those of the sketch artists who surrounded Perry's fleet when it first arrived in 1853. The text includes a song. It explains that the ground moves under the great country, collapsing a mountain of treasure into the city. There is a play on words here. 'Ground of the great country' is '*Daikoku no tsuchi*'. 'Great country' is pronounced the same as the deity Daikoku, whose wealth-giving mallet happens to be '*Daikoku no tsuchi*'. Daikoku, the deity, means 'Big Black'. In short, at least some Japanese at the time of the Ansei earthquake, explicitly linked Perry's expedition, the earthquake, and the state of their society. Reading the song part of the text requires turning the image upside down. Doing so alters the visual elements, turning the spray of coins into the mountain of wealth mentioned in the song.

tremors to human illnesses such as loss of circulation or ague (Oeser 1996–2001). Some scientists still find it useful to consider the Earth as a living body. The Gaia hypothesis, proposed by James Lovelock (1972), is capable of stimulating integrative thinking and lively debate about large-scale ecological phenomena. Similarly, speculations and descriptions found in earthquake folklore can serve as a springboard for contemplating earthquake effects at particular geographic sites.

Comparing the earthquake-related lore of Cascadia with the *namazu-e* of Japan, we find similar motifs and notions of causal mechanisms. In both areas, for example, a chthonic, serpentine creature of great power, associated with water and living under the earth or ocean, is the immediate cause of earthquakes. Although the Japanese *namazu* is typically a type of catfish, it was a development from earlier notions of subterranean dragons. Similar notions are found throughout the world. Legends from Sumatra attribute earthquakes to a horned water serpent that struggles to shake off the land above him (Dixon 1916; Frazier 1918). Piccardi (2001) has reported that the lairs of chthonic dragons in Greek mythology are located directly above active faults, as is Scotland's Loch Ness monster. Although not all mythical or folk theories of earthquakes view the causal mechanism of earthquakes as the movement of a fish, serpentine, or reptilian creature within or beneath the earth or waters, this theme seems to be common to diverse cultures throughout the world.

Another widely distributed theme regarding earthquakes is the connection between earthquakes and thunder. In the Japanese case, we find the close association of the Kashima deity and the thunder deity. In the southern part of Cascadia, thunder appears in human form and frequently appears as the companion of Earthquake. Along the middle and northern Cascadia coast, the Thunderbird appears in numerous stories describing marine flooding and/or ground shaking. In European thought, thunder is closely associated with earthquakes in the Bible (King James version: Isaiah 29:6; Revelation 16:18; 11:13, 19), in sermons (Wesley 1750), and in *c.* 1750 scientific thought (Franklyn 1750; Stukely 1749–1750; Bina 1751 & 1758). In India, texts from the eleventh to sixth century BC say that 'once upon a time mountains could fly and move. Thus they were frequently falling on the earth causing earthquakes continuously. At the request of the earth, the Creator ordered *Indra* (thunder) to cut the wings of the mountains so that the earth became stable.' (Iyengar 1999).

Moving beyond images of the mechanical causes of earthquakes, we find that many cultures throughout the world regarded earthquakes as purposeful events, not random occurrences. More specifically, there was a pronounced tendency for local populations to regard earthquakes as divine punishments. The Japanese notion of world-rectification, although not solely punitive, includes the idea that earthquakes punish those who have harmed society such as merchants who hoard wealth or a corrupt and ineffective government.

In European thought, unspecified sin was said to cause earthquakes, with piety put forth as a cure. The sermon of the British minister Charles Wesley (1750) makes this clear 'Earthquakes are set forth by the inspired writers as God's proper judicial act, or the punishment of sin: Sin is the cause, earthquakes the effect, of his anger.' Stories from Cascadia and Alaska include examples of earthquakes following misdeeds such as cruelty to animals (Fig. 1, story 1c), greed (Fig. 1, story 23), unbridled lust (Adamson 1934, p 216–217) and incest (Krause 1956, p. 183–184).

From the above examples, it is likely that at a deep level many or most of the world's premodern societies regarded earthquakes in a similar way. The earth shook because of the movements of a water-dwelling fish, whale, snake, dragon, or reptile within the earth or beneath the water. This shaking process was connected with the phenomenon of thunder, and the shaking was, at least in part, a world-altering retribution visited on earthly inhabitants by the cosmic forces. The alteration of the world included destruction of the existing social and material equilibrium, destructive and constructive changes in physical landforms, and opportunities for some to advance in social or material status while the fortunes of others declined.

The Japanese case is noteworthy in that the *namazu* figures comment extensively on both the destructive and constructive aspects of earthquakes. As we have seen, images produced soon after the main earthquake, at a time when aftershocks continued to shake the ground, stressed the destructive power of the *namazu*. Once the most hazardous aspects of the earthquake had passed, then the emphasis shifted to opportunity for labourers and other members of the general population who stood to benefit economically from the reconstruction. More broadly, the earthquake represented opportunity for social renewal. On balance, especially looking at it in hindsight, ordinary Japanese tended to view the Ansei earthquake of 1855 as more of an opportunity than a hazard. The *namazu* image was sufficiently complex that it could accommodate a range of earthquake-related phenomena. Furthermore, many other Japanese supernatural creatures, such as the *oni* (demon) and *tengu* (goblin) have a similar quality. They are fearsome, powerful, and often destructive. On the other hand, they can also be beneficial in certain circumstances (Smits 2002; Shimizu 2003, p. 136).

In the case of Cascadia, evidence for considering earthquakes to have a constructive aspect is sparser, and the cultural context distinct. Rather than relatively centralized and highly stratified governance, as in Japan, there were numerous distinct and relatively isolated tribal groups with generally more fluid social hierarchies. Although reports of death and destruction are present in many stories (and indeed, are one of the factors that helps us to identify them as earthquake- or tsunami-related), various tales from Cascadia do attest to human flexibility in response to earthquakes. A story from Vancouver Island tells how, following the 1700 tsunami, remnants of a tribe that had been largely obliterated offered tribal leadership to a newcomer arriving after the event (Fig. 1, story 6). Another account from the same area tells how, after the 1700 tsunami washed away the people of Pachena Bay, property rights passed to a group related by marriage (Fig. 1, story 7).

Another story, from the northwest tip of Washington, tells of extreme hunger when the tide refused to go out (Peterson 1976), a possible reference to shellfish beds subsided below the low-tide level. Starvation was averted when the Thunderbird brought a whale to shore. Stories from northern California report improved fishing at sites where the earth subsided and was inundated (Fig. 1, stories 31b and 32). Like the Japanese, the Yurok of northern California saw earthquakes as an indication of an unbalanced world, and held annual midwinter world-renewal ceremonies with a Jumping or Deerskin Dance intended to stave off earthquakes and other impending catastrophes and restore balance to the world (Kroeber 1976).

Although earthquake-related figures in Cascadia are generally treated with great respect and sometimes fear, a few stories present a comical aspect to the Thunder figure, characterizing him as a hostile father-in-law who sets dangerous challenges for his human son-in-law, including bringing two fighting stones, called White Agate and Blue Rock, into the house. The son-in-law has special powers that protect him, and manages to turn the danger around to injure the father-in-law (e.g. Adamson 1934); the warring rocks tear Thunder's house to pieces.

Large earthquakes create a geographically distributed set of shared and individual experiences that are amenable to a broad range of human analysis and interpretation. Although individual fortunes or even cultures rise or fall, the stories of the survivors persist. Listening to and integrating local stories into our consideration of what an earthquake means anchors us in our geographic and historic setting in multiple and thought-provoking ways. Earthquakes belong to communities, and their popular representations are worthy of a place alongside the persuasive explanations of science.

Authors' contributions:

Ludwin: compiled and interpreted stories from Cascadia, co-wrote article text. Smits: compiled and interpreted Japanese material, co-wrote article text. Carver: compiled stories and cultural background for northern CA and southern OR coast. James: located Puget Sound stories and provided cultural background. Jonientz-Trisler: located Puget Sound story and provided cultural background. McMillan: compiled stories and cultural knowledge of British Columbia. Losey: compiled stories and cultural knowledge of central OR coast. Dennis: provided Vancouver Island cultural expertise and unpublished information. Rasmussen: provided Puget Sound cultural expertise and unpublished information: De Los Angeles: provided Puget Sound cultural expertise and unpublished information. Buerge: provided information and references on Puget Sound Native cultures. Thrush: Puget Sound ethnographic archaeological and ecological background, Clague: Vancouver Island tsunami deposits and ethnographic accounts. Bowechop: provided cultural expertise and located Olympic Peninsula story. Wray: located Olympic Peninsula stories and provided cultural knowledge.

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The AD 60 Denizli Basin earthquake and the apparition of Archangel Michael at Colossae (Aegean Turkey)

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Abstract: This paper illustrates the results of a multidisciplinary study on the active tectonics of Hierapolis and Colossae in Aegean Turkey. Tectonic analysis is combined with a study of historical seismicity, highlighting the use of historical sources from oral tradition (legends and myths) to derive important geological information for which the legendary account is the only witness. Strong correlation between tectonic and historical/mythological data suggests that the legendary narration is based on real geological events. This allows a better understanding of the local active tectonics and seismic history. At Hierapolis, it is possible to recognize evidence of surface faulting from the AD 60 earthquake. At Colossae, we can reconstruct the local geomorphic evolution, and show its relationship to the AD 60 earthquake.

In particular cases, deciphering local folk tales, legends and myths may provide useful data on the historical seismicity of an area. This subject has only recently been investigated by geologists (Bentor 1989; Guidoboni 1989; Armijo *et al.* 1991; Nur 1991; Piccardi 2000, 2005), but is still complicated because it deals with documents derived from oral tradition. Many of these documents are based on a codified religious terminology, which sounds unfamiliar today and contributes to the lack of precision. In specific cases where geological phenomena are clearly quoted, geological analysis can be used as an interpretative key of legends.

This study presents a case history where legendary narrations from the Denizli Basin (Aegean Turkey, Fig. 1a) provide useful geological and palaeoseismological information. In particular, traditions related to a famous earthquake that occurred in AD 60, and two famous ancient sanctuaries of this area: Colossae, located at the southern margin of the basin, and Hierapolis, about 15 km to the NW, are examined (Fig. 1b). Early Christian and medieval legends, based on geological events are attached to these two places: the apparition of Archangel Michael at Colossae and the apocryphal account of the arrival of St Philip at Hierapolis. Both legends were later commemorated by famous sanctuaries, that have attracted pilgrims through the centuries. Moreover, at Hierapolis the geological basis for these legends constituted the source event for local religious rituals also at an earlier level, in the Greek-Roman sanctuary of Apollo.

Only sparse descriptions about the effects of the AD 60 earthquake are available in historical documents; thus oral tradition is the only source of further information. The natural phenomena that led to these legends are coseismic geomorphic effects related to that strong earthquake, for which legend is the only existent testimony. The cases illustrated here are clear examples of how particular hagiographic legends can constitute 'quasi-historical' documents.

Following a tectonic study of the area and review of historical accounts, this paper focuses on two main aspects of local myths and geology. The first recovers important information to reconstruct the seismotectonic parameters of the AD 60 earthquake, in particular identifying its source as being the master fault of the Denizli basin, and the second gains insight into the true origin of particular legends and the reasons for sacred site selection. In addition, this multidisciplinary approach sheds light on important developments in the evolution of western religious thought.

The Denizli Basin

The Denizli Basin belongs to the Turkish Aegean extensional province, which is one of the most rapidly extending regions in the world. Two main effects dominate the active regional deformation: the westward tectonic escape of the Anatolian plate, and the south-westward migration of the Hellenic trench system (McKenzie 1978; Le Pichon & Angelier 1979; Jackson 1994; Barka & Reilinger 1997). At present, Aegean Turkey is undergoing extension at a rapid rate in a roughly NNE–SSW direction (Angelier *et al.* 1981; Jackson 1994). The main tectonic expressions of the extensional stress-regime in this area are the Gediz and Menderes grabens, each more than 200 km long (Fig. 1a).

The Denizli Basin is situated at the eastern ends of the Gediz and Menderes grabens, where they meet (Fig. 1a,b). It is an approximately rhomb-shaped

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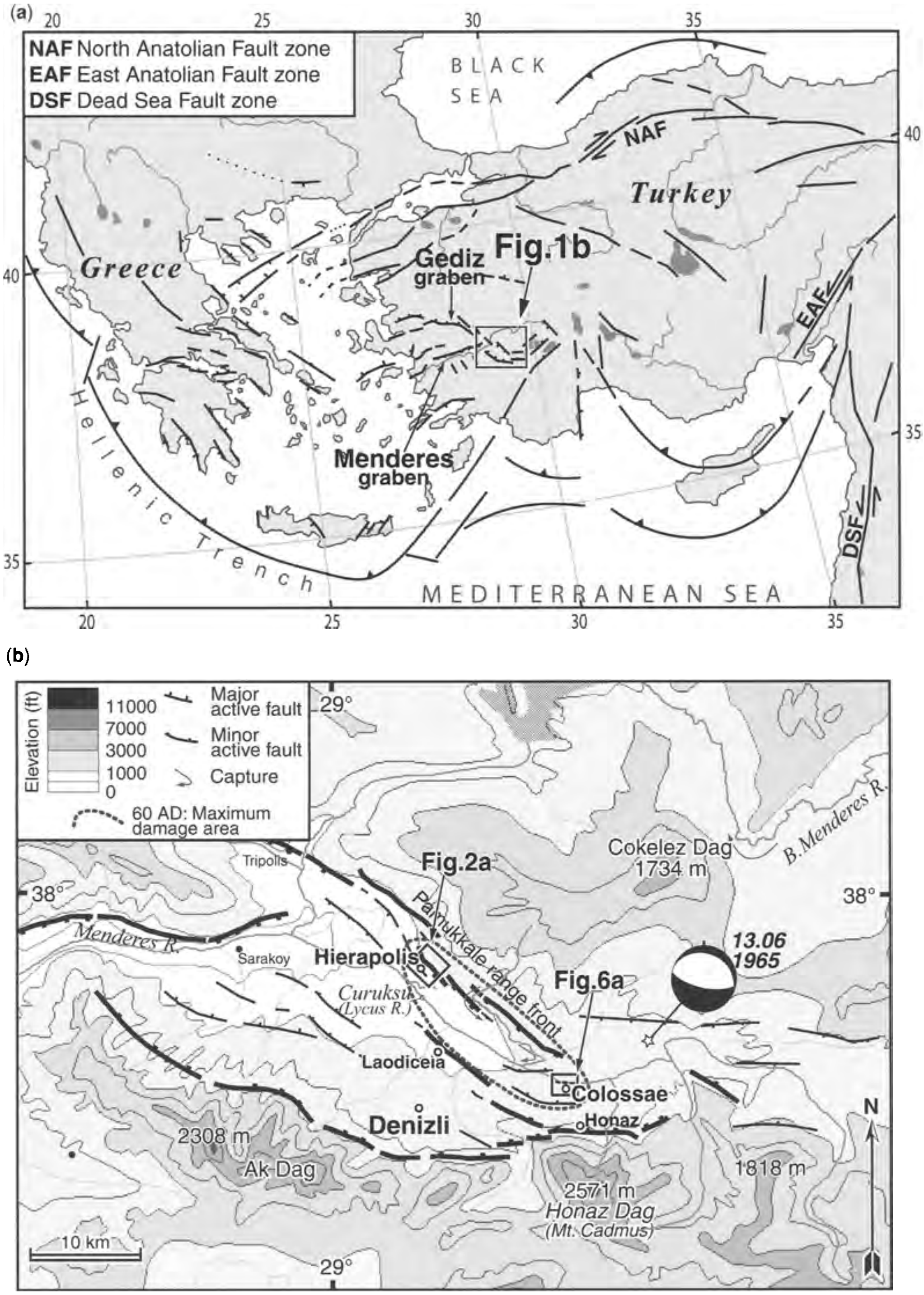

Fig. 1. (**a**) Main active faults in Turkey (modified from Taymaz *et al.* 1991; Barka 1992; Sargolu *et al.* 1992). (**b**) Seismotectonic map of the Denizli basin. Active faults identified from remote sensing (Landsat TM image) and field work, as well as from Westaway (1993) and Altunel & Hancock (1993*b*). Topography, in feet, is from D.M.A., (1992). Focal mechanism for the event of 13 June 1965 (M = 5.7) is from Westaway (1993).

NW–SE elongated tectonic depression, which has experienced subsidence since the late Miocene, with the extension axis orientated mostly NE–SW (Angelier *et al.* 1981; Westaway 1993; Hancock & Altunel 1997). The basin bedrock is made of Mesozoic metamorphic rocks discordantly overlain by Neogene deposits.

Active extensional faults bound the basin on all sides, as a result of the complex interaction between NW–SE directed faults, corresponding to the prolongation of the Gediz graben to the SW, and east–west orientated faults, belonging to the system of the Menderes graben (Westaway 1993; Altunel & Hancock 1993*a*,*b*). The NW–SE orientated fault system determines the Pamukkale range bounding the basin to the east. At the surface, the Pamukkale fault system is composed, at the surface, of left-stepping segments with step over zones 1–2 km wide, and shows a total downthrow into the basin exceeding 450 m (Hancock *et al.* 1999; Koçyigit *et al.* 1999).

Thermal activity in the area is very intense, and its relationship with active faults has been described in detail by Altunel & Hancock (1993*b*), Hancock *et al.* (1999) and Koçyigit *et al.* (1999). The main hydrothermal product is the travertine deposition which occurs in the region surrounding Pamukkale (Fig. 1b). These travertine deposits have been dated back to at least 400 000 years ago (Altunel & Hancock 1993*a*). The abundance of travertine deposition in this area is mainly attributed to the interaction between the NW–SE orientated fault system of the eastern border and the roughly east–west faults of the Menderes graben, which provide large pathways for circulation of hydrothermal fluids.

Historically, this basin suffered many strong earthquakes. Due to the presence of important cities like Colossae, Hierapolis and Laodicea, historical records of past earthquakes in this region are relatively abundant (e.g. Bonito 1691; Guidoboni 1989; Ambraseys & Finkel 1995, and references therein). The destructive effects of the earthquakes are well documented by archaeological evidence in Roman and Byzantine relics (Peres 1987; De Bernardi Ferrero 1993; Hancock & Altunel 1997), as well as by geological evidence (Westaway 1993; Hancock & Altunel 1997). The strongest and most famous event was the so-called 'Neronian' earthquake of AD 60.

Hierapolis of Phrygia

Hierapolis was built as a Greek colony at the end of third and beginning of the second century BC over a pre-existing settlement on top of the summit travertine plateau NE of Pamukkale (Fig. 2a). Archaeological and historical data indicate that the town had to be entirely rebuilt after the earthquake of AD 60, and was abandoned after the 1354 event, the two strongest historical shocks (Bean 1971; D'Andria 1985; Peres 1987; De Bernardi Ferrero 1993; Altunel 2000; D'Andria 2001).

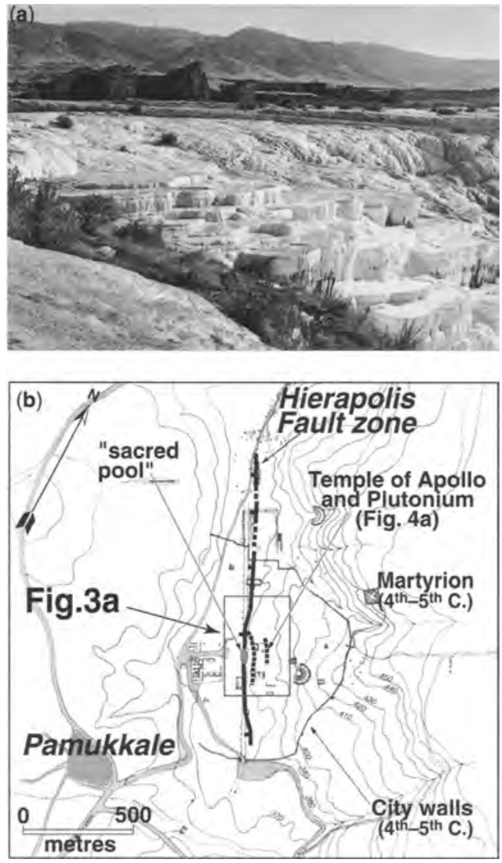

Fig. 2. (**a**) Ruins of Hierapolis of Phrygia on top of the travertine terrace, view toward the east. (**b**) Hierapolis, map of the archaeological site (topography is from Baysal *et al.* 1997).

The main active fault at the toe of the Pamukkale range-front is a normal fault, dipping 55–85° SW, with a minor left-lateral slip component (Altunel & Hancock 1993*b*). These authors estimate a slip rate of 1.5–3 mm a^{-1} and slip increments of about 1.5 m for this fault zone. Based on fault length, the authors consider the fault capable of earthquakes of at least magnitude 6, with recurrence times in the range of 500–1000 years (Hancock & Altunel 1997; Altunel 2000). They also argue for at least two recent seismic ruptures of this fault: the earthquake of AD 60, and an event in Byzantine times (possibly second half of the fourth century, early seventh or, more likely, 1354).

At present, most of the active thermal springs are aligned along the trace of the active NNW trending fault zone, about 100 m wide, that cuts across the ancient town (Hierapolis fault zone in Fig. 2b). The main road (the *plateia*) was constructed after the earthquake of AD 60, and it may be no coincidence that it roughly follows the trace of the active fault. The road seems to mark the trace of the rupture identified by Hancock & Altunel (1997). They indicate that a vertical displacement of 1.5–2 m has occurred on this fault since mid-Roman times.

At Hierapolis, there is striking evidence for the deliberate placement of the main sacred site directly above an active fault trace. The fault scarp extends from the temple of Apollo to the major thermal spring (traditionally called the 'sacred pool'; Fig. 2b). The sanctuary of the native community, at the site of the temple of Apollo and Plutonium, was sacred to the Anatolian mother goddess Cybele. From well before the time of the Greek colonization, it was considered, as a place of communication with the underworld because of the relevant and localized gas emission (mostly CO_2 and H_2S) from a hot spring, which still continues to exhale today. Later, the Greeks associated the male god Hades (*Pluton*) and Persephones to the infernal Goddess Cybele, and for this the spring was known in classical times as the *Plutonium*. The Temple of Apollo was positioned directly above it.

In 1965, Italian excavations unearthed the Plutonium (Excavation Reports in *Annuario della Sc. Atene* onwards), which corresponded in all essential elements to the ancient accounts (e.g. Strabo). There is a dark chamber, *c.* 3 m square, with a gap about 1 m wide at the back, where the natural rock is split by a deep cleft through which flows a fast-flowing stream filled with strong-smelling toxic vapours (Bean 1971).

The sacred area of the temple of Apollo is organized on two terraces, separated by a vertical throw of about 2 m which corresponds to a fault scarp (Figs 3a,b & 4b). The front part of the temple stands on a podium, whereas the rear part rests on the natural shelf of rock of the footwall. Thus, the Temple of Apollo bridges the fault scarp, and the Plutonium is positioned inside the fault itself. Apollo was worshipped here with the names of *Pythian* and *Archegetis* (founder), which points to a Delphic origin of the Greek colony.

On a topographic profile traced across the Hierapolis fault zone (Fig. 3a,b), the upper surface, at the temple of Apollo floor level, has a similar inclination as the surface of the main travertine plateau immediately to the west of the fault zone. Originally, the two surfaces were presumably continuous. The offset of this surface on the profile, is calculated at between 7.5 and 9.5 m. If one assumes a vertical throw of about 1.5–2 m for the whole fault zone since Roman times (i.e. $\leq$2000 years; Hancock & Altunel 1997), the fault would have a slip rate of 0.75 to 1 mm a^{-1}. At this rate, the total observed throw would have taken 10 100 $\pm$ 2600 years to develop.

Recent activity along the fault has migrated basinward inside the fault zone. A chasm in the earth that has opened at the *nymphaeum* at the base of the scarp (Figs 3a,b & 4a), opened as a consequence of the 1965 M = 5.7 Denizli earthquake (Prof. De Bernardi Ferrero, pers. comm., Director of the archaeological excavation at Hierapolis at that time). As at Plutonium, poisonous gases are emitted from this rupture.

The slaying of Echidna

Local legends contain reference to earthquakes and elements which specifically associate the original cult of Cybele with a chasm in the earth, as for instance in the Apocryphal 'Act of Philip' (e.g. Moraldi 1994). This story tells of the arrival of the Apostle Philip in AD 70–80 at Hierapolis and his martyrdom. His arrival is highlighted by two extraordinary phenomena: first the apparition of a dragon associated with a strong earthquake and lighting; and second, the opening of a deep 'abyss' in the earth in the middle of the city. This abyss is said to have swallowed 7000 men and the Viper (or Echidna)—the infernal snake-goddess which dominated the town at that time—a clear echo of the Phrygian mother goddess Cybele. The men were later rescued, but the Viper was left in the abyss. Just like the snake-dragon Python at Delphi, she had the chasm as her grave. This hagiographic tale, written about AD 300–330, is known to have reused pre-existing local legends (Moraldi 1994). As the events are referred to AD 70–80, it is therefore likely that this legend reworked memories of real natural events such as the destructive earthquake of AD 60, which is likely to have opened a long rupture along the trace of the main road, just in the middle of the town.

Colossae

Colossae is located at the SE end of the Denizli Basin where the main border faults of the basin converge and meet (Fig. 1b). The most evident structure is the active fault that crosses through Honaz (ancient Chonae) at the base of Mt Honaz, about 3 km south of Colossae (Fig. 5).

Colossae, located on the main road leading from Aegean Anatolia toward the East, is described by Herodotus (*Histories*, 7.30 1924) as a major town in 480 BC. It declined due to a change in

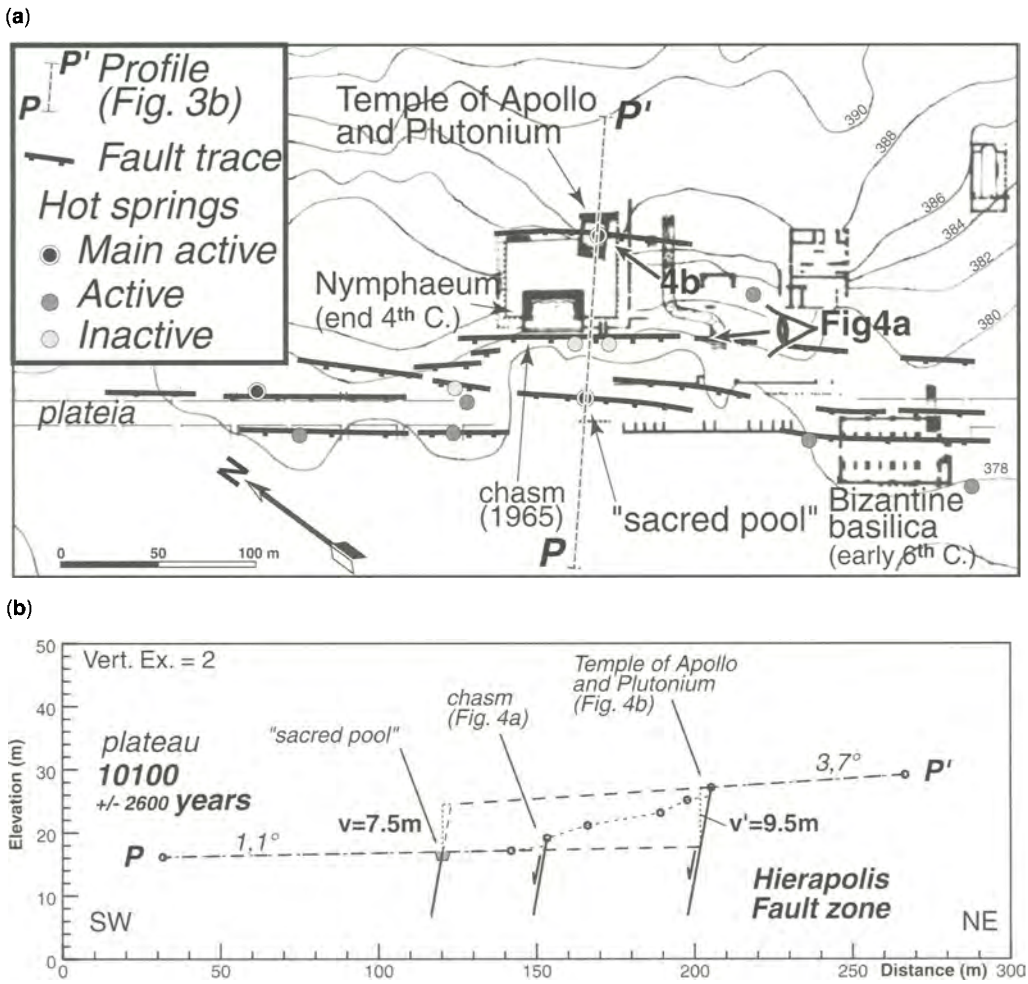

Fig. 3. (**a**) Map of the central area of the town (topography is from Peres 1987). (**b**) Topographic profile across the fault zone (location in Fig. 3a). The terrace, with lower inclination in respect to the average dip of the scarp, reveals movement being mainly concentrated on two faults: one lying under the temple of Apollo and the other one at the base of the scarp.

commercial road systems and the foundation of the nearby town of Laodicea, and finally it was completely destroyed by the AD 60 earthquake. After that, it survived only as a small village before being finally abandoned in eigth century, AD, replaced by Chonae (today Honaz, Figs 1b and 5; Bean 1971; Baysal *et al.* 1997). At present, the archaeological site is only a mound over the surrounding flat plain (Figs 5 & 6a).

The apparition of Archangel Michael

Tradition says (e.g. Bollandisti 1762) that pagans decided to destroy the sanctuary at Colossae where the local priest, Archippus, the eye-witness of the apparition, lived. To this end, they diverted a watercourse toward the temple, attempting to submerge the area. Invoked by Archippus the Archangel appeared and, striking the rock with his staff, opened a wide fissure in the earth and channelled a new path for the flowing waters. The name of the new settlement was derived from that fissure: Chonae (= funnel). This legend was strongly believed and the sanctuary at the site of the apparition became a famous destination for pilgrimages through centuries, until it was suppressed after the collapse of the Byzantine Empire (thirteenth century).

Today, there are no remains of the sanctuary and even its location is unknown. The area has not yet

Fig. 4. (**a**) Photo of the chasm opened after the earthquake of 1965 (the standing man between the walls of the 'nymphaeum' gives scale). (**b**) Temple of Apollo and Plutonium.

been subjected to systematic excavation, and lacks detailed archaeological data. Some authors think that the sanctuary was located near the present-day city of Honaz (Fig. 1b). Hamilton (1842), on the basis of direct observations made in 1836, maintained instead that the sanctuary may have been located slightly to the north of the ruins of Colossae, in the area of the necropolis (Fig. 6a). Our observations are more consistent with this latter hypothesis.

That this miracle may have been an interpretation of some unspecified, natural phenomenon is

Fig. 5. Colossae: panoramic view on area. Triangular facets of the Honaz active fault are highlighted.

accepted even in specific religious studies (Caraffa 1967). Although not stated in the text, the occurrence of a strong earthquake at the same time as the apparition is clearly suggested in the narration, and has thus been generally accepted. Many of the quoted elements in the original text of the legend (see Bollandisti 1762, in Greek and Latin) are in fact typical effects of earthquakes: (i) the indications of shakings ['*tremors*'] or of the shocked region ['*omnis commota regio*']; (ii) the 'sudden and horrible thunder-like sounds', and the 'loud voice' of the archangel; (iii) the extreme turbulence in the water bodies ['*diuque suspensa tremore quodam veluti trepidans in altitudinem quandam elevata est*']; (iv) the drastic change in the direction of flow in watercourses ['*redundantem fluviorum torrentium . . . retro avertit, perenniter in contraria fluxurum*']; (v) the occurrence of the relevant ground ruptures ['*hiatus*']. Finally, the archangel appeared to Archippus in the form of a huge 'column of fire, reaching from earth to heaven' ['*tamquam columna igea pertingens à coelum in terra*']. The scenario described in the legend would correspond to a large earthquake according to the scale proposed by Michetti & Hancock (1997), in agreement with the intensity of the AD 60 earthquake (Io = IX, Altunel 2000).

The text of the legend is maintained to have been fixed in written form by the seventh

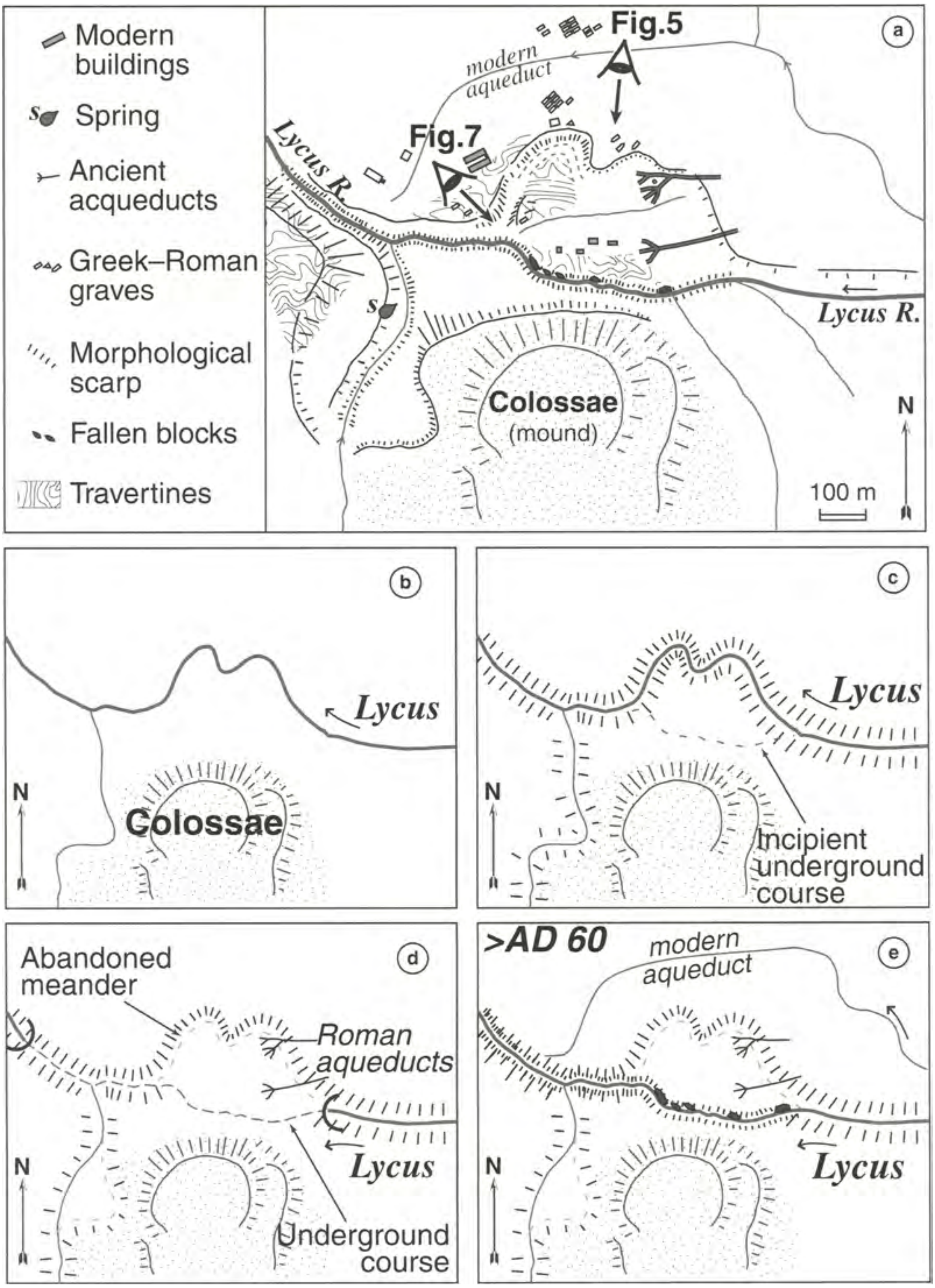

Fig. 6. (**a**) Schematic map of the area of Colossae. (**b**) Geomorphic evolution of the area: First stage: plain with meanders of the Lycus river. (**c**) Second stage: uplift of the area induces rejuvenation with incision of the meanders into the plain. An underground course starts developing; (**d**) Third stage: the Lycus river disappears into its underground course. Meanders are abandoned; (**e**) Fourth stage: the earthquake of AD 60 causes the collapse of the underground course's ceiling, opening the narrow part of the canyon.

century AD (Carletti & Otranto 1994), but the date of the apparition has not been clearly dated until now. Many ancient scholars (e.g. Bollandisti 1762) maintained that the apparition appeared between the sixth–seventh and the ninth century AD. However, most authors agree that the event happened in the first century (e.g. Caraffa 1967). We can constrain the date with fairly good approximation to AD 60 through two lines of historical evidence: the mention in the legend of Colossae as a big city capable of large hydraulic works, which necessarily limits the date to AD 60 when Colossae was destroyed; and the reference to Archippus as a guide of the recent Christian community at Colossae in two epistles of St Paul ('to the Colossians' and 'to Philemon', both dated to *c.* AD 61–62). The identification of the legendary earthquake as the AD 60 event is also reinforced by the convergence of hagiographic and secular descriptions of the earthquake. The huge 'column of fire, reaching from earth to heaven' observed by Archippus during the earthquake, and that marks the climax of the narration, corresponds to the important electrostatic phenomena (lightening) that was witnessed in the Denizli basin during the AD 60 earthquake and described in the seismological literature (e.g. Bonito 1691: 'three suns were observed').

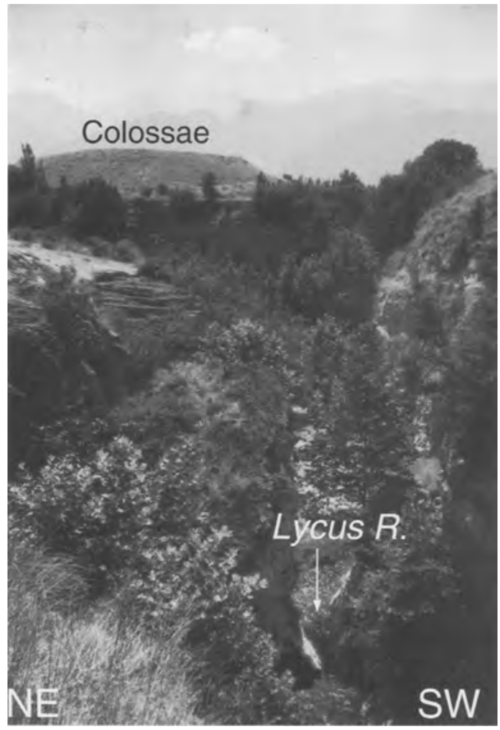

Fig. 7. Canyon of the Lycus River. The destruction by earthquakes of the tunnel of an underground course of the Lycus was also suggested by Hamilton (1842), as origin of this canyon.

Geomorphic evolution of the area of Colossae

Besides its thermal springs, Colossae was famous in the ancient world for a peculiar natural phenomenon: the underground course of the Lycus River. Herodotus (in the fourth century BC), Strabo and Ovid (both at the beginning of the first century AD), agreed that part of the course of the Lycus flowed underground, from Colossae to '5 stadia' (800–900 m) downstream, where it re-emerged. At present, the Lycus river near the ancient town flows in a narrow and deep gorge for a length of about 3.5 km. The narrowest sector of this gorge forms a deep canyon about 1 km long and some 10 m deep, incised due north of the city mound (Fig. 7). This canyon is partially filled with large blocks of rock fallen from the adjacent vertical cliffs (Fig. 7).

The morphology of the plain where the canyon is carved reveals an incised palaeomeander, which forms a closed depression with respect to the surrounding flat plain. This is the only floodable area near Colossae (Figs 5 & 6a). At the eastern margin of this area (upstream), the ends of ancient Roman aqueducts, which poured water into that closed area, are visible. At its west and north border, there is the necropolis where the sanctuary was located. All these elements occur in the legend and allow identification of the setting of the narration.

Piecing historical, legendary and field data together, it is possible to reconstruct the geomorphic evolution of the area. Initially, uplift of the Lyeus river meander plain (Fig. 6b) caused fluvial incision (Fig. 6c). As uplift continued, the Lycus straightened its course cutting an underground channel (Fig. 6d), which was probably facilitated by the presence of a minor fault with travertine deposits above it. The earthquake of AD 60 caused the collapse of the ceiling of the underground course of the Lycus, giving the area its present aspect (Figs 6e & 7).

The interpretation proposed above is in accordance with the iconography of the Michaeline apparition in Colossae, which shows the crumbling of the ceiling of an underground cavity (Fig. 8). Such a dramatic collapse in the AD 60 earthquake, which was probably accompanied by an eruption of gases ignited by friction, was probably the origin of the legend.

Fig. 8. Archangel Michael appears to Archippus, at Colossae (fourteenth century icon, Museum of Novgorod).

Concluding remarks

The interdisciplinary study of the legends and myths related to the archaeological sites of Hierapolis and Colossae shows that we can interpret the information contained in documents derived from the oral tradition as codified descriptions of real geological phenomena and historical events. Following this approach, it is possible to recover important information to further our understanding of the active tectonics of the area.

The AD 60 earthquake appears to have created the setting for two different legends in the two most affected areas: the apparition of Archangel Michael at Colossae, and the slaying of Echidna at Hierapolis. These legends are the only reference documents in existence today that give accounts of the local geomorphic coseismic effects. They are therefore potentially valuable historical and geological sources of information on the area. The earthquake appears to have induced relevant surface effects both at Hierapolis and at Colossae. This indicates that the whole fault system of the eastern border of the Denizli basin may have been activated in that event, in agreement with the damage area of that earthquake (Fig. 1b).

The understanding of the geological events also provides new insights for historical research. Apollo and Michael are similar figures in their iconography: Michael crushing the Dragon corresponds with Apollo killing the snake-dragon Python. Apollo and Michael show similarities also in the geological setting of their most famous sanctuaries, Delphi in Greece and Monte Sant'-Angelo in Italy, for both sanctuaries appear to have been positioned above seismic ground ruptures (Piccardi 2000, 2005).

Both cults, largely diffused in the Mediterranean, appear to have been derived from this same area. Apollo is generally considered to have entered the Greek pantheon deriving from Aegean Anatolia (Maddoli 1977), and here he had Hierapolis of Phrygia as its particularly sacred town. The cult of Archangel Michael, in its modern aspect, may also be traced back to its origins in Phrygia (western Anatolia) before the fourth century AD (Carletti & Otranto 1994). Michael, is in fact reported to have appeared at Colossae before eye-witnesses for the first time in the Christian era, and from there the cult spread (Carletti & Otranto 1994).

The cult of Archangel Michael appears to have derived from the ancient Jewish 'worship of angels' which is said to have been particularly intense in Colossae. The so-called 'Colossian heresy' was a local syncretism, that is a mixture of Jewish and native pagan elements. Its teachers worshipped intermediary spirits, angels, seen as personifications of natural elements and forces, and insisted on a very strict asceticism.

There is a passage in St Paul's Epistle to the Colossians that has always puzzled historians and philologists, who refer to it as 'most enigmatic'. It is the final recommendation to Archippus (Col. 4.17): 'And say to Archippus, "Take heed to the ministry, which you have received in the Lord, that you may fulfil it".' According to historical research (Lightfoot 1875; Dunn 1996), Archippus, the eye-witness, had converted to the new Christian faith only in AD 54–57, just a few years before the claimed apparition. In the description of his life given by the legend, we can recognize elements typical of the Hellenistic religion (Archippus, originally a citizen of Hierapolis, had started service in religion at 10 years old, as was usual at the temple of Apollo) and Jewish regulation (food restrictions). The legend may therefore be regarded as a Christian re-conversion into the cult of Michael of the syncretistic worship of the Angels known as the 'Colossian heresy'. The cult of Apollo, so important in this area, may have played a key role, providing the cultual connection with the opening of chasms in the earth.

At Hierapolis, the coincidence between the positioning of the main cult-site directly above the active fault is similar to that observed at Delphi and at Monte Sant'Angelo as well as in many other sanctuaries in the ancient world (Piccardi 2001). It is therefore likely that, together with the natural gas emission from the fault inside the Plutonium, the fault itself was venerated and regarded as a material opening to the underworld.

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Writing on the walls: geological context and early American spiritual beliefs

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Abstract: Native American culture in many parts of California is preserved in fragmentary oral and conventional written histories, but also in sometimes dramatic petroglyphs and pictographs throughout the state. The symbolism of these images has been interpreted to reflect the natural environment, in particular issues related to rain. Although there is little doubt that rain was of paramount concern to native tribes, I suggest that geological context also played an important role in shaping early spiritual beliefs in general, and petroglyph sites in particular. From the standpoint of Native American philosophies and spiritual beliefs, geological unrest is not merely a reflection but in some cases an actual embodiment of the spiritual world. To understand the significance of petroglyph sites, they must be considered in the context of overall Native American beliefs. In this context, sites of repeated geological unrest would invariably have evolved great spiritual significance. Petroglyph locations and ages may thus provide independent age controls on 'prehistoric' earthquakes in California.

Petroglyphs: history and conventional interpretations

The conventional history of California dates back only to the late eighteenth century: the 1769 Gaspar de Portola expedition was the first land exploration of present-day California by people of European descent. However, the usual distinction 'historic' versus 'prehistoric' reflects an immediate bias: for thousands of years before 1769 California was inhabited by native tribes who (it is generally believed) first immigrated to North America along a Bering Strait land bridge.

Early California tribes left behind no conventional written history. However, they did leave their mark on the land itself: intriguing and sometimes intricate art painted or etched onto rock (Whitley 1996). Rock art comprises two distinct forms: petroglyphs, which are etched into rock (and sometimes painted as well), and pictographs, which are only painted. The former are less easily erased by weather and erosion. Petroglyphs and pictographs were a nearly ubiquitous form of expression among cultures with no tradition of conventional writing (e.g. Moore 2003). Drawing on the expertise of living tribe members, archaeologists have pieced together explanations for the sometimes intricate symbology (Patterson 1997; Moore 2003).

Clearly, rock art represented a complex form of expression and served more than one function. The practice was strongly associated with shamanism: the traditional medicine men who were considered to have the ability to commune with supernatural powers (e.g. Hedges 1976, 1992; Whitley 1992, 1996). The tradition of the shaman's trance, generally induced by natural hallucinogens such as native tobacco, is also well established. Anthropologists have shown that the response of the brain in trances is essentially 'hard-wired'; a function of humanity rather than local culture (Lewis-Williams & Dowson 1988). According to modern research, people in trances experience four types of reactions including both audible and visual hallucinations. Moreover, the latter tend to fall into several established categories, including wavy or parallel lines, nested curves, and spirals.

The brain is essentially programmed to visualize certain patterns: the rock art of native California peoples was inevitably also shaped by their culture. Zigzag lines, one of the most common patterns found in rock art, can be understood in terms of the 'neurophyschological' model (e.g. Lewis-Williams & Dowson 1988), yet were often imbued with a culture-specific meaning, in particular related to snakes and serpents.

Snakes and serpents, in turn, were commonly associated in many early cultures with unrest within the earth. In legends of the Mogollon culture in southern New Mexico and northern Mexico, the Horned Serpent is at times fierce and punitive, and is credited for causing both floods and earthquakes (Schaafsma 1980). Ludwin *et al.* (2005) suggest that reports of the AD 900 Seattle earthquake were handed down for 1100 years by storytellers, in the form of stories about a horned

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water-serpent said to have lived near the Seattle fault. At Nanaimo Petroglyph Park in British Columbia are images of the Kwakiutl Sisiutl, a double-faced serpent with a snout resembling that of sea snakes (Moore 2003).

'Wiggly line' motifs are also interpreted in other ways. Whitley (1996, 2002) interprets wiggly lines in California petroglyphs in terms of 'rain shamanism': spiritual beliefs centred around rain-making.

Shaman sometimes travelled considerable distances to reach locations that were strongly associated with supernatural powers (Whitley 1996). Historical evidence documents the pilgrimages made by shaman from as far away as northern Utah to one of the most famous petroglpyh sites in the Coso area on the eastern side of the Sierra Nevada. Shaman had many reasons for seeking communication with the sacred realm, including rain-making, curing (and maybe sometimes causing) illness, and commemoration of puberty rites (e.g. Oxendine 1980). In arid desert regions in California and the Southwest, surviving legends—and rock art—invariably portray drought as the natural hazard of prime concern.

But if the archeologists' understanding of California petroglyphs focuses on the spiritual, the seismologist considering a map of sites in the state cannot help but be struck by a different thought: many of these sites are close to especially seismically active parts of the state.

Is it possible that California's earliest inhabitants left writing on the wall in response to California's earliest historic earthquakes? That rock art is found close to faults is not in itself surprising, as, to a fair approximation, rocks in California are found in proximity to faults. Away from the state's fault-controlled mountains, are valleys and basins filled with sediments that have washed down from higher elevation over the ages. With this caveat in mind, in the following sections I summarize the petroglyphs and other lore from several specific regions in California (Fig. 1). I then move on to discuss these sites in the context of overall Native American beliefs, in particular with respect to the natural environment.

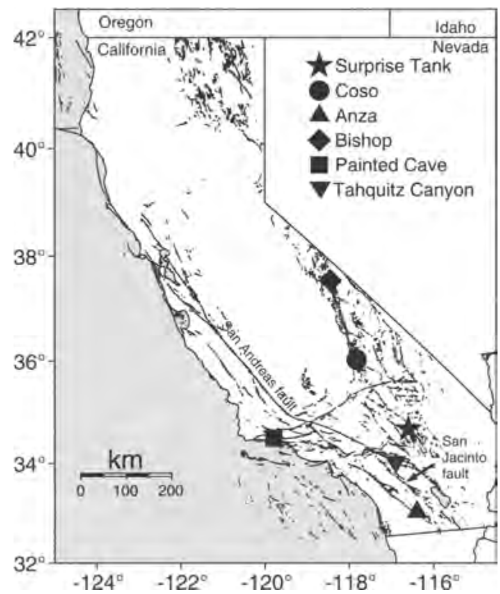

Fig. 1. Map of California petroglyph and pictograph locations discussed in this paper. The Little Blair Valley petroglyph site (upward triangle, 'Anza') is within the larger Anza–Borrego region. Active faults are also shown (Jennings 1994).

Coso

The Coso region is known for a high current rate of earthquake activity in modern times and volcanic activity in recent geological times. Although the last eruption was several thousand years ago, underground magma still exists close enough to the surface to generate an economically exploitable source of geothermal energy (Austin 1978). The ongoing volcanic processes in turn give rise to high rates of earthquake activity as well as obvious manifestations of active geothermal processes. Coso experiences one of the highest rates of potentially felt (magnitude 3+) earthquakes of any place in California; very typically earthquakes will occur in swarms of hundreds of events. Six moderate earthquakes, with magnitudes of 5.0–5.8, struck in or near Coso during the 1990s; in this same time period nearly 300 earthquakes of magnitude greater than 3.0 occurred near enough to Coso to be felt there.

Still, the existence of a correspondence between two phenomena is not enough to demonstrate a cause-and-effect link. To argue for a causal relationship requires evidence beyond a simple correspondence.

Some petroglyphs are strongly suggestive of unrest within the earth (Figs 2, 3). Interestingly, the shamans shown in (Fig. 2) are notably common in the Coso area. Patterson (1997) refers to such figures as 'patterned body anthropomorphs', and notes that they are found commonly in Coso and in the northern Sonora desert in Mexico; shaman pictographs from other regions are not commonly adorned with such elaborate internal patterns. Whitley (2002) interprets the figures as 'rain shamanism' because drought was of paramount concern for tribes throughout the arid Great Basin. As he notes, however, this begs the question of

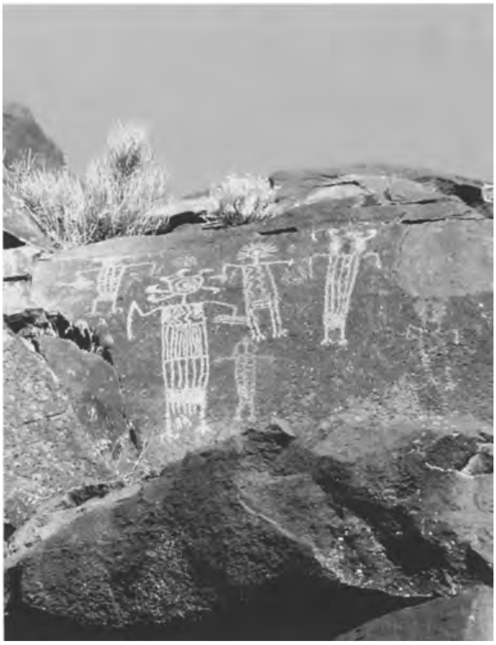

Fig. 2. Patterned-body anthropomorphs (shaman figures) at the Coso site.

why an 'immense concentration of rain-shamanism rock-art [would be found] within the Coso Range, an arid landscape west of Death Valley, the driest spot in the Great Basin'. Noting that 'coso' translates literally as 'fire,' Whitley suggests that the region became associated with rain because of 'symbolic inversion'. Symbol rituals operated on the principle of inversion. He argues that shaman journeyed specifically to this markedly arid region to 'find the most verdant aspect of the supernatural and, from this experience, to make rain in the natural world'.

Fig. 3. A petroglyph at the Coso site that appears to depict volcanic activity. The central image in particular is suggestive of steaming or erupting ground, with lava flowing towards the right. The overturned anthropomorphic figure and pot are further suggestive of effects of an eruption on human settlement. (To the author's knowledge, this is the only anthropomorphic figure of many in the area that is not drawn upright.)

However, the translation of the word 'coso' suggests a more direct interpretation. The Coso volcanic field consists of Pliocene to Quaternary rhyolite domes and basaltic cinder cones covering 150 square miles (Duffield 1975). The most recent eruption of Red Hill, just west of Coso, was 10 000–14 000 years ago; a small flank eruption may have occurred as recently as 400 BP (Lanphere *et al.* 1975). Humans first arrived in the region between 10 000 and 20 000 years ago (e.g. Gilreath & Hildebrandt 1997); it is thus likely that the earliest human settlers in the Mojave Desert would have stumbled across active volcanism, leading to a name meaning 'fire'. Even today, the Coso region exhibits obvious manifestations of an active geothermal region, such as boiling mud pools. Native Americans in the region today, descendents of earlier tribes, speak of an association between the ongoing geological unrest and the spiritual significance of the region (David Garboni pers. comm., 2004). Following this line of reasoning, the squiggly lines within the Shaman figures still represent symbolic communication with the supernatural, but via 'volcano shamanism', or perhaps 'earthquake shamanism', rather than 'rain shamanism'.

One can appeal to several possible explanations for why patterned body anthropomorphs are also found in northern Sonora. The area also experiences strong earthquakes, for example a large (M7+) earthquake in 1887 (e.g. Sbar & Dubois 1984). Art styles can also simply be imported from one region to another. However, such explanations are speculative. The key point is that these distinctive petroglyph styles are abundant in the Coso area in particular and not found commonly, if at all, in other regions.

Surprise Tank

The Surprise Tank petroglyph site represents a substantial concentration of rock art in the Mojave Desert. This site is extremely remote: about 30 km SE of Barstow (population 21 000) and 30 km SW of Ludlow (often regarded as a 'ghost town'.) At the Surprise Tank site there is a remarkable concentration of 'wiggly line' motifs, with relatively few of the symbols, such as sheep and shamans, that are found commonly at other petroglyph sites. These wiggly lines are both vertical (Fig. 4) and horizontal (Fig. 5). As previously discussed, early cultures commonly use 'wiggly line' motifs to

Fig. 4. An example of the prominent 'wiggly line' motifs found at the Surprise Tank site in the Mojave desert.

Fig. 5. A second example of a wiggly line motif at Surprise Tank. The seismologist notes an intriguing similarity to a modern seismogram.

represent snakes and serpents; snakes and serpents are, in turn, commonly associated with geological unrest.

The location of the site is approximately 5 km from the northern end of the 1992 Landers rupture (Fig. 6). Geological investigations reveal the penultimate rupture on these faults occurred 5800 years BP (Rockwell *et al.* 2000), which also overlaps with the period of human habitation at this site. The oldest dated petroglyphs at Surprise Tank are estimated to be about 10 000 years old (Whitley 1996).

The strongest recorded shaking during the 1992 Landers earthquake, 798 cm s^{-2}, occurred at station LUC, about 5 km from the Surprise Tank site. Shaking of this severity is associated with Modified Mercalli Intensity IX: strong enough to cause serious damage to well-built masonry structures and substantial liquefaction and other ground failure. In prehistoric times, this level of shaking—along with the energetic aftershock sequence that would invariably have followed—would almost certainly have been a profound event, and one that would probably have been interpreted in spiritual terms. Moreover, both geological evidence (Rockwell *et al.* 2000) and recent history suggests that large Mojave Desert earthquakes are clustered in time. Common sense suggests that a succession of large earthquakes would have likely made an especially indelible impression.

Owen's Valley

Four petroglyph sites are located east of Bishop, in Paiute territory just south of Long Valley Caldera.

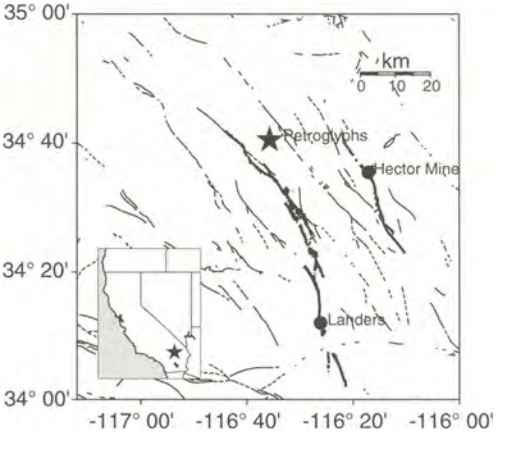

Fig. 6. Map showing the location of the Surprise Tank site as well as the mapped surface ruptures (dark lines) and epicenters (circles) of the 1992 M7.3 Landers, California and 1999 M7.1 Hector Mine earthquakes. Mapped faults are also shown (light lines).

These sites (access to which remains restricted) include the Chidago site, where 'the majority of the motifs ... are entoptics, the geometric patterns perceived during the initial stage of a shaman's trance' (Whitley 1996). Because these petroglyphs were inscribed on volcanic tuff, a relatively soft rock that is easily eroded, the petroglyphs are thought to be of relatively recent origin: about 1000 years, or less.

Again, this overlaps with periods of known, significant volcanic unrest. The caldera-forming eruption of Long Valley, just north of Bishop, occurred approximately 760 000 years ago: however, Long Valley has remained volcanically and seismically active through to recent Holocene times (e.g. Bailey 1989). Smaller eruptions have occurred within the last 600 years, including lava flows and more explosive eruptions (Miller 1985). These recent eruptions occurred towards the NNW side of the caldera; but, in recent decades, the region to the SSE of Long Valley has been highly active seismically (e.g. Hill *et al.* 1985). Savage & Clark (1982) showed that this seismic activity can be explained as a response to deep magma movement within the caldera. Thus, the Bishop petroglyphs are concentrated in a region that experiences high rates of earthquake activity in response to ongoing volcanic processes at Long Valley.

Anza–Borrego

Petroglyph sites abound within the Superstition Mountains and their environs. Many of them are intricate and evolved. Rock art sites are so abundant in the Superstition Wilderness area that some scholars have proposed that native peoples in this region simply had a great deal of free time on their hands. Although this explanation is discredited by serious archeologists, it does testify to the prevalence of features in this area.

As summarized by Knaak (1988), distinct styles of rock art are found in the Anza–Borrego area. To the NNE of the modern town of Borrego Springs one finds the so-called western petroglyph style that is found throughout much of the Great Basin and Southwest. A distinct San Luis Rey style is found to the WNW of Borrego Springs, in regions once inhabited by the Northern Diegueno tribe. This art dates from about 1500 AD. The San Luis Rey style is characterized by rectilinear motifs primarily in red, including vertical rows of chevrons, dots, Xs, zigzags, and diamonds. The well-known Little Blair Valley site within Anza–Borrego Desert State Park contains multiple panels and motifs, predominantly combinations of zigzag lines and diamond chains.

The Anza–Borrego region has experienced a high rate of large earthquakes over at least the last 10 000 years. The Little Blair Valley is located within a region that is more broadly known as 'Earthquake Valley' (For example, this is the name of the USGS 7.5' topographic quad of the region). The Superstition Mountains are almost literally surrounded by active faults, including the San Jacinto fault system, one of the most active faults in California. According to the most recent scientific investigations, the San Jacinto and southern San Andreas faults are the two dominant plate boundary faults in this region. Somewhat surprisingly, it is possible that these two faults might now experience comparable strain rates (Anderson *et al.* 2003). The San Jacinto fault may experience relatively more frequent, but somewhat smaller shocks than the southern San Andreas fault (Wesnousky 1994). In recent years, the single most active fault in California, at least as measured by the rate of magnitude 2–6 earthquakes in recent decades, has been the San Jacinto fault. As was the case at Coso, the correspondence is striking: abundant earthquakes, abundant petroglyphs.

Earthquake iconography in other cultures

The suggestion of 'earthquake iconography' in California rock art is by no means without precedent. Earthquakes and other natural phenomenon feature clearly in the iconography of other cultures where geological unrest is common. In central and northern Mexico, pictorial codices are known to depict not only earthquakes but also in some cases to indicate the number of events and dates (see Kovach 2004, for a recent summary).

Other dramatic natural phenomena were clearly interpreted as spiritual signs in other cultures, and depicted in rock art and other forms of iconography. Comets were commonly viewed in spiritual terms in early cultures (e.g. Sugden 1995). Solar eclipses were also interpreted in this manner: among the Tewa peoples of the Rio Grande solar eclipses were interpreted as a sign that the Sun Father had moved farther away from the Earth out of displeasure with human behaviour (Williamson 1987). Masse & Espenak (2006) discuss the connection between natural phenomena, in particular solar eclipses, and the iconography of the early Hohokam culture of the American Southwest. Because dates of past eclipses can now be determined with precision, it is possible to compare in detail the correspondence between specific eclipses and cultural imagery (Masse & Soklow 2005). It might be possible to investigate such correspondences for the sites discussed in this paper, although such an approach would be complicated by an imperfect record of past geological events as well as, in some cases, the fact that geological unrest at locations such as Coso is often persistent rather than strongly episodic.

Echoes from the past: surviving oral traditions

Interpretations of rock art are inevitably subjective, the aforementioned correspondences notwithstanding. However, in some cases one can also consider surviving oral traditions. These include stories told by the Southern Diegueno tribe, for whom the Superstition Mountains featured prominently in their oral traditions (Strand 1980). The very name of the mountains reportedly resulted from an earthquake that occurred during a ceremony by ancient tribe members. Other legends describe moans and terrible sounds emanating from the caverns at the base of the mountains. These caverns were believed to be the home of a great and evil serpent that changed the very face of the mountain with his writhings. (Here again one finds the association mentioned earlier: snakes and quakes).

The creation myth of other tribes, including the Northern Diegueno and Kumeyaay, also incorporated earthquakes. In these stories, the world was formed by two brothers, Tuchaipa and Kokomat, who sought to create man out of yellow clay. Unable to create figures as successfully as his brother, Kokomat returned to the earth beneath the sea, where he was said to create earthquakes as he moved about (Knaak 1988).

The roots of the Cahuilla Indians trace back to the Palm Springs area. Their legends describe Tahquitz Canyon, at the foot of Mount Tahquitz just south of Mount San Jacinto, as the home of the spiritual being Tahquitz. According to legend, Tahquitz is immortal and malevolent, stealing the souls of young women who dare venture too far into the canyon at night: his growlings account for the rumblings sometimes heard emanating from the mouth of the canyon. One version of the 'Tahquitz legend', published in 1950, mentions an earthquake explicitly:

> No sooner had her lips sounded the last syllable of the feared name (Tahquitz), than there was an explosive-like rumble from the direction of Tahquitz Canyon. It grew steadily louder until it became a deafening roar. The earth shook and quivered underfoot. Rocks tumbled loose and started landslides. Clouds of dust curled into the overhead darkness (Smith 1950).

Almost all of the petroglyphs within Tahquitz Canyon have been erased by vandalism, but surviving remnants of one prominent image near the mouth of the canyon appear to depict a large shaman and a snake.

Like Anza–Borrego, Tahquitz Canyon is surrounded by active faults, most notably the San Andreas fault to the north and the San Jacinto fault to the south and west. Fumal *et al.* (2002) present evidence that 4–5 surface-rupturing earthquakes occurred along the Mission Creek strand of the San Andreas fault in the last 1200 years. The most recent large earthquake appears to have been in the late seventeenth century (Sieh & Williams 1990). Sieh & Williams (1990) preferred date for the most recent event is 1676 $\pm$ 35 years. Interestingly, this is close to the inferred date of the most recent Cascadia megathrust event (Satake *et al.* 1996): it is thus reasonable that an earthquake might figure as prominently in the present-day Tahquitz legend as does the 1700 Cascadia event in present-day Pacific Northwest oral traditions.

A final observation is that the competent granitic rocks of the San Jacinto mountains are a known 'high-Q' environment (Hough & Anderson 1988): potentially audible high frequency energy generated by earthquakes on the San Jacinto fault will travel efficiently between in this environment, consistent with reports of audible rumblings and 'moanings'. A journalist who lives near the mouth of Tahquitz Canyon reported that earthquakes are very commonly heard before they are felt (David Garcia pers. comm., 2004).

Although earthquakes are not a major theme in the legends and stories of native California tribes, surviving stories, such as those discussed above, indicate that earthquakes were a familiar part of life for these peoples. Ludwin (2002) reaches a similar conclusion about oral traditions from the Pacific Northwest region of North America.

Geological unrest and spiritual beliefs

Although 10 000 years is a very long period of time by cultural standards, it is a very short period of time by geological standards. It is therefore likely that California's earliest residents experienced earthquake rates that were similar to those seen in recent times. The duration of human habitation in prehistoric times was much longer than the short historic record in California, spanning several thousand years that are known to have included a cluster of earthquakes in the Mojave Desert and active volcanism at Coso, as well as many major earthquakes on the San Andreas fault.

Clearly, no one explanation can possibly account for all rock art in California, or anywhere else. These drawings had complex and disparate purposes, perhaps practical as well as spiritual. But it cannot long escape the attention of any resident of California that they are living in earthquake country. Indeed, the Portola expedition experienced a series of earthquakes near present-day Santa Ana in 1769.

Further, geological unrest has been interpreted in spiritual terms in more modern, 'western' cultures as well. Through historic times in western civilization, earthquakes such as that in 1755 in Lisbon, which struck on the morning of All Saint's Day, were commonly interpreted in spiritual terms, typically, 'signs from God'. (John Wesley, credited as the founder of the Methodist Church, preached famously that 'earthquakes are the works of the Lord'. See http://www.segen.com/wesley/sermon04.html).

It would be more surprising if earthquakes, and other attendant phenomenon, did not figure prominently in the oral traditions and spiritual beliefs of native tribes. This inference may appear speculative, but it is also important to consider petroglyphs in the context of the overall Native American view of the natural environment. The association of seismic and volcanic unrest with spiritual forces is a common theme among earlier (and sometimes recent) legends and stories. In the State of Hawaii, traditional cultures have remained part of the modern cultural fabric to a greater extent than native cultures have in California. In Hawaii, one does not need to resort to inference to interpret native stories and petroglyph sites. Stories from a still-vibrant culture link the prominent gods with the Island's volcanoes. At the Pu'u Loa site on the flanks of Kilauea volcano one finds the largest concentration of rock art anywhere in Hawaii: over 20 000 separate petroglyphs of human, animal, and geometrical form (Lee & Stasack 1999).

The Pu'u Loa site perhaps illustrates how locations of pronounced volcanic unrest were naturally (one is tempted to say 'invariably') interpreted as sites of spiritual significance. The petroglyphs themselves may not be directly linked to geological unrest, and the specific location of the Pu'u Loa site might have been chosen for practical reasons. In a broader sense, however, the active volcano was—and still is—viewed as a portal to the supernatural world by virtue of its geophysical attributes. This view of sacred sites is expressed by Versluis (1992), who describes current philosophies:

> We have discussed in an earlier context how certain places manifest special power. There are translucent places through which the spiritual landscape is particularly visible: petroglyph sites, for instance, or sacred mountains. These sites are particularly sacred because there the spirit realm is closest to the human world.

Lake-Thom (1997) further illuminates the view of sacred sites:

> . . .some of the larger mountains, such as Mount Shasta and Mount Saint Helens, were not used for vision quests and power training by indigenous people not because the Indians lacked sophisticated mountain climbing skills, but because they 'knew exactly what kind of power was there and the reason it was there.' 'Native people recognized certain mountains not as the home of spirits and gods but as a giant spirit in the hierarchy of Earth spirits. My elders have taught me that such places are where the Great Creator resides from time to time'.

Lake-Thom further notes that the conventional western interpretation of Mount Saint Helens focuses on geological unrest, whereas the Native American view focuses first on 'why the power centre is powerful *per se*'. In this view, all power centres have a 'specific purpose and function'. He further distinguishes shaman as uniquely able to connect with spiritual power, whereas most people cannot.

Intriguingly, the above passage from Lake-Thom (1997) is reminiscent of the Bible passage, Exodus 24: 16–17: 'The presence of the Lord abode on Mount Sinai, and the cloud hid it for six days. On the seventh day He called to Moses from the midst of the cloud. Now the Presence of the Lord appeared in the sight of the Israelites as a consuming fire on the top of the mountain'.

Considered in the context discussed by Lake-Thom (1997), sites of persistent geological unrest represent not only a portal to the spiritual world, but in some cases nothing less than an embodiment of it. A modern scientific view distinguishes Mount Shasta and Mount Saint Helens as two of the larger, more active volcanoes in the Cascadia chain: the Native American view distinguishes them as the incarnation of the Great Spirit. This leads to the 'speculative' conclusion expressed earlier: the spiritual significance of sacred Native American sites was inexorably intertwined with (literally 'rooted in') their geological settings. Indeed, in the context of Native American beliefs, the view is not that 'spiritual significance stems from geological unrest', but rather that 'geological unrest stems from spiritual significance'.

Having reached this conclusion, it appears that in some cases, California's surviving petroglyphs and pictographs represent a written record of 'prehistoric' earthquake and volcanic activity. This hypothesis could be tested further by comparing dates of petroglyphs at sites such as Coso and Surprise Tank with the timing of volcanic/earthquake activity as estimated from geological investigations.

If the results of such comparisons supported the hypothesis, rock art locations might provide clues to previously unrecognized 'prehistoric' activity. One intriguing site, for example, is found in the Sierra de San Francisco in Baja California. Described in detail by Crosby (1997), the Cueva de la Serpiente site features a remarkable mural approximately 8 m in length: a horned serpent feature around which 50 human and animal figures are positioned. 'The small figures do not interfere with the movement of the large one; indeed, their placement creates an odd, rocking effect that enhances the apparent weaving of the serpent' (Crosby 1997). Crosby goes on to note that, compared to the usual style in which animals are drawn very simply and literally, 'The conception of the serpents is astonishing. In any context these eared, antlered, and fork-tailed monsters would seem bizarre and fanciful concoctions. In the land of the Great Murals, where animals regularly have literal outlines, they are downright iconoclastic'. Crosby further notes that in front of this cave, the arroyo, which is aligned generally north–south, makes a sharp bend east and then in 183 m makes another sharp bend to continue to the north—a description that is tantalizingly suggestive of an east–west trending strike-slip fault.

A second intriguing site is the Chumash Painted Cave Pictographs just north of Santa Barbara, California. The painted panels are thought to be recent, no more than 1000 years old, and are dominated by dramatic geometric motifs in which snake images figure prominently (Whitley 1996). Whitley likens two shaman figures at the site to the patterned-body anthropomorphs found at Coso, and discusses the strong undercurrent of supernatural themes evident in these and other paintings at the site. In this case, the site is located almost directly on top of a known active fault: the Arroyo Parida fault, part of a larger system of east–west trending left-lateral faults that run along the southern flank of the Santa Ynez Mountains (Jennings 1994).

Like many faults in California, the Arroyo Parida fault is active but little is known about earthquake occurrence on the fault through the Holocene. Rock art sites such as Painted Cave, as well as Cueva de la Serpiente and others, may in fact represent a previously unrecognized historic record of earthquake (and volcanic) activity during the Holocene, and may thus help point scientists to particular fault locations where further field investigations are warranted. I note in closing that petroglyphs and pictographs represent a written record, albeit an unconventional one. The conventional distinction of 'historic' versus 'prehistoric' thus represents an inherent—perhaps outdated–cultural bias.

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The Fenris Wolf in the Nordic Asa creed in the light of palaeoseismics

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Abstract: The Nordic Asa Creed talks about a giant wolf, 'the Fenris Wolf', that was trapped and chained deep in the mountains. When he howled, the ground trembled violently and fractured. With the discovery of frequent high-magnitude palaeoseismic events in Sweden not only in de-glacial time but also in Late Holocene time, it seems both natural and logical that the Fenris tale refers to frightening earthquake events in the past. Once again tales and sagas have been shown to be rooted in facts.

In ancient times, natural phenomena were usually explained in terms of actions by gods. Phenomena such as earthquakes and volcanic eruptions were directly frightening; so too were ordinary phenomena like thunderstorms.

In the Norse mythology or the Nordic Asa creed, there are many examples of this. Thunderstorms were explained by the noise created by the god Thor throwing his hammer. The land uplift was explained by the giant Ymer slowly rising out of the sea. The end of our world—'Ragnarök' in the Asa crede—is described as a most terrible event when the ground fractures and rocks fragments are thrown higgledy-piggledy, like at a violent earthquake. Grant (2003) concludes that recent observations indicate that 'some of the tales were firmly rooted in fact'.

The Asa Creed originates in pre-Viking time. The mythological chronology given suggests that Odin and Thor arrived at Svealand in Late Iron Age and formed a new dynasty 'Ynglingaätten'. However, there is no discontinuity in the cultural evolution to account for this. On the contrary, there is continued cultural evolution back in time, to at least the Bronze Age and possibly even into the late Stone Age. The oldest place names owe their origin in the Bronze Age. The Asa Creed was written down in the thirteenth century AD by people on Iceland in their famous Edda (as recently reviewed by Grant 2003).

The Fenris Wolf

The god Loke had a son with the giantess Angrboda. The child took the form of a giant wolf—the Fenris Wolf—and became a threat even to the gods themselves (e.g. Grant 2003). Finally, the Fenris Wolf threatened to destroy the whole world. By magic, he was captured and chained deep in the mountains. When he howled, the ground and mountains trembled violently and deep fractures formed and rock fragments were thrown around.

Today, one might say; what a perfect description of a high-magnitude earthquake. Until recently, earthquakes above magnitude 5 on the Richter scale were not known from Sweden. Therefore, no one proposed a seismic origin for the story of the Fenris Wolf. It was simply sidelined as something less interesting. However, in recent years the situation has changed (Mörner 1994, 2003).

The new concept of a high palaeoseismic activity

During the last three decades, it has become increasingly clear that Sweden was subjected to strong seismic activity at the time of deglaciation some 9000–11 000 radiocarbon years BP. From the notion that 'big earthquakes rather were the rule than the exception' (Mörner 1985), there is an extensive palaeoseismic database (catalogue) including 54 magnitude 5–8 events (Mörner 2003). This catalogue even includes several magnitude 7 or 6–7 events in Late Holocene time, i.e. at times when they may have influenced not only the Norse mythology but also ancient place names (Mörner 2003; Mörner & Strandberg 2003).

As Swedish palaeoseismicity has been presented elsewhere (Mörner 2003, 2004, 2005) this paper focuses on the Late Holocene events and their possible influence on place names, mythology and tales.

In the last 5000 years, nine high-magnitude palaeoseismic events are recorded (Fig. 1). All these events are likely to have affected human life physically as well as spiritually. Effects such as faulting, fracturing, ground shaking, earth slides, tsunami waves, would have had considerable

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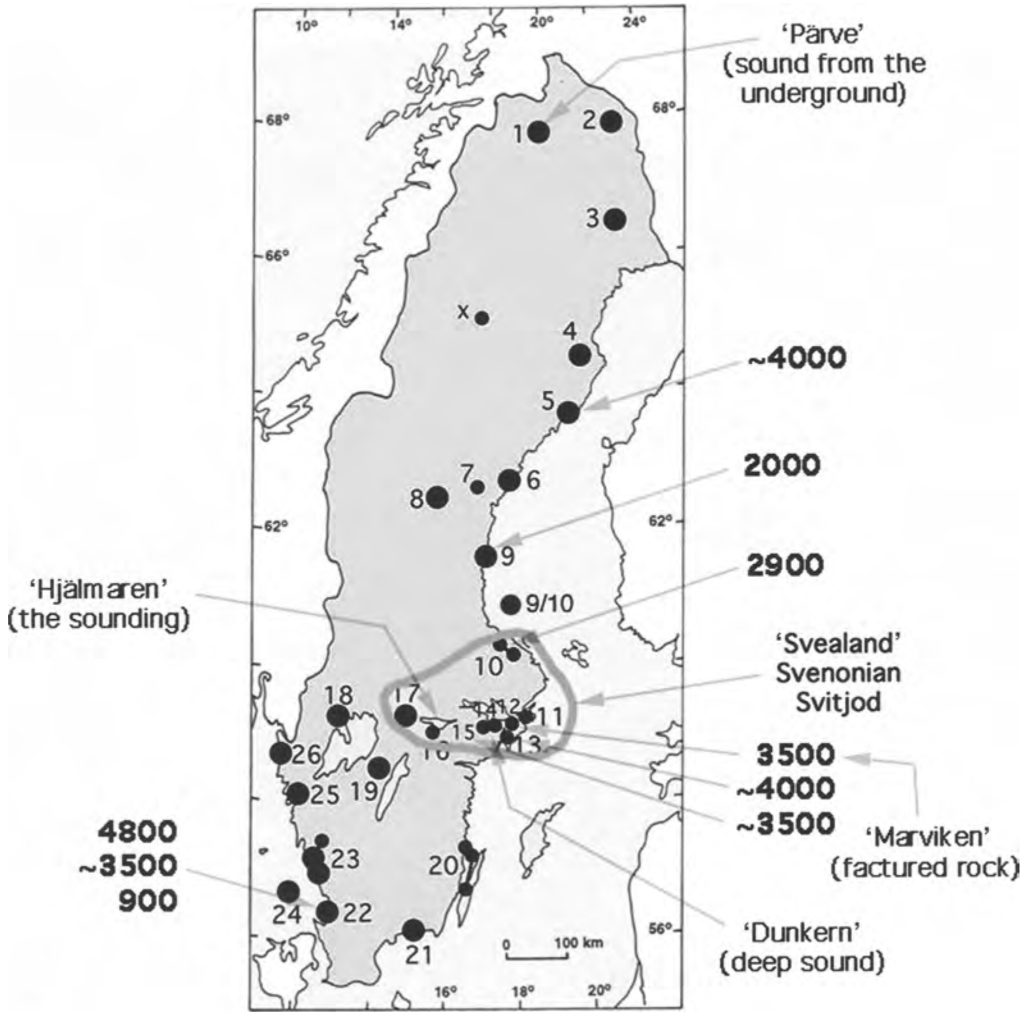

Fig. 1. Map of Sweden with areas of recorded palaeoseismic activity (black dots 1–26; further discussed in Mörner 2003, 2004, 2005). Nine high-magnitude palaeoseismic events are recorded in the Late Holocene. Their ages in C^{14}-years BP are given in black outside the map frames. A few place names referring to noise or fractured rock are given (outside the map frames). 'Svealand' refers to an area from where much of the Asa Creed owes its origin. It seems significant that so many earthquakes and place names are located just within this region.

destructive effects. The 2000 BP event at Hudiksvall (site 9) set up a huge tsunami wave that washed in over land at least 20 m above sea level. The 2900 BP event at Forsmark (site 10) represents another huge tsunami that broke into lakes at least 25 m above sea level. The 3500 BP event at Marviken (site 12) caused a 5 km fracture, nine large slides (including the down-slope movement of a Bronze Age burial mound) and a local lake tsunami. The 900 BP event on the Swedish west-coast includes a 1.0 m fault-scarp, rock shattering and liquefaction (with two Viking ships buried in sand by a possible tsunami).

Our oldest place names are said to have originated in the Bronze Age. There are many names in Sweden that refer to sounds, noise or fractured rock. The Lake 'Marviken' name seems to refer to fractured rock which fits well with the effects of the 3500 BP event there. Lake 'Dunkern' refers to deep noise (an earthquake just at the spot is dated 8000 BP which seems too old to have affected the place name, but younger events may have followed in the same zone). Lake 'Hjälmaren' refers to 'the noisy' and it seems significant that the area is traversed by faults active in postglacial time (Mörner & Strandberg 2003). 'Pärve' in the far north is a Lapish name referring to noise from the underground. This area was struck by a violent seismotectonic even about 9000 BP (Lagerbäck 1979). This seems far too early for an imprint in the place name. However, there may have been subsequent activities on the fault.

Much of the Nordic Asa creed seems to have originated in the region of 'Svealand' (termed 'Svenonian' by Tacitus, 79 AD, and 'Svitjod' in the Icelandic sagas), where the gods Thor and Odin were said to have emigrated and formed a new dynasty. Thus, it is interesting that we have so many traces of earthquakes just here (Fig. 1).

All these facts make it highly likely that the tale of the Fenris Wolf owes its origin to actual natural phenomena; that is high-magnitude earthquakes in the Late Holocene (Fig. 1) and their associated effects (faulting, fracturing, shaking, liquefaction, tsunamis).

Conclusions

Until a few decades ago, we had no idea of the high frequency of de-amplitude earthquakes that struck Sweden in deglacial time. Therefore, no one had thought of the possibility that the tale of the Fenris Wolf could refer to actual earthquake events. With the novel findings of a high magnitude palaeoseismic activity in postglacial time including several high-magnitude events in the Late Holocene, it seems likely that the tale of the Fenris Wolf, in fact, provides a good description of palaeoseismic events in the past. This is further supported by a number of place names referring to sounds and fractured rock.

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Band-e-Amir Lakes and Dragon Valley (Bamiyan): myths and seismicity in Afghanistan

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Abstract: Located SW of the Hindu Kush range, the Band-e-Amir lakes and other continental bioherms around Bamiyan are famous for their ordering into terraces and their great variety of colours. Numerous legends, the earliest likely dating to the establishment of the Zoroastrian religion, refer to the topography, ecology, and colours of the lakes and seismic activity of the area. The lakes have been formed by the chemical and biologically-induced build-up of semicircular or successive linear travertine dams. The discovery of a highly truncated karstic network located at an elevation of around 4000 m, along the base of Maastrichtian carbonate cliffs surrounding the lakes, may explain the presence of this carbonate sedimentation which has fluctuated with time and was responsible for legendary floods. Localized at the eastern end of the Herat strike-slip fault, the timing and duration of the build-ups and lakes are under the influence of intense seismic activity, partially due to the seismic activity of the nearby Hindu Kush, in relation to the northern drift of the Afghan Gondwanian block towards the Eurasiatic plate. These bioherms and lakes occur in an area of high risk: a zone of floods, freezing temperatures, earthquakes and rock avalanches caused by the high altitude and location in the Himalayan alpine belt. These natural features have affected local populations beginning with the movement into the area of more or less sedentary people, apparently coming from the Bactrian province. Such a fragile biological and sedimentological environment should be maintained by organized governmental assistance, with a primary goal of protecting the local inhabitants, but also preserving this exceptional environment for others to enjoy.

Afghanistan is located at a crossroads of oriental and occidental civilizations. In fact, the whole area has received the influences, traditions and the legends of different populations, from Persia to Greece, through Mongolia and from India to China. Afghanistan lies in an exceptional geological position between the Eurasiatic plate and the North Gondwanian blocks after the closure of the (Palaeo)-Tethys. This area is extensively faulted and seismic, because it represents an extension of the Indian Ocean Owen transform fault system.

Within this cultural and geological context, the marvellous and colourful lakes of Band-e-Amir have been incorporated in legends based on ecology, hydrology or geology on one hand, and historical and human background on the other. The Band-e-Amir lakes are so famous for their ordered terraces and their great variety of colours, from deep blue to pale turquoise, that the area formed the first Afghan national park, established in 1973. It is also a famous Shiite pilgrimage site and pilgrims immerse themselves in their cold waters.

The Bamiyan area is another exceptional site with wonderful colours, well known in ancient times as a restful and pilgrimage destination among the desert mountains. It no longer exhibits its giant Buddhas (53 m and 35 m high: Anonymous 1934): they were destroyed in March 2001, but their cliffs, cross-hatched by huge faults, are still visible. Close to Bamiyan, the Dragon valley or Ajdaha valley is still an important mythical area. Its high valley is interrupted upstream by a fossil and broken natural dam exhibiting faults and mineralogical deposits. In the same area, 15 km north of the Bamiyan, Awpar village also exhibits two lines of destroyed natural dams partly resting among waters that are still running in between.

The exceptional and colourful landscape surrounding natural high travertine dams and their freshwater in the mountainous desert environment of Band-e-Amir, the Dragon valley and Awpar valley have astonished not only nomadic tribes or invaders, but also pilgrims, travellers, explorers and, now, tourists. From time immemorial, in each

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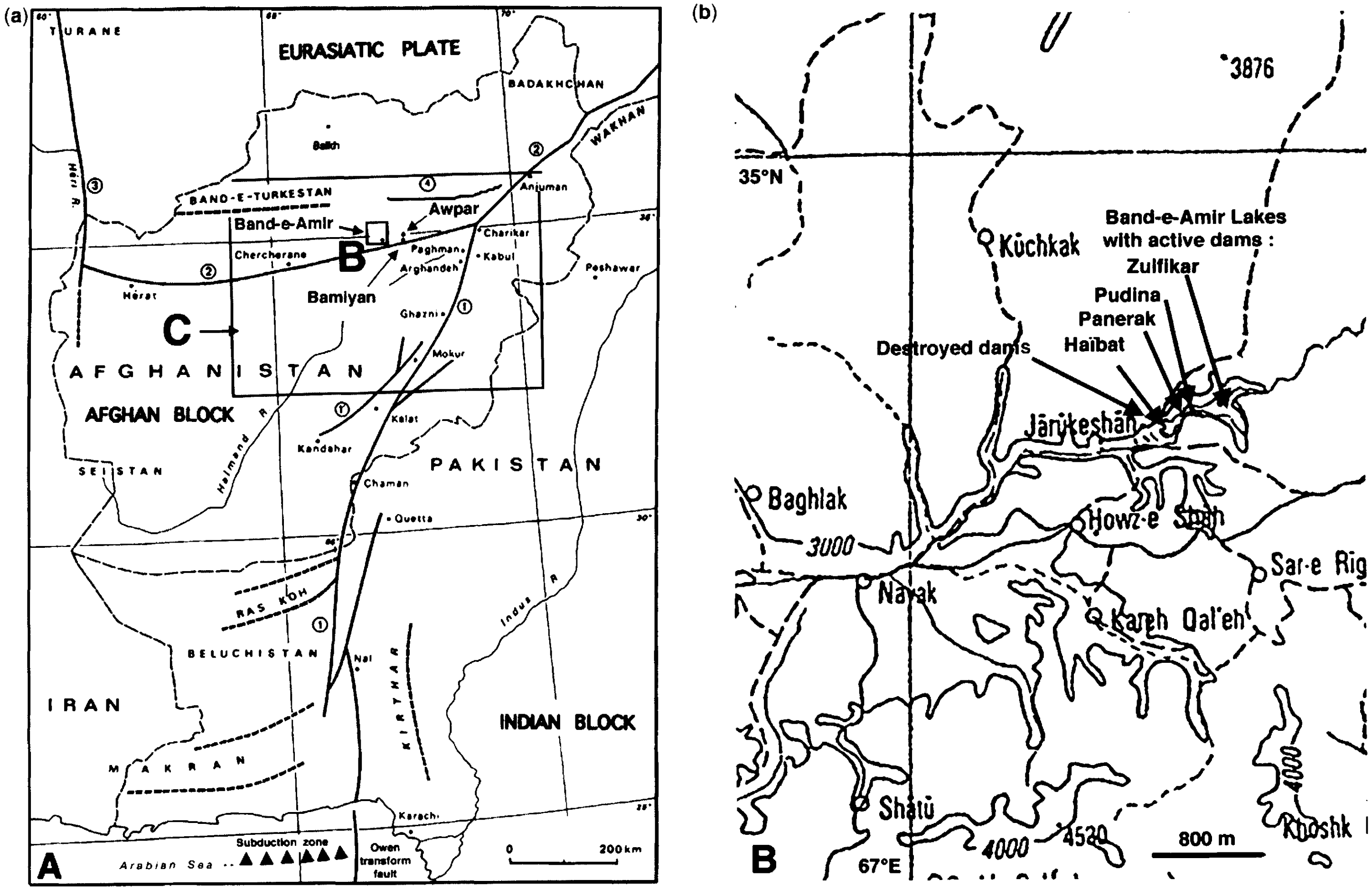

Fig. 1. (**a**) Locality map of Band-e-Amir lakes, the Dragon valley (Bamiyan area) and the Awpar dams in Afghanistan, with major faults. 1, Chaman-Arghandeh fault and Mokur-Kandahar fault; 2, Herat fault. 3, Heri Rud fault; 4, Andarab fault; from Lapparent (1972*a*) and the *Geological Map of the World* 1:25 000 000 (Bouysse 2000). (**b**) *Topography of the area of Banda-e-Amir lakes, details from the International Map of the World* 1:1 000 000 Kaboul Sheet, edition 6-DMA, series 1301 sheet NI 42, prepared and published by the Defense Mapping Agency Hydrogaphic/Topographic Center Washington D.C., with kind permission of the Institut Géographique National, Paris, France. Altitude in metres; – – –, administrative districts;

(c)

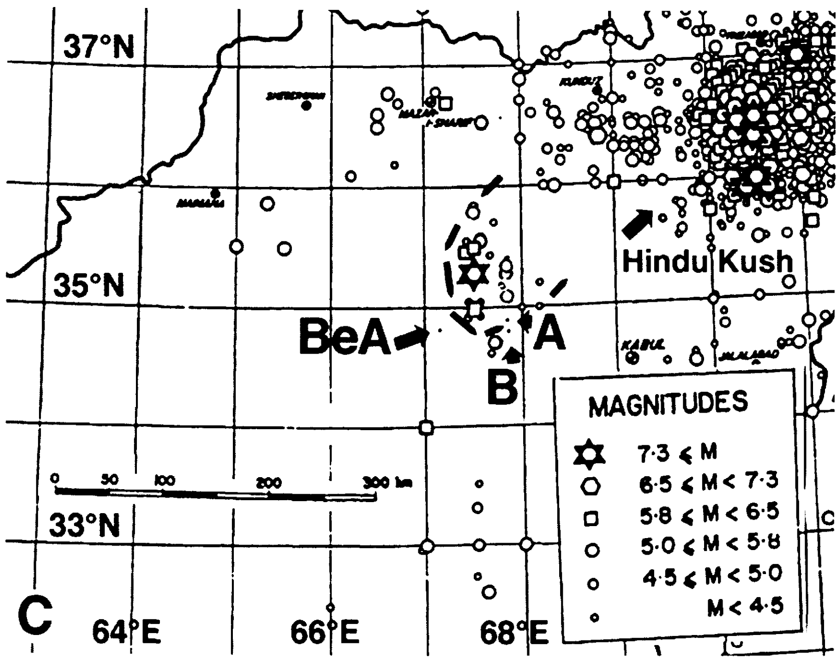

Fig. 1. (*Continued*) (c) Main earthquake epicentres from 1893 to 1969 (Heuckroth & Karim 1973), completed, only inside the following longitude and latitude: 67°E to 68°E and 34°N to 36°N, between 1969–2003 from NEIC source and IPG Strasbourg (France). The major earthquake, north of the studied area, occurred on 9 June 1956, with a magnitude >7.3. BeA, Band-e-Amir; B, Bamiyan; A, Awpar. Notice that this north–south line of earthquakes coincides exactly with the Moho isopach dashed line localized at 50 km depth in the area and drawn on the *Seismotectonic Map of the Middle East* 1:5 000 000 of Haghipour 1992. From Heuckroth & Karim 1973, completed, and Haghipour 1992.

of these three locations, legends that originated thousands of years ago, are closely related to the morphology, hydrology, ecology, climatology, geology and above all seismicity of the area.

Thus, the studies of these lakes and their associated biohermal natural dams allow us to view the effects of natural hazards such as flood and earthquakes to which the populations have always been exposed and which pilgrims and tourists now face. This preliminary study shows the interaction that may exist between legends and myths that are in fact real, hazardous events, recorded and modified by the oral tradition through re-telling over long periods of time.

Geological setting of some Afghan continental biohermal lakes: Band-e-Amir lakes, the Dragon valley, near Bamiyan, and the Awpar bioherms

Band-e-Amir lakes and dams, the Dragon valley and the Awpar dams are located in the SW final secondary mountain belt of the Hindu Kush, which is linked to the east–west Paromissus mountains to the Hesar chain. The three ranges are tangential to the central main Afghan plateau (Fig. 1a) with the east–west strike-slip fault of Herat. These mountains and the Afghan plateau slowly slide along this fault little by little, over millions of years, with a dextral movement (Fig. 1a) (Wellman 1966; Lapparent 1972*a*,*b*; Molnar & Tapponnier 1975; Carbonnel 1977). It has been previously shown on the 1/50 000 000 sketch map by Pavoni (1961) and Heuckroth & Karim (1973), with a total length of 1200 km. This is demonstrated by river displacements observed from air-photo-mosaic studies. Toward the east, it joins the Chaman–Arghandeh fault near Charikar (North of Kabul; Fig. 1a) recognized by Lawrence & Yeats (1979). Geological maps exist but without any details (Pavoni 1961; Chmyriov & Mirzad 1972; Wittekindt & Weipport 1973; Aghanabati 1993). As for topography of the Band-e-Amir lakes area, we used close-up views of the International 1/1 000 000 Map of the World, Kabul

Sheet, edition 6-DMA, series 1301 sheet NI 42, prepared and published by the Defense Mapping Agency Hydrographic/Topographic Center Washington D.C., kindly obtained by the Institut Géographique National, Paris (Fig. 1b).

The Band-e-Amir lakes

The natural lakes of Band-e-Amir (latitude 34° 50′ north and longitude 67° 10′ east, Fig. 1b) are located to the north of Kohe Baba mountain (culminating at 5143 m), in the massif of the Hazaratjat and constitute a succession of lakes with an east–west orientation in a mountainous range, at 2850 m in altitude, marking the course of the Band-e-Amir river, in the extension of the Hindu Kush chain (higher summit, the Noshaq, 7492 m). The Band-e-Amir river then flows towards the north after being stopped by the Hesar chains (4549 m). The area is 55 km by air from the small town of Bamiyan and 215 km from the Afghan capital, Kabul.

Enshrined between beige cliffs, the beauty spot of the Band-e-Amir terraced lakes is unique in the world, not only because of the beauty of its lakes but also because of the biological and geological interest that it represents with its still active encrusting waters allowing continental bioherms to grow (Lang & Lucas 1970). These bioherms are also refered to as phytoherms (Pedley 1992; Pedley *et al.* 1996) (Fig. 2a,b).

Four lakes were studied (Bourrouilh-Le Jan *et al.* 2004): the Haïbat lake (or the Fear lake, flanked by a mosque built in 1914), the Cheese lake, the Mint lake and Zulfikar lake, also called the Ali's sword lake. On its northern and southern sides, the Haïbat lake is overhung by 1200 m thick marly and calcareous cliffs attributed to Upper Cretaceous–Eocene (Lapparent 1972*a*) forming a 4000 m high zone or 'high plains' at the top, gently shaped by a previous Miocene (?) peneplanation. They display three thin, harder levels bracketing thick marly layers (Campanian) with Maastrichtian on top (Lapparent & Lavigne Sainte-Suzanne 1964). The Haïbat lake extends for several kilometres and its upward part is hidden by topography. It butts against the dam of a higher lake, the Cheese lake (Panerak Fig. 2b), the name deriving from the whiteness of its banks and bottom of the same colour and consistency as cheese. The Cheese lake is a few decimetres deep, so that its waters exhibit a turquoise colour. After climbing up another dam, it passes to another lake, the Mint lake, i.e. of the wild mint, Pudina, leading to the famous Ali's sword, named Zulfikar, lake. The Ali's sword lake ends at a gentle slope, covered by a village and tillage with two other, small ephemeral ponds.

Legendary history and European writers (Kessel 1967) note that six or seven lakes existed in the past. Downstream from Haïbat lake we observed one destroyed dam corresponding to a fifth lake (Fig. 2c). Upstream from its destroyed dam, several steps exhibiting Cretaceous outcrops exist in between that the Haïbat lake and may have contained a sixth smaller lake, the Slave lake (Ghulaman or Gholaman) and/or the lake of the Stable man. Downstream, the Band-e-Amir valley joins a south–north valley and continues its track towards the west and then NW to the Balkh depression (Fig. 1a). The destruction of the fifth and/or sixth lake of Band-e-Amir is recent and attributed to an earthquake. This historical destruction is not the only seismic sign of the area.

The Dragon valley (Ajdaha), near Bamiyan

Fifty kilometres east of Band-e-Amir, lies the small city of Bamiyan, well known for its Graeco-Buddhist (called also Ghandara art) statues that were recently destroyed, and a few kilometres WSW of Bamiyan, is Ajdaha, the Valley of the Dragon (Fig. 2d–f).

Upstream in the Valley of the Dragon is a fossil natural dam (Fig. 2d), similar to those of Band-e-Amir bioherms. Upstream from the dam, the ancient shallow lake has been filled with deposits and transformed into a vast flat area covered by dry savana. Downstream, gigantic blocks (Fig. 2e) are scattered all over the slope, and exhibits the same type of travertines as in Band-e-Amir. The position of ancient waterfalls can be identified by the sedimentary structures created by running water when the travertines were formed (Fig. 2f). Calcitic pisolites have been found (Lang 1975) confirming the intense travertine formation under both organic and inorganic processes (Chafetz & Folk 1982).

This ancient lake and natural dam were destroyed by an earthquake. The earthquake caused the rupture of the dam, the collapse of the blocks and a huge longitudinal fissure running along the dam (Fig. 2d). Previous U–Th ages obtained on the Dragon dam indicate dates of 47 400 ± 5000 BP, 27 800 ± 3000 BP and 16 100 ± 2000 BP (Lang 1975).

Although the waters of the upstream basin no longer run across the landscape, they still flow through the rocks below the surface, producing sounds and mineral deposits at the exit of some springs and showing a strong hydrothermal activity (Fig. 2d). The growling of the confined waters can be heard on the ancient dam and has given its name to the valley, sounding to the inhabitants

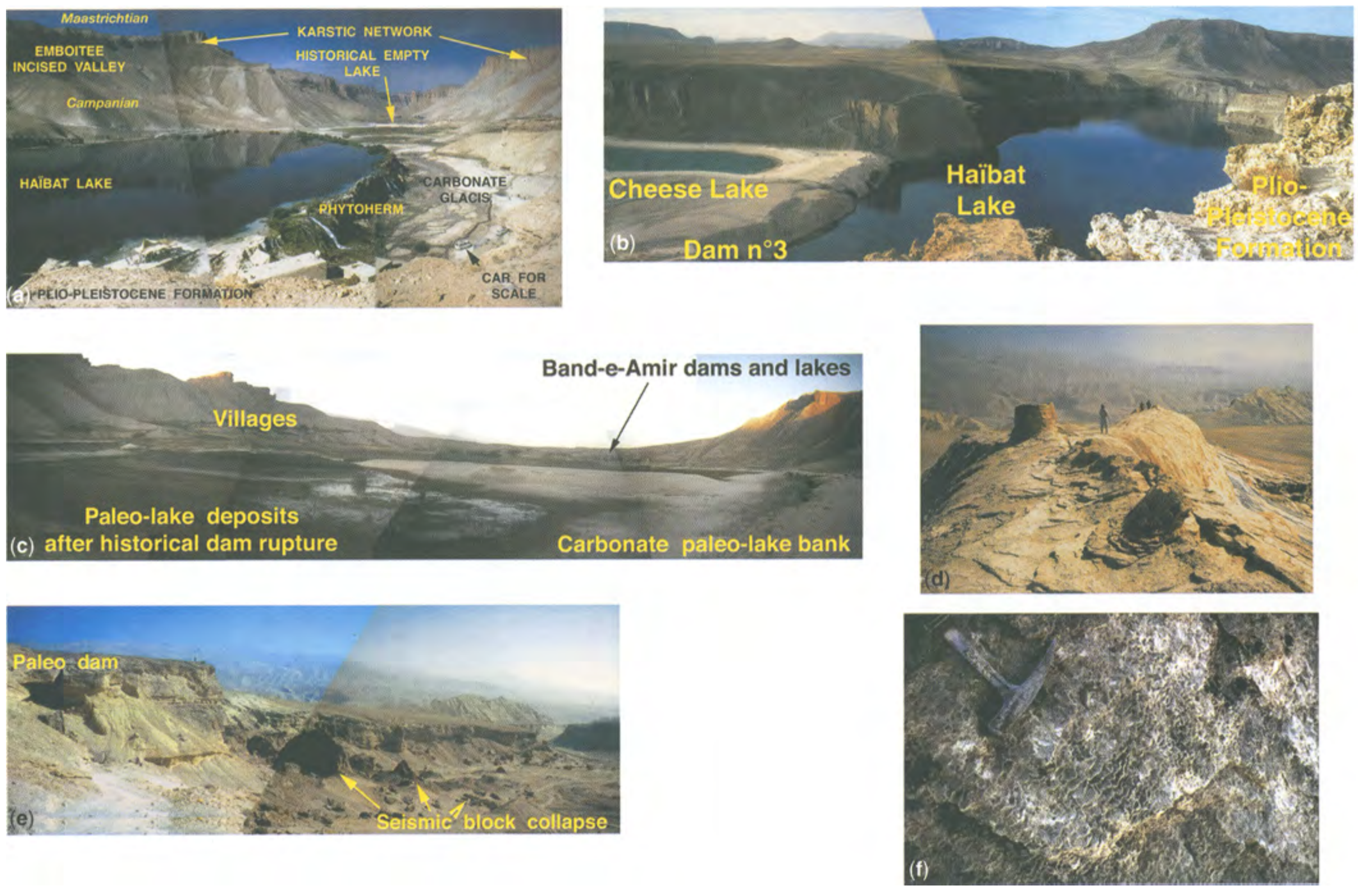

Fig. 2. (**a**) The Haïbat lake (with a mosque built in 1914), view towards west. This is the fourth and most beautiful lake of Band-e-Amir with its bioherm forming a natural dam, and lower, the carbonate glacis or slope. Lower down, houses and a concrete terrace replace the natural dam, and the glacis is used as a parking and a camping area by tourists and pilgrims (Bourrouilh-Le Jan 2004). In the background, on the left, are Cretaceous cliffs with the perched karst system at the top. (**b**) General view of the Cheese lake (Panerak lake) and the Haïbat lake. (**c**) The fifth and sixth vanished lakes of Band-e-Amir after seismic fractures in the related dam. (**d**) Carbonate chimneys from the thermal activity on the palaeo-dam of the Dragon valley. (**e**) The palaeo-dam of the Dragon valley (Ajdaha), near Bamiyan, viewed downstream from the palaeo-dam, toward the east showing numerous giant collapsed blocks from the fossil biohermal dam (interpreted as mythic dragon teeth). (**f**) Fossil travertine from the Dragon valley palaeo-dam showing running water sedimentary features.

like the growling of a subterranean dragon. This thermal activity has resulted in a number of myths and supernatural legends. Archaeological reports (Anonymous 1934) testify that Ajdaha was an important pilgrimage site for the mountain-dwelling tribe of the Hazarahs who recognized the petrified body of the dragon, fortunately killed by Haznet Ali. The dead dragon now forms the rocky ridge (i.e. former biohermal dam), 300 m long, oriented north–south and covered by white encrustations from mineralized springs.

Awpar bioherms

The bioherm complexes of Awpar village are located 15 km North of Bamiyan, 34° 54′ north and 77° 52′ west. Three destroyed biohermal dams are dated >40 000 BP for the base and 24 750 ± 700 BP for their summit. Other still active continental bioherms are dated back to 14 230 ± 190 BP and 11 670 ± 165 BP and show intense fracturing (Bouyx & Pias 1971).

Ethnography and legendary heritage of the Band-e-Amir lakes

At a crossroads of nomad civilizations of Central Asia, Band-e-Amir has been inhabited by the Hazaras for thousands of years. Today, a great number of Kuchi nomad tribes travel to the area also from Jalalabad from the end of May to the end of September. The province of Bamiyan has permitted three other tribes the rights to graze their flocks: the Taraki, the Amarkhil and the Nurzaï. Belonging to the Shiite Muslim religion, Band-e-Amir lakes are a sacred area for all these tribes.

The lakes have played an important part in the cultural heritage and the economy of the province. The villages are distributed around the periphery of the lakes, such as the perched village at the now vanished ancient Slaves lake (Fig. 2c). Shepherds still conduct their flocks to the water as we observed in September 2003 at the Cheese lake. The waterfalls were exploited for their hydraulic energy until recently. The natural dam of the Haïbat lake was exploited by half of dozen small mills until recently.

How has the beauty of the Band-e-Amir Lakes, and its vital importance in the economy of the local tribes who inhabit the area been recorded in the collective imagination? Going back through time in the memories of populations, we can observe what myths and legends exist around Band-e-Amir (Anonymous 1934; Hackin & Kohzad 1953; Pazwak 1981). It seems that the Band-e-Amir and Dragon valley myths have been assimilated into Islamic history, and more precisely to Shiite Islam, of Ali and of his successors. Three alternative popular legends are summarized here.

Band-e-Amir legend 1

According to the first legend, the King Zamir, who used to worship the fire, was reigning over Balkh and Bamiyan (the Bactrian Province of Alexander the Great). He was a Zoroastrian, a religion born in Central Asia (including Afghanistan) among farmers, between 1700 BC to 1000 BC (Anker *et al.* 1996). At the same time, the wife and children of a merchant from Bamiyan, travelling with a caravan on one of the antique Silk Roads, were captured and taken to be slaves close to the King Zamir. The caravan continued and arrived in Arabia where the merchant asked for the aid of the Prophet (Muhammad) who sent him to his cousin and son-in-law, Ali, son of Abou Taleb.

Ali recommended that the merchant return to the court of King Zamir and carry out an heroic deed. The merchant accepted and, at once, they were both transferred near the King Zamir. King Zamir required that three conditions were met before liberating the merchant's family: to build a dam that nobody had yet succeeded in building; to kill a dragon; and to deliver Ali, son of Abou Taleb.

With only one slash of the Ali's sword Zulfikar, the merchant built the dam, which was then called Zulfikar lake. But, this was not enough. Ali had to tear up plants and to form a second dam called Band-e-Pudina (the dam of the wild mint). According to King Zamir's rules it was necessary to build a third dam. Ali therefore requisitioned cheeses that women were carrying and built the third dam, Band-e-Panir (*sic*), the cheese dam. But, the water was still not controlled. Ali built a fourth dam, Band-e-Haïbat, the prestigious dam, and then a fifth, with the help of his squire, Band-e-Kambar, the dam of the stableman. A sixth dam was still necessary to enclose the streams. This time, Ali asked the help of a servant of King Zamir, forming the Band-e-Gholâman, the dam of the slaves. All the dams collectively received a prestigious name, the Band-e-Amir, the dam of the Nobleman. This nobleman was Ali, who then killed the dragon and met King Zamir.

King Zamir put Ali under arrest, covered him with chains and ordered his death. Ali shook himself free by breaking his chains. All these deeds dazzled and conquered the King Zamir. He renounced his fire worship and converted to Islam.

Band-e-Amir legend 2

The second legend tells that the King of Balkh (the Greek Bactra), a town located at the northern outflow of the Band-e-Amir river, near Mazar-e-Charif, had wished to build a dam on this area to regulate the waters of the river Kujtuk. The local population refused to help him and he asked Ali, the son-in-law of the Prophet who, thus, miraculously created the first lake, called Band-e-Khamar. Thus, the river flow was stemmed, but the local people had no more water for their fields. So Ali placed five nicks in the first dam so that the water could flow again to irrigate the fields.

Band-e-Amir legend 3

According to the third legend, under the reign of the wise and powerful Moghol Emperor Babur the Great (1483–1530), the melting of snow, with the arrival of spring, caused a huge flood which destroyed all the countryside near the modern village of Kupruk. Babur then ordered a dam to be built, but all his efforts to stop the flood failed. So the caliph Ali, son-in-law of the Prophet, interposed again. With his wide sword, Zulfikar, he cut the summit of the mountain, creating the first dam, Zulfikar.

Nevertheless, the deluge continued and the torrents broke down the dams. Ali dug up trees and plants to build the dam Pudina, or the wild mint. Then, Ali asked the women to make cheese for him to pour into the torrent to form the Panerak dam, or the cheese dam. But the flood continued and Ali, furious, lifted up an enormous block in the torrent and created the barrage of the Haïbat dam, *haïbat* meaning anger, fear, frightening miracle. These last efforts succeeded in containing the flood, despite some small streams that continued to flow.

Then, the Moghol Emperor Babur ordered his slaves to build the dam of Gholaman or dam of the slaves, for irrigation and mills. At the end, to celebrate his victory against the elements, Ali would have said two sets of prayers, called Ragat, on the edge of Haïbat dam.

As Bamiyan has been interpreted as a Persian name coming from the Persian Bamikan, the names of the other dams may also be of Persian origin (Anonymous 1934).

Relations between legends and geological facts

What can be concluded from these legends? First, they pertain to the magnificent, popular oriental tales but also are excellent examples of local popular tales. They have roots in the various ancient memories of the nomads and invaders, who were amazed by the marvellous and astonishing landscape of the Band-e-Amir lakes or of the Ajdaha valley. Thus, these tales do not have a single origin but have superimposed origins and memories.

The legend of King Zamir seems the most ancient legend because it refers to the Zoroastrian religion, prior to Islam, perhaps dating back to 1000 years BC (Anker *et al.* 1996). More precisely, the legend appears to have been formulated sometime between the time of Zoroastr, or Zarathustra, born around the seventh century BC in Bakhtar (Balkh) (Pazwak 1981). The two others legends appear to be different versions of this same history, the fight of an already agricultural people against the natural risk of flood in a high mountainous area.

The story of a merchant going from Afghanistan to Arabia is interesting because it positions Afghanistan as a turning place of the Silk Roads. In addition we know that the lapis lazuli trade was already in existence in 4000 BC, the gemstone being extracted from the mine of Badakhshan, north of Kabul, and transported westwards toward Suse, one of the Persian capitals (Wyart *et al.* 1972). However, Greek rationalism and observation of nature do not appear in these legends. They jump from Zoroastrianism to Islam, seemingly omitting not only the Greek chapter of Alexander the Great in Afghanistan but also the Buddhist philosophy known to exist in Bamiyan from the first century AD and visited by Chinese and Korean monks around the sixth and seventh century AD (Anonymous 1934).

What do these legends reflect when we compare them with our field and laboratory observations?

There is probably little if any gap between Zoroastrian tales and Islamic legends, but only a lack of written historic text to help explain the actual transformation of the legends. Based on our field and laboratory description of the Band-e-Amir lakes and of the Dragon valley palaeo-dam, and on bibliographical studies for the Awpar dams, a strong link appears to exist between each of the lake names and, either their morphology, ecology, sedimentological or geological controls. Overall, the legends try to explain and provide a context for the local names, geomorphology, ecology sedimentology and risk analysis, starting from the first peoples crossing or settling in the area.

The flood risk: palaeoclimatology from the Pliocene to Holocene

In this part of Afghanistan, glaciers left scarce erratic rocks and polished surface outcrops, rarely below 3500 m in altitude, and more numerous in areas higher than 4000 m in altitude (Popol & Tromp 1954; Lapparent *et al.* 1972). An important cover of loess deposit (Pias 1971) indicates that this part of Afghanistan was not directly covered by extensive permanent glaciers. So, important lacustrine sedimentation became established during the Plio-Pleistocene, in the SW part of the country (Pias 1972). Bioherm formation may have started during the Upper Pleistocene as demonstrated by previous studies (Bouyx & Pias 1971; Huu Van *et al.* 1973; Lang 1975).

In the field, we have observed the presence of a perched karstic fossil network localized at the base of the Maastrichtian cliff, testifying to an old erosional surface and to an ancient contrasting climate with high rainfall, much higher than now. Today, with a rigourous weather system of the mediterranean type of climate, less than 400 mm of annual precipitation falls on most of the country, although reaching 1200 mm on higher mountains (station of Salang tunnel, 3100 m altitude) (Stenz 1947; Lalande 1968).

The third legend evokes a historical person of distinction, the Moghol Babur the Great (1483–1530). The Turkman Babur was born in Fergana (north of Pamir). He conquered Kabul in 1504 and few years later the province of Bactriana, the modern Balkh, with Band-e-Amir and Bamiyan (Sellier & Sellier 2004). These dates, when Babur began to reign over Balkh and the Band-e-Amir valley, correspond to the Little Glacial Age in Europe (Ruddiman 2000). The spring melt of snow and glacier ice, coupled with rainfall allowed recharge and circulation of waters, creating a new subterranean karst system inside the Cretaceous sedimentary succession and a hydrographic network on the surface. Therefore, the passage of these waters through the Cretaceous limestones and marls of the ancient stratigraphic Afghan suite dissolved the carbonate which in turn precipitated as calcite and formed biohermal travertines. So, in Afghanistan, this third legend seems to indicate an increase of rain and torrential discharges (mentioned in Babur's memoirs; Beveridge 1969), followed by a considerable human struggle against flood during Babur's reign. Thus, this legend seems to superimpose Little Glacial Age events on ancient myths. It could be explained by an increase of rainfall, with more snow, and above all, a temperature increase causing the melting of further snow and the flooding of downstream valleys and a temporary fear in the local settlers.

Geomorphology: the shape of Zulfikar lake

Ali's sword was known to be magical and had a bifid termination. This is the shape of the most upstream lake, called Zulfikar lake, in Band-e-Amir. The lake has flooded two valleys and the periphery of this bifid configuration serves as the Ali's sword.

Sedimentology: aspects of dams and biohermal travertine formation

These lakes are caused by the formation of natural dams made by travertines from continental bioherms (Fig. 2) which grow as the water trickles through and progressively stops the water running down the drainage basin. The causes of their formation and development are numerous and are now well known. These natural dams are due to the following factors (Lang & Lucas 1970; Ramon 1983):

Physico-chemical parameters. The physico-chemical precipitation of calcium carbonate by decreasing of CO_2 partial pressure with altitude and decreasing temperature (Emeis *et al.* 1987; Guo & Riding 1994, 1998; Zhang *et al.* 2001). The CO_2 partial pressure drops abruptly when water flows out of fractures or springs of resurging subterranean rivers. The higher the altitude, the faster is this reaction. Precipitation occurs at each break of slope, waterfall and cascades (Zhang *et al.* 2001).

Biological parameters. The area is inland, the fluid is fresh water and the carbonate is low magnesian calcite (Chafetz & Folk 1982). In addition, the proliferation of bacterial colonies, mosses and vascular plants and thus, the biological activities, with photosynthesis during the day and respiration during the night, induce ionic displacement within the fluid, leading to further $CaCO_3$ precipitation (Emeis *et al.* 1987; Zhang *et al.* 2001).

The organisms observed in Band-e-Amir are varied, from bacteria, cyanobacteria, diatoms, *Equisetum*, charophytes (already studied by Lang & Pierre 1973), bryophytes (mosses), and vascular plants such as mint, *Juncus* (Lang & Lucas 1970). Because of calcium carbonate precipitation, a specific rock 'travertine' is formed, and specific bio-sedimentary formations with stromatolites and carbonate particles (intraclasts) are made by flocks. Recently four-wheeled vehicle tracks have destroyed the thin newly-lithified upper layers of the travertines (Bourrouilh-Le Jan 2004). This continental carbonate sedimentation seems to have occurred since about 120 000/133 000 BP (following Huu Van *et al.* 1973) in the area.

Contrary to the study of Emeis *et al.* (1987) on Yugoslavian travertine, no sediment was found by divers of our expedition on the flat hard bottom of the Haïbat lake (*c.* 30 m deep). In the same way, no sediment seems to fill the first Band-e-Amir lake (Zulfikar lake). However, the Cheese lake and Wild Mint lake are being filled up; the beautiful turquoise colour indicates only a few tens of centimetres of water. This difference relates to the observations of Zhang *et al.* (2001) showing a 'waterfall effects' inducing calcite precipitation. The depth of the two main lakes, Zulfikar and Haïbat, does not permit precipitation which is possible in the Pudina and Panerak lakes where stromatolites with cyanobacteria and old shoreline levels can be observed, indicating fluctuations of the level of the Cheese lake.

In conclusion, the Cheese lake is actually filled with by a white carbonate mud, looking like fresh white cheese (Fig. 2b). The lake is very shallow with an accessible path from the cliff tops for watering flocks; the tribes could and still can camp around the reduced Cheese lake on its wide and low-angled slope banks.

Ecology: the naming of Mint lake

The Wild Mint lake takes its name from the plants growing around, Pudina, the wild mint.

Geophysics: seismic and thermal activity in Band-e-Amir lakes and in Bamiyan areas: the Dragon valley and the Awpar dams

The violent appearance and sudden nature of seismic events can explain Ali's gesture in the first legend, with the making of nicks in the upper dam of Zulfikar lake; the same remark may apply to his anger in building the Haïbat (anger, fear, frightening miracle) from where giant blocks have been detached and, in the legend, thrown down to create the dam near the ancient mills.

The geophysical impact also appears in the story of the dragon, in the oldest legend of the Zoroastrian King Zamir, revived lately by the Ajdaha pilgrimages. This dam has been destroyed, as have the sixth and seventh lakes of Band-e-Amir and shows fissures and numerous enormous block collapse from the dam itself, interpreted, in the legend as the dragon teeth (Fig. 2e).

The seismicity of the Hindu Kush

Most seismic activity in Afghanistan is concentrated in the Hindu Kush (Fig. 1c). It has the highest number of earthquakes with the largest magnitudes. It is considered to be the final stage of subduction of oceanic lithosphere along the collisional boundary between continental India and Eurasia (Nowroozi 1971, 1972; Billington *et al.* 1977; Prévot 1978; Chatelain 1978; Quittmeyer *et al.* 1979; Roecker 1982; Dercourt *et al.* 1993). Large intermediate-depth earthquakes are commonly felt throughout adjacent regions. Shallow activity is characterized by moderate to high level of magnitude and distributed over a wide area (Quittmeyer & Jacob 1979).

The east–west Herat fault versus north–south 50 km deep Moho isopach line

Heuckroth and Karim (1973) synthesized the seismicity of Afghanistan from 1893–1969. Historically, activity of the Herat fault is known by the destruction of numerous Afghan monuments. Its east–west track (Fig. 1a) is marked by the destruction of the mosque and three minarets in Herat, heavily damaged in 848 AD (Heuckroth & Karim 1973) and in 1950, the destruction of the buildings surrounding the five Herat minarets, but not recorded due to the low magnitude (below 4.5) of the earthquake. This list has been completed with the help of the USGS National Earthquake Center and the Institut de Physique du Globe in Strasbourg (France) for the area between longitude 67° to 70° east and latitude 34° to 36° north (Fig. 1c, Table 1). The seismicity of the area from 1950 to the end of 2003, indicates that earthquakes are localized on both terminations of the Herat fault, the lack of any epicentres along the Herat fault having been noted previously by Heuckroth & Karim (1973).

The Band-e-Amir and Bamiyan areas are seismically active, but this is not as intense as in the nearby high chain of the Hindu Kush (Fig. 1c). Between 1893 and 2003 the activity at Band-e-Amir and Bamiyan included eight earthquakes with the following magnitude: 1 of $7.3 \leq M$; 3 with $5.8 \leq M \leq 6.5$; 1 with $5.0 \leq M \leq 5.8$; and 3 with $M \leq 4.5$. All these earthquakes are centred on a north–south trend line, roughly following the 67° 30′ meridian (Fig. 1c), appearing perpendicular to the two major faults of Herat and Andarab faults (Fig. 1a). Furthermore, this north–south fault coincides with the north–south dotted line of the 50 km deep Moho isopach line drawn on the seismotectonic map of the Middle East, 1/5 000 000 scale (Haghipour 1992), and mentioned earlier by Roecker (1982). These characteristics have been commented on by Quittmeyer & Jacob (1979) regarding the Saygan earthquake (35° 13′ N, 67° 48′ E). However, they did not relate it to the Herat fault; instead, they defined a zone of distinctly different orientation.

Table 1. *Seismicity around Band-e-Amir and Bamiyan (Central Afghanistan), from 34°30′ to 35°30′ north and from 67°30′ to 68°30′ east, from 1950 to 2003, i.e. during 53 years. Remarks: the indications of longitude are schematic and simplified and the lack of magnitude means imprecision in records. The second earthquake on the table list is known as the 'Sayghan Afghanistan earthquake', with a magnitude ≥7.3, 67° 48′E and 35° 13′N (Quittmeyer & Jacob 1979).*

Date	Hour (UTC)	N-Latitude	E-Longitude	Depth-(km)	Magnitude
08/06/1956	04: 07: 26.0	35.00	67.50		
09/06/1956	23: 53: 41.0	35.00	68.00		
10/06/1956	01: 01: 35.0	35.00	68.00		
22/03/1980	18: 13: 25.0	35.18	68.25	207	3.5
14/05/1983	07: 00: 33.4	35.18	67.90	33	4.3
05/03/1988	00: 57: 16.8	35.04	67.93	33	4.1
22/11/1992	23: 28: 19.2	35.39	67.73	33	4.6
18/12/1992	00: 13: 17.5	35.16	67.91	33	4.4
23/03/1997	18: 47: 55.3	35.57	66.12		
17/05/1997	19: 00: 01.4	34.68	67.61	33	
25/05/1997	02: 01: 41.4	35.23	67.85	33	3.6
28/05/1997	05: 20: 55.6	34.77	67.78	33	4.9
24/12/1997	07: 22: 19.9	35.21	67.53	75	3.7
14/11/2001	13: 52: 40.4	35.13	68.79	33	
27/12/2002	02: 48: 36.6	35.15	68.53	33	

Sources: NEIC and Rénass (Réseau national de surveillance sismique, Institut de Physique du Globe (IPG) Strasbourg, France).

The map drawn by Burtman (1980) in an area located NW of the Band-e-Amir and Bamiyan areas shows a high density network of faults. The same net exists on Band-e-Amir and Bamiyan but has not yet been mapped in detail. We cannot give more precise details of the real fault involved in these earthquakes, but the seismic activity is directly related to the Hindu Kush seismic activity and the 50 km north–south deep Moho isopach line (Fig. 1c).

In conclusion, the east–west Herat fault is a brittle superficial fault located in the fragile lithospheric zone whereas the 50 km north–south deep Moho isopach fracture zone, revealed by the Saygan earthquake and the bioherm dam destruction described through myths and field observations, represents a deep ductile crustal fault, most probably related to the shifted prolongation of the Owen transform fault system (Fig. 1a).

Thoughts on the dating of the myths in relation to the seismic damage

Because archaeology gives us the likely date of between 1700 and 1000 BC for the birth of the Zoroastrian religion in Central Asia, one of the earthquakes that destroyed and dried the Dragon valley probably occurred between 1700 BC and the tenth century AD when Islam started to conquer Afghanistan (Ghaznavides and Ghorides civilizations, Pazwak 1981).

By comparing the damage observed on each bioherm system at the three localities, a trend becomes apparent. The maximum damage and destruction occurred not only at Awpar, completely destroying the bioherms, opening fissures and collapsing numerous blocks on the Dragon valley dam, but also destroyed dams, collapsed blocks and opened cliff fissures in the furthest Band-e-Amir area. This pattern suggests a possible large magnitude earthquake in the vicinity of the later Saygan earthquake of June 1956 (Fig. 1c).

Conclusions

The Band-e-Amir lakes and the Bamiyan area are very fragile (Bourrouilh-Le Jan 2004) because of their complex geological history and because of their location in a constantly active seismic zone. They represent a zone of high risk: floods, freezing temperatures, earthquakes and rock avalanches caused by high altitude and their presence in the seismically active Himalayan alpine belt. These natural forces have affected local populations from when the area was first settled several thousands of years ago by more or less sedentary people, apparently coming from the Bactrian province.

The natural dams of this region are continental bioherms or phytoherms. Their remarkable and unique appearance in this high and cold desert-like environment inspired the local nomadic tribes to develop legends and myths that recorded and interpreted natural geological and biological facts. These legends and myths were accepted, assimilated, and perpetuated by different religions and cultural groups so that their most important message has been to warn inhabitants of the geological hazard of the areas.

This paper is dedicated to the memory of Guillaume Bourrouilh (1980–2005) graduate in political sciences and student in history.

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The Bible and geology: destruction of Sodom and Gomorrah

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Abstract: The biblical story of the destruction of Sodom and Gomorrah is interpeted as a reflection of a real natural disaster. According to the Bible, Sodom and Gomorrah were situated near the southern part of the Dead Sea basin or in the Jordan River valley. The description of their destruction in the Bible can be interpreted only as volcanic eruption. Evidence of middle Holocene volcanism is absent both in the Dead Sea and Jordan River regions, but has been found in the Neogene–Quaternary lava highland in the southern Syria. At two settlements, Khirbet El-Umbashi and Hebariye, dated around the second part of the third millennium BC, many animal bones were covered by the basaltic lava. It is possible that, the Bible's story of the destruction of Sodom and Gomorrah combined collective memories about two events. Located in the Dead Sea region, Sodom and Gomorrah were most probably destroyed by a strong earthquake or flood, but the fresh memory about two settlements perishing from a volcanic eruption caused the population to merge these two events.

Three components can be distinguished in the Bible. The first is the basic spiritual and religious element of the tale which is not discussed here. The second is a statement of ancient history about the Jewish people that can be verified partly by other historical documents. The third component is that of myths and legends of Semitic and other tribes that were created before separation of the Jews within the Semitic family. These myths and legends may be a reflection of real natural and historical events that were subsequently passed on orally from one generation to another, and in a didactic sense, attributed to the events in the Bible. The most important details for reconstruction of the sources of legends are those that are neutral to the didactic sense of the legend and that can be examined in their environmental and historical context. In the present paper, this approach to the Bible is illustrated by studying the story of the destruction of Sodom and Gomorrah. The tale is well known and is therefore not given in full here. Instead, attention is drawn to some details suggestive of the source and sense of the legends.

The legend is a part of Genesis, the first book of the Bible. Because 'the Lord said to Moses: Make a record of this in a book, so that it may be kept in memory' (Exodus 17:14), it is possible that the main concept of the new monotheistic religion attributed to Moses was fixed in the thirteenth century BC. However, according to Frazer (1923) and Keller (1980), the final version of Genesis was formed later by using two written sources known as Y-source and E-source. The Y-source gave God the name Yahweh (the Lord in English) and was created in Judah in the tenth or ninth century BC. The E-source named the God El or Eloah (pl. Elohim) and was created in about the eighth century BC in Israel. At around the same time, or slightly later, the sources were joined together. The sources differed in some details, and these differences remain in the combined text. It causes difficulties for an accurate interpretation of some Bible details, particularly for those related to location and a way of destruction of Sodom and Gomorrah. Bentor (1990) emphasizes another difficulty: 'The Bible makes frequent use of geological events, but ... it does not care much about dates and places, shifting geological events around to suit its purpose'.

Uncertainty in location of Sodom and Gomorrah

The Bible story of the destruction of Sodom and Gomorrah is as follows. Lot was a nephew of the rich cattle-breeder Abram, and they lived and worked together around the Dead Sea. Because of tension between their herdsmen, they separated and 'Lot took for himself all the valley of Jordan ..., moving his tent as far as Sodom' (Genesis 13:11–12). God decided to exterminate the sinful inhabitants of Sodom and Gomorrah, but to save pious Lot and his family. God's messengers had told them to leave the town; one of them said: 'Flee for your lives, without looking back or waiting in the lowland, go quickly to the mountains or you will come to destruction' (Genesis 19:17). The towns were destroyed. Lot's family left for Zoar, 'then went up out of Zoar to the mountains' (Genesis 19:30) and was saved, 'but Lot's wife, looking back, became a pillar of salt' (Genesis 19:26).

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The following fragments are important in locating Sodom and Gomorrah. 'Now in the days of Amraphel, king of Shinar, Arioch, king of Ellasar, Chedorlaomer, king of Elam, and Tidel, king of Goiim, they made war with Bera, king of Sodom, and with Birsha, king of Gomorrah, Shinab, king of Admah, and Shemober, king of Zeboiim, and the king of Bela (which is Zoar). All these came together in the valley of Siddim (which is the Salt Sea)' (Genesis 14:1–3). 'And the king of Sodom with the king of Gomorrah and the king of Admah and the king of Zeboiim and the King of Bela (that is Zoar), went out, and put their forces in position in the valley of Siddim' (Genesis 14:8). The 'Sodom–Gomorrah' coalition sustained a defeat. The conquerors 'took all the goods and food from Sodom and Gomorrah and went on their way' (Genesis 14:11). Because 'in addition they took Lot ..., who was living in Sodom ..., Abram ... took a band of his trained men, three hundred and eighteen of them ..., and went after them as far as Dan. And separating his forces by night, he overcame them, putting them to flight and going after them as far as Holah, which is on the north side of Damascus' (Genesis 14:12–15).

These quotations show that the conquests came from the nearby territory of Syria or Lebanon and Sodom and Gomorrah were situated southerly. The armies met 'in the valley of Siddim which is the Salt Sea' (the Dead Sea), and this suggests that the valley may have been situated in or near the recent shallow southern part of the Dead Sea which may have flooded later. It is reasonable to assume that Sodom and Gomorrah were situated not far from there. 'Salt pillars' in Mount Sodom, west of the site under discussion, as well as general salinity of the area support this idea. This idea was published by Bentor (1990) who argued it by interpretation of the old settlement in Tel es-Safi (south of the recent Dead Sea) as Zoar. But excavations have not found Early–Middle Bronze layers under the ruins of the Arabic (Middle Age) Zoar and the location of the Biblical towns in or near the southern part of the Dead Sea continues to be questionable.

At the same time, given that 'Lot took for himself all the valley of Jordan (during the division with Abram), and went to the east ... to the lowland towns, moving his tent as far as Sodom', the latter could be situated in the eastern side of the Jordan valley, north of the Dead Sea. Such a location is supported by the other fragment of the Bible text: 'And Abram ... went to the place where he had been talking with the Lord and looking in the direction of Sodom and Gomorrah and the lowland ...' (Genesis 19:27–28). That place was identified in Samaria as lying to the west of the Jordan valley, closer to the Mount Garizim (Keller 1980).

Both locations mentioned above may be in doubt if the way God had chosen for destruction of Sodom and Gomorrah is taken into account. 'Then the Lord sent fire and flaming smoke raining down from heavens on Sodom and Gomorrah. And he sent destruction on those towns, with all the lowland and all the people of those towns and every green thing in the land' (Genesis 19:24–25). 'And looking in the direction of Sodom and Gomorrah and the lowland, he (Abram) saw the smoke of the land going up like the smoke of an oven' (Genesis 19:28). The Bible also says that the neighbouring Zoar (several hours' walk from Sodom) was not affected. Fire, smoke of the land and destruction of 'all the lowland ... and every green thing in the land' and, at the same time, absence of destruction in Zoar all suggest a volcanic eruption as the most probable cause of the described disaster. It is unlikely to have happened near the Dead Sea or in the Jordan River valley, since signs of eruption as young as the one supposed have been found only in the southwestern Syria and an adjacent part of Jordan.

Middle Holocene volcanism in southwestern Syria

To the south and to the SE of Damascus, the Jebel Arab highland with Neogene–Quaternary basaltic lavas stretches for a distance of 450 km (Ponikarov 1964; Ponikarov *et al.* 1967; Rukieh *et al.* 2005) (Figs 1 & 2). Its altitudes are usually more than 600 m and the tops of some volcanoes are as high as 1200–1800 m. In this area, individual centres of volcanism form northwest trending chains and mark extensional fault zones, which branch from the active sinistral strike-slip Levant Fault (the Dead Sea Transform). The basaltic flow of Kra looks the most recent and has been dated as Holocene (Ponikarov 1964). The basalt was erupted from a small volcano on the NW-trending active fault on the NE slope of the Druze Mountains near the present village of Rdemet Ash-Shakhur (about 80 km SE of Damascus and 100 km to the east of the Sea of Galilee). The eruption began from two adjacent centres located on the fault, several hundred metres from each other and later concentrated in a single volcano (the height of which was about 1050 msl). The lava flow spread 32 km to the NE of the Druze Mountains along two wide dry valleys (wadis), Ar-Rampliyat in the south and Kra in the north (Fig. 3). Distal parts of the lava flow covered the remains of two settlements, burying mass accumulation of bones, Khirbet El-Umbashi on the northern side of the flow and Hebariye 7 km to the south. Their altitudes are about 670 m. The lava flow is 4–5 m thick

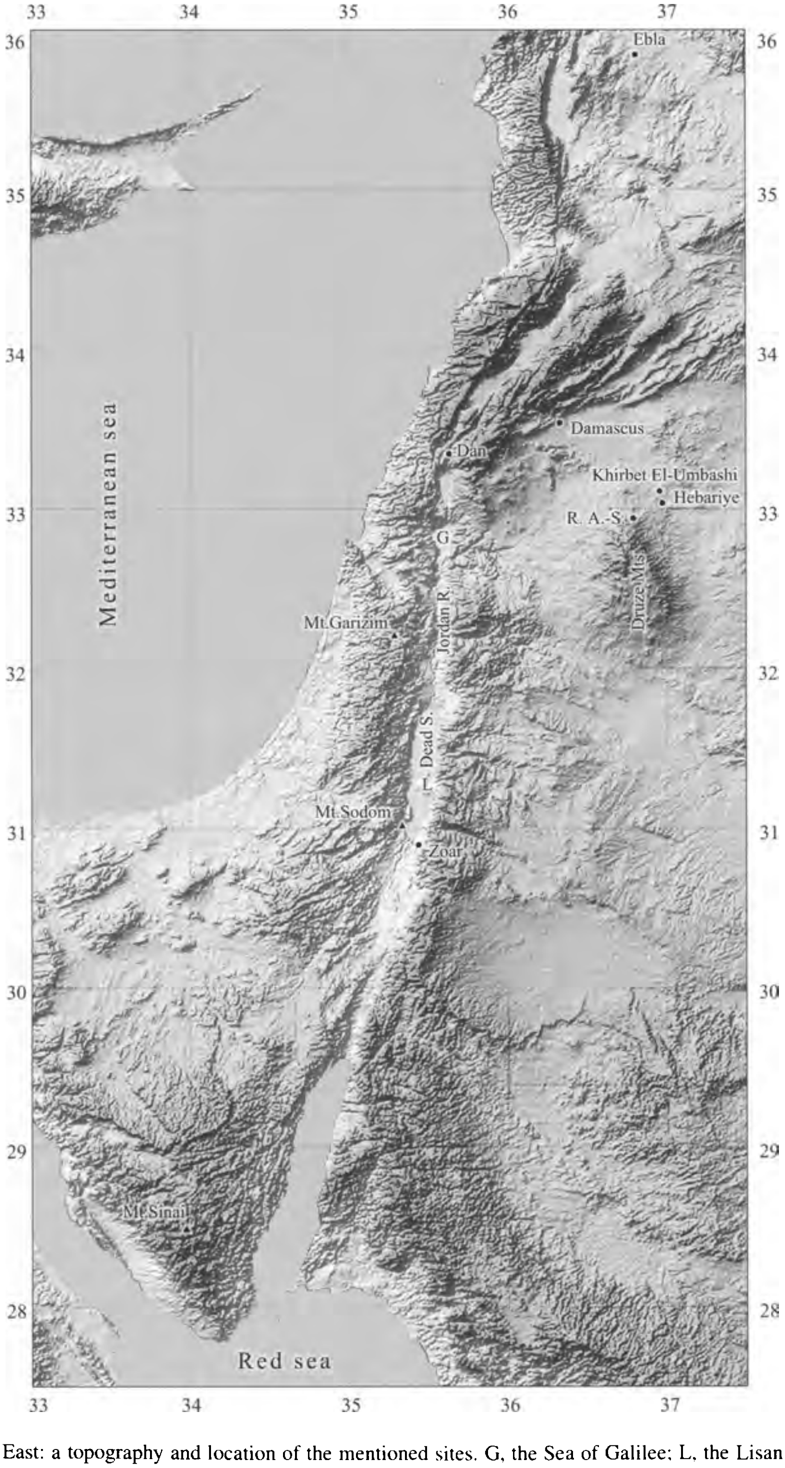

Fig. 1. Near East: a topography and location of the mentioned sites. G, the Sea of Galilee; L, the Lisan peninsula; R. A-S, the village of Rdemet Ash-Shukhur; Zoar, the Middle Age town.

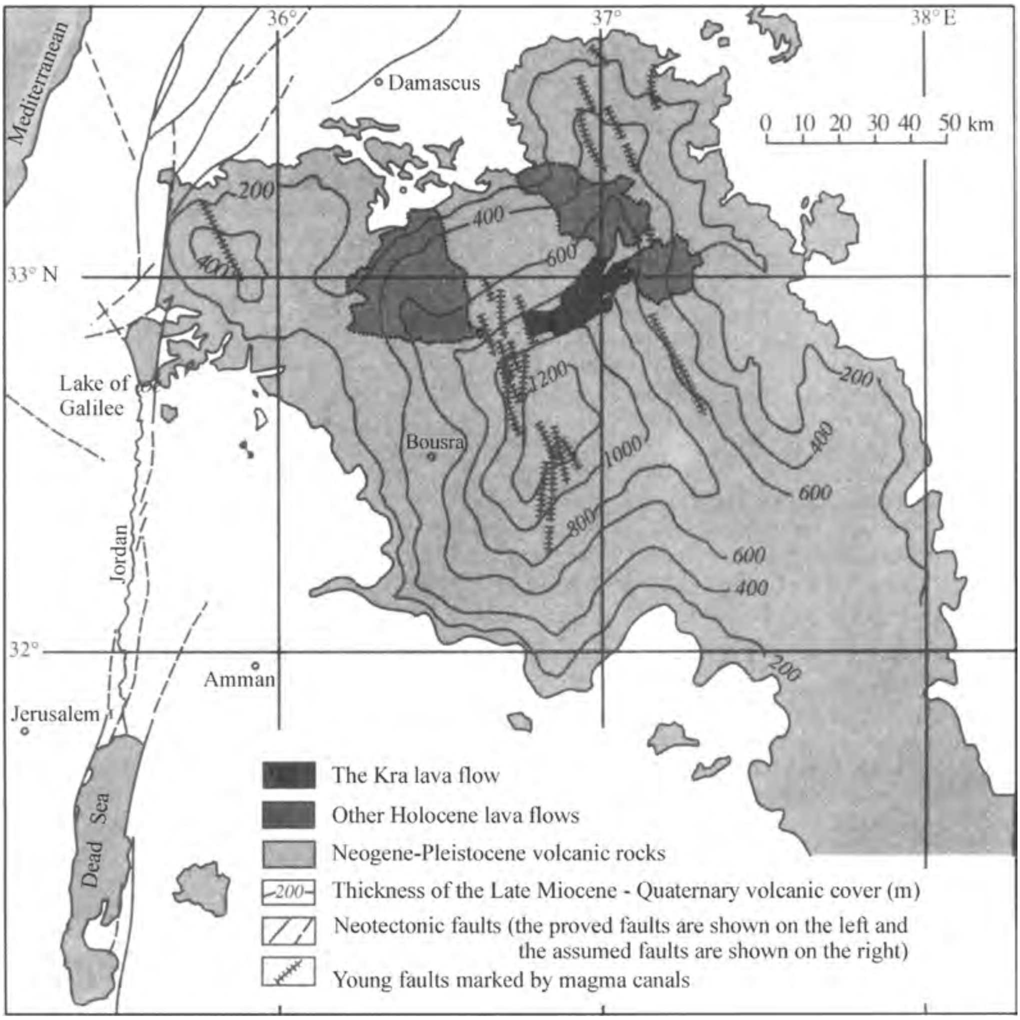

Fig. 2. Active faults and manifestations of the Neogene–Quaternary and Holocene volcanism in the southwestern Syria and adjacent part of Jordan (Trifonov & Karakhanian 2004).

and the surface is formed by *a-a* type basaltic boulders.

These sites with bones were discovered by Cyril C. Graham in 1857. Later, J. C. Wetzstein, Consul of Prussia, described the sites according to the story of a local Sheikh. The detailed studies were carried out by Dubertret & Dunand (1954–1955). The author visited the area first in 1986 together with the Syrian geologists F. F. Al Baqqa, H. Al Maleh, Yu. El Khair and T. Zaza (Trifonov & El Khair 1988; Trifonov & Karakhanian 2004).

In Khirbet El-Umbashi, the bones are concentrated, along with other settlement remains, in the upper cultural horizon of the layer. This layer is up to 2.5 m thick with pebbles and gravel in the carbonate loam matrix occuring on the uneven surface of the Late Pleistocene lava (Fig. 4). The layer forms a lower terrace of the wadi and is horizontally stratified. Its pebbles and gravel represent local basaltic material and are not rounded; they are mountain alluvium from a temporary stream. Its carbonatization (the strongest in the upper surface) has been caused by climatic influence and is typical of the Quaternary alluvium terraces in Syria. The carbonate matrix contains small fresh pyroxene crystals which were produced by the youngest eruptions of the Khaldieh Late Pleistocene basaltic stratovolcano situated 31 km westward. So, the layer may be have not only fluvial, but have a more complex origin.

Fig. 3. Space ERTS imagery of the Kra lava flow region in the southwestern Syria (Space Image Atlas of Syria 1996). U, Khirbet El-Umbashi; H, Hebariye; R, Rdemet Ash-Shukhur.

The cultural horizon with bones is usually several tens of centimetres thick. Thickness increases near the ruins of some buildings up to 1.2 m. The primitive buildings were covered by the Kra lavas and therefore predate the eruption. More complex buildings were constructed after the eruption, on top of the lavas. Within the horizon, many fragmented bones as well as fragments of flint tools, moulded ceramics and cone-shaped stones with drilled holes along axes (were probably tied with cords and used to catch cattle) were found. The ceramics were made with red clay and were well fired (Fig. 5). Rough vessels with admixed coarse sand predominated, but same fine, glossy pottery was also found. Some fragments were covered by a scored comb-like ornament or were coloured by crossing brown, white and black stripes. A fragment of a painted figure of bull or deer was also found.

The ruins, partly overlain by the lava on the southern side of the recent wadi Kra, represent the remains of rectangular constructions made with basaltic stones. Beside those, two other types of construction were found at a distance from the lava flow. Rare findings of ceramics support a synchronism between both types of ruins with ruined buildings near the lava flow. The first type is represented by several rounded pits of 2–2.5 m in diameter and up to 0.5 m deep, hollowed out basalt. Probably, they served as foundations for temporary homes. The second type is represented by numerous graves that look like little houses made with flat basaltic blocks and contain rectangular or oval pits inside. Some of them have several pits. We found fragments of skeletons there. Standardization of the graves and very poor implements are signs of a catastrophe, as was shown for the cemetery in the town of Trianda in the Rodos Island after the Great Minoan earthquake–eruption of the middle of the second millenium BC (Marketou 1990).

Discussing the bones, we differentiate 'kitchen-midden'—fragmented bones within the cultural

Fig. 4. Section of the Kra lava flow and its basement in Khirbet El-Umbashi. Rough surface of the Pleistocene lava is covered by horizontally stratified carbonate-terrigenous sediments and the latter are covered by the Kra lava flow. The bone fragments form thin lenses between the Kra lava and the sediments.

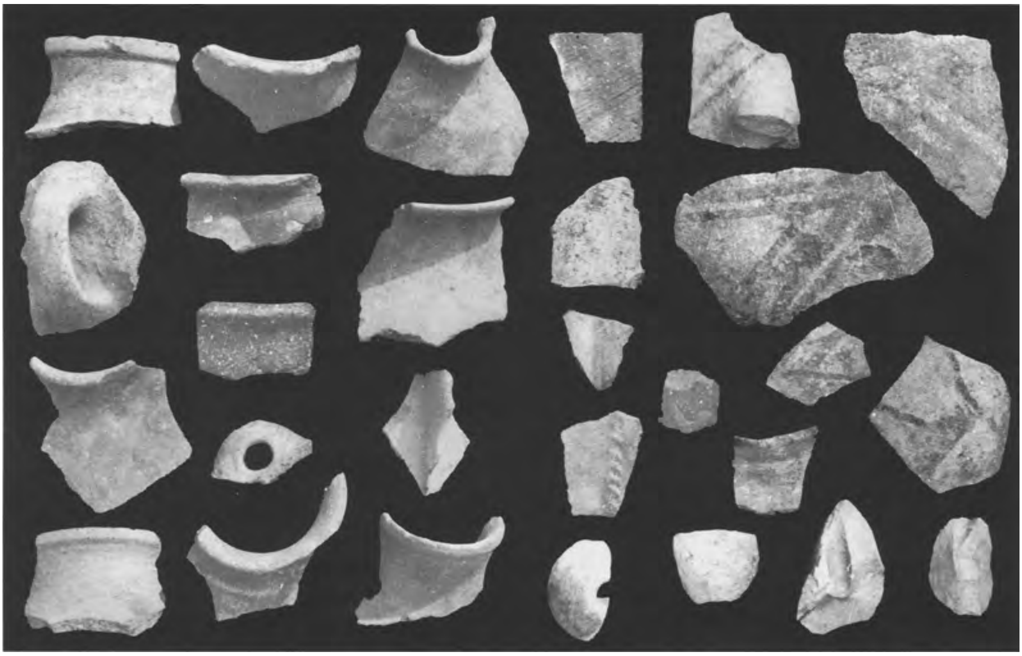

Fig. 5. Ceramics and other archaeological findings from Khirbet El-Umbashi (Trifonov & El Khair 1988).

horizon—and numerous bones at the top, although they probably belonged to identical animals. The 'top' bones cover a larger area. At minimum, they belonged to several tens of thousand of animals. According to the published data (Dubertret & Dunand 1954–1955) and data of our collection analysed by Dr E. M. Vangengeim, they are mostly the bones of domestic animals, such as bulls, goats, sheep and gazelles. They were similar to recent Syrian cattle, but slightly smaller. Single bones of *Bos primigenius* and camel as reported by Dubertret & Dunand, and probably of donkey or mule were also found in our collection. In contact with the basalts, the bones were soldered into the lava bottom (Fig. 6). Dubertret & Dunand (1954–1955) observed two different effects of the eruption on the bones. Those bones heated up to 600 °C were scorched, but kept their primary microstructure. Other bones that were heated more strongly were calcinated and partly converted into hydroxyapatite.

In Hebariye, the interaction of the bones and the Kra lavas is similar to that at Khirbet El-Umbashi, but the settlement and the area of bone accumulation is smaller. Besides the described buildings and bones, Dubertret & Dunand (1954–1955) reported younger rectangular and rarer oval constructions in both settlements. In Khirbet El-Umbashi, they were built with large basaltic blocks without cementation, were covered by basaltic slabs and had a single door and interior supporting column. Some of these were accompanied by a small yard fenced by a low stone wall having pens similar to those in the Syrian country-side. In Hebariye, similar constructions were built using bigger blocks and did not have the supporting columns. The inner height of the constructions in both settlements does not exceed 1.2 m. So, they could hardly have been built for living, although they were used later for temporary visits by nomads. They were probably built as sepulchres. Dubertret & Dunand attributed these 'megalithic' constructions to the Amorites whose Middle Bronze culture is dated now by 2100–1600 BC. Some are situated above the Kra basalts in Hebariye. So, the constructions were built later. The youngest archaeological generation is represented in Hebariye by the square building of the third–fourth centuries AD.

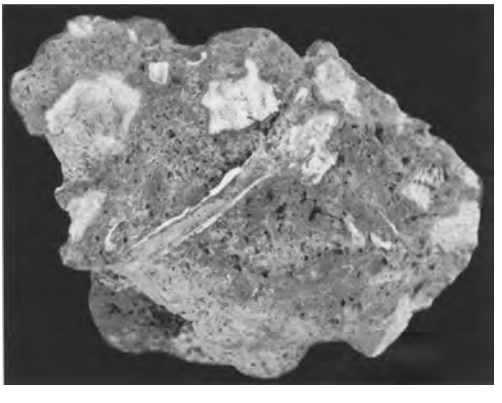

Fig. 6. Breccia of animal bones cemented by the Kra lava, Khirbet El-Umbashi.

Thus, two settlements existed on wadi banks of the Jebel Arab highland in pre-Amorites time. Cattle-breeding was an important occupation of the inhabitants. The existence of the settlements was interrupted by the Kra eruption. Just before their destruction many animals (both domestic and wild) were concentrated near the settlements; although they escaped the eruption, they still died. The lava could not kill them, because it moved slowly along the gentle wadis and hoofed animals like gazelles could easily run away. It is likely that they (as well as people?) perished from volcanic gases, and subsequent lava partially covered what remained by that time. According to the S. Thorarinsson (1969) data, the fluorine explosion during the similar Laki eruption of 1783 in Iceland killed half of the cattle and a significant proportion of inhabitants. We could not find any human remains among the bones and the former investigators had not reported this either. But the necropolis, with numerous standard burials from this period most probably served as the burial place for those who had not been covered with lava. After the eruption, the settlements became populated again.

The age of the Kra eruption is close to that of the settlements and bones and is older than the Middle Bronze 'megalithic' constructions. Dubertret & Dunand (1954–1955) dated the ceramics from the settlements by the Early Bronze epoch. Dr H. Saliby from the Damascus Archaeological Museum dated our collection (Fig. 5) by the last third of the third millennium BC.

The bones do not contain carbon. The ruins of rectangular construction partly overlain by lava in the southern side of the recent wadi Kra contain bones of domestic hoofed animals. Probably, the construction served as a stall. Its floor represents a mixture of the dug palaeosoil and the remains of cattle activity. The material was collected by W. L. Liere in 1954 and dated by H. Vries and G. W. Barendsen from the Groningen University (Dubertret 1963). They reported: '... part of the present material had obviously been charred with absence of oxygen. It was nearly black and it contained as much as 25% of carbon. The age was found to be 4075 ± 160 years' (calendar 2880–2460 BC). So, the ^{14}C date is several hundred years older than the archaeological one.

A similar relationship was observed within a soil in Armenia during trenching of the Bronze Age settlements in the Khanarasar active fault zone near recent village of Ghegadzor (Subatan) and in the Fioletovo segment of the Pambak–Sevan active fault zone. In Fioletovo, the dug palaeosoil from the floor of the archaeological object gave the ^{14}C date 5030 ± 170 years (calendar 3982–3647 BC) and contained ceramics of the twenty-sixth–twenty-second centuries BC (Philip *et al.* 2001; Trifonov & Karakhanian 2004). Alexandrovsky (1996) studied the problem in the example of the 'Trayan' man-made bank in Western Ukraine. Using detailed ^{14}C dating he showed that a soil formed over a long period and its age could differ by several hundred or even more than a thousand years in the surface horizon and at a depth of 10–20 cm, where the huminic acid accumulation and transformation was still continuing. Because the surface horizon could be destroyed during building and exploitation of the construction, its real age might be younger than the ^{14}C date of the preserved soil top. So, the last third of the 3rd millennium BC is probably the most reasonable age of the eruption under discussion in Syria.

Correlation between the legend of destruction of Sodom and Gomorrah and the eruption of Kra

The most likely explanations of the destruction of Sodom and Gomorrah as natural phenomena are the following four hypotheses: (1) environmental (climatic) change; (2) flooding; (3) strong earthquake; and (4) volcanic eruption.

(1) '... The valley of Jordan ... was well watered everythere, before the Lord had sent destruction on Sodom and Gomorrah; it was like the garden of the Lord, like the land of Egypt, on the way to Zoar' (Genesis 13:10). The catastrophe resulted in 'destruction on those towns, with all the lowland and all the people of those towns and every green thing in the land' (Genesis 19:25). Nissenbaum (1994) added the accompanying destruction of the towns environmental change to this. He compiled historical, archaeological, hydrological and palynological data on Palestine and Egypt and Sumer and showed that the devastation of Sodom and Gomorrah correlated with drought conditions causing famine, a decline of the population, desolation of urban settlements, collapse of burgeoning kingdoms and flourishing agricultural societies and their replacement by more primitive heminomadic cultures. The process was dated in the second half of the third millennium BC with a peak in the twenty-fourth–twenty-second centuries. We found synchronous environmental and historical changes not only in the Fertile Crescent, but also in the circum-Black Sea region, the Trans-Caucasus, and the southern Turkmenia (Trifonov & Karakhanian 2004). Environmental change occurred over a fairly long time (even in such climatically fragile semi-desert area as Palestine) and could not have been the direct source of the destruction of Sodom and Gomorrah. Understanding it, Nissenbaum (1994) considered probable 'that a major earthquake occurred during this period to provide a *coup de grace* to already collapsing society'.

(2) Strabo (first century AD) was possibly the first person who supposed that the destruction was caused by the Dead Sea waters bursting its bounds and flooding the towns. Bentor (1990) developed the hypothesis. He remarked on the very shallow depth of the sub-lacustrine swell in a continuation of the Lisan peninsula that joins the larger deep northern and smaller shallow southern parts of the Dead Sea. Very slight fluctuations of the lake level may have separated these parts and the southern one had to be dried because of a high evaporation. Bentor showed that such a situation had probably existed for some time. He proposed three mechanisms for the flood: the climatically-induced rise of the lake level, subsidence of the swell by salt solution, and a strong earthquake. The first mechanism is doubtful, because destruction of the towns happened during a drought, when the lake level could only decrease. And as Nissenbaum (1994) showed by using the Neev & Emery (1967) data, even at that time the southern basin of the Dead Sea existed and had been characterized by massive deposition of salt. If the basin became desiccated immediately prior to the destruction of the towns, the plain could not have been 'well watered everythere, ... like the garden of the Lord, like the land of Egypt'. This argument could hardly correspond to the second mechanism of flood. So, if it took place (although the flood was not combined with destruction of the towns by 'fire and flaming smoke'), its most probable source may have been a strong earthquake.

(3) The two previous hypotheses had to invoke a strong earthquake as a direct source of the destruction of Sodom and Gomorrah. This explanation of the destruction is now the

most popular. It is based on high seismicity and both historical and prehistorical strong earthquakes identified in and near the Dead Sea transform fault (Ben-Menahem 1991; Nur 1991). Although the earthquake may have happened there at or close to the time of a collapse of the towns, it is not commensurate with 'fire and flaming smoke' attributed to the event and 'destruction on those towns, with all the lowland and all the people of those towns and every green thing in the land'. The Bible also identifies earthquakes as a particular phenomena, telling 'about Israel in the days of Uzziah, king of Judah . . . , two years before the earth-shock' (Amos 1:1) or '. . . as you went in flight from the earth-shock in the days of Uzziah . . .' (Zechariah 14:5). Description of the destruction of Sodom and Gomorrah is different.

(4) Block (1975) located the destructed towns near the Dead Sea and suggested that the destruction may have been caused by a volcanic eruption with pyroclastics-tuffs and volcanic bombs. He considered that the ascending magma may have come into contact with oil deposits and caused the burning of petroleum. Such deposits may have existed in the area, because 'the valley of Siddim was full of holes of sticky earth' (Genesis 14:10) which Bentor (1990) interpreted as asphalt wells. The main objection to Block's hypothesis is the absence of manifestations of the Holocene and Late Pleistocene volcanism near the Dead Sea.

Bentor (1990) paid attention to the description of signs of a volcanic eruption in the Exodus. When the Jews continued to move towards Mount Sinai, 'the Lord went before them by day in a pillar of cloud . . . and by night in a pillar of fire . . .' (Exodus 13:21). Just before God descended on Mount Sinai, 'when morning came on the third day, there was thunder and flames and a thick cloud on the mountain and a horn sounding very loud. . .' (Exodus 19:16). 'And all the mountain of Sinai was smoking, for the Lord had come down on it in fire; and the smoke of it went up like the smoke of a great burning; and all the mountain was shaking' (Exodus 19:18). 'And all the people were watching the thunder and the flames and the sound of the horn and the mountain smoking' (Exodus 20:18). If we ignore the fact that the Exodus was several hundred and perhaps a thousand years after the destruction of Sodom and Gomorrah, no evidence of recent volcanism has been found in the Precambrian rocks of the Mount Sinai. According to Bentor's (1990) notion, this can be explained by peculiarities of the Bible which 'does not care much about dates and places, shifting geological events around to suit its purpose'. Discussing where the narrators of the legend could listen to volcanism, Bentor refers to the young volcanic manifestations in the Druze highland, that describes the Kra eruption. Could it be really a source of the legend about destruction of these towns?

Bentor (1990) argued that the flood origin of the destruction by the command of the God's messengers to Lot 'Flee for your lives, without . . . waiting in the lowland, go quickly to the mountain or you will come to destruction' (Genesis 19:17). But going to the mountain is a way to escape not only from the flood, but also the moving lava. The Bible division of pastures between Abram and Lot does not seem to contradict the location of Sodom and Gomorrah in the south of Syria and the suggested destruction by the lava flow from Kra, since 'Lot took for himself all the valley of Jordan . . . , moving his tent as far as Sodom'. Supporting evidence is contained in the texts of the third millennium BC found during the excavations of ancient town of Ebla (Tell Mardikh, 40 km to the SW of Aleppo, Syria), which mentions both Abram and the towns of Sodom and Gomorrah lost in fire. However, the translation of these texts has to be revised (Keller 1980). In the meantime, assuming that the lost cities were in southern Syria, we could hardly explain how Lot could reach Zoar in few hours (if it was situated in the Jordan River valley or near the Dead Sea), and how Abram could see what happened to the cities from the mountain that was situated on the western side of the Jordan River.

Particular difficulty for the volcanic as well as Nissenbaum's climatic interpretations of the destruction of Sodom and Gomorrah is that, according to the Bible tradition, Abram and Lot lived early in the second millennium BC, but the eruption and synchronous climatic changes occurred in the second half of the third millennium BC, most probably in the twenty-fourth–twenty-second centuries. The flood and earthquake interpretations do not involve the same difficulty, because they do not have the geological dating documentation. Attributing the event to the period of patriarchs, Nissenbaum (1994) estimated its age by comparing the Biblical text with the historical and archaeological data: 'The era of the patriarchs has been dated as late as the 19th or 18th century BC by scholars who found similarities between the social structure as described in texts from Mari, dating to the early second millennium and the Bible . . . Others have proposed that from an archaelogical point of view the second half of the third millennium BC, that is Early Bronze IV (2300–2000 BC), provides the best conditions for the movement of seminomadic people as described in the Bible for the migrations of the patriarchs'. The represented data on the Kra eruption conform well with this archaelogical estimate.

It is possible that the Bible tale about the destruction of Sodom and Gomorrah combines collective memories from two events. Located in the Dead Sea region, Sodom and Gomorrah were destroyed by a natural disaster, which was most probably a strong earthquake or a flood provoked by such an earthquake, but the fresh memory about two settlements perishing from a volcanic eruption caused the population to equate these two events and it strongly enhanced the didactic effect of the legend. Such joining is characteristic of old legends.

A very interesting circumstance is synchronism between the climatic change for the worse and the geodynamic activation manifested by strong earthquakes and volcanic eruptions in the second half of the third millennium BC. The synchronism was found not only in the Near East, but also in the Armenian Highland (Trifonov & Karakhanian 2004). The combined effect of both groups of natural phenomena may have led to the social, economic and political crisis that took place in that time in the Oykumena.

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Geological histories and geohazard potential of Pacific Islands illuminated by myths

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Abstract: Understanding of the geological history of the Pacific, especially its geohazard potential, can be improved using details in ancient and properly-authenticated Pacific Islander myths. To demonstrate this, a synthesis of Pacific Island origin myths involving islands having been either 'fished up' or 'thrown down' is presented, with an account of origin myths for the island Niue used as a case study. A discussion of geohazards and myths in the Pacific focuses on tsunami, coseismic uplift, and island flank collapse, the last being illustrated by the first analysis of myths recalling 'vanished islands' in the Pacific.

For several reasons, the long-term geological history of the Pacific Ocean and its constituent islands—a vast area covering around one third of the Earth's surface—has not proved nearly as easy to reconstruct as that of the continents (Menard 1964; Nunn 1994, 1999*a*). One reason is that almost the entire area is covered with ocean and, despite the development of innovative techniques of mapping and sampling geology at depth, the ocean floor is inevitably known in less detail than equivalent areas of dry land. An associated reason is that much basic mapping of such areas, being mostly either international territory or belonging to poorer nations, is driven by private enterprise interested ultimately in exploiting their natural resources. The combination of a general lack of commercially exploitable resources on the Pacific Ocean floor and the costs involved in extracting such resources from beneath several kilometres of ocean has contributed to a general downturn of interest in Pacific ocean-floor geological mapping in recent decades.

Many Pacific islands are valuable indicators of ocean-floor geology (lithologies and structures) but some are difficult to reach, difficult to map particularly for reasons of access and visibility, and have never been subject to systematic geological survey at a regional level. Many geological accounts of Pacific Islands date from the Second World War or earlier, and have proved difficult to reconcile with more recent accounts, particularly those produced by marine geologists.

This piecemeal geological picture of the Pacific Ocean and islands may be adequate for global models, even for locating particular resources or identifying areas particularly prone to certain types of geological hazard. Yet while the picture remains uneven, as it is likely to do for a long time, and less detailed in many places than for areas of equivalent size on the continents, then a greater number of unknown hazards and hazard-prone areas are likely to remain. The imperative of discovering more about these lies in appreciating that the influence of such hazards and the extent of hazard-prone areas may reach beyond the region and onto the Pacific Rim. For example, little is known about the potential for mega-tsunami associated with island flank collapse in the Pacific yet the conclusions reached by scientists modelling this phenomenon in the Atlantic (Carracedo *et al.* 1999; Day *et al.* 1999; Ward & Day 2001) underline the importance of advancing equivalent research in the Pacific (McMurtry *et al.* 1999; Clouard *et al.* 2001).

This paper takes an unorthodox approach towards improving our understanding of geological history and geological hazards (geohazards) in the Pacific Ocean and Islands by examining selected Pacific Islander myths. People have occupied most of the western Pacific Islands for around 3000 years and most of the remainder since at least AD 400 (Fig. 1). Traditional stories, passed down through the generations orally, were recorded by many of the first non-Pacific Islander (European) visitors to the region. Although the value of such myths in reconstructing cultural histories in the region has been vigorously debated (Malinowski 1954; Maude 1971; Gunson 1993), there seems to be considerable merit in using carefully-chosen myths to illuminate post-settlement geological histories (Vitaliano 1973; Cronin & Neall 2000; Nunn 2001, 2003).

Following a discussion of the nature of the database and how it is interpreted, the first part of this paper looks at Pacific Island origin myths, and relates them to various processes operating in particular parts of the Pacific. The second, by way of example, looks specifically at the origin stories for

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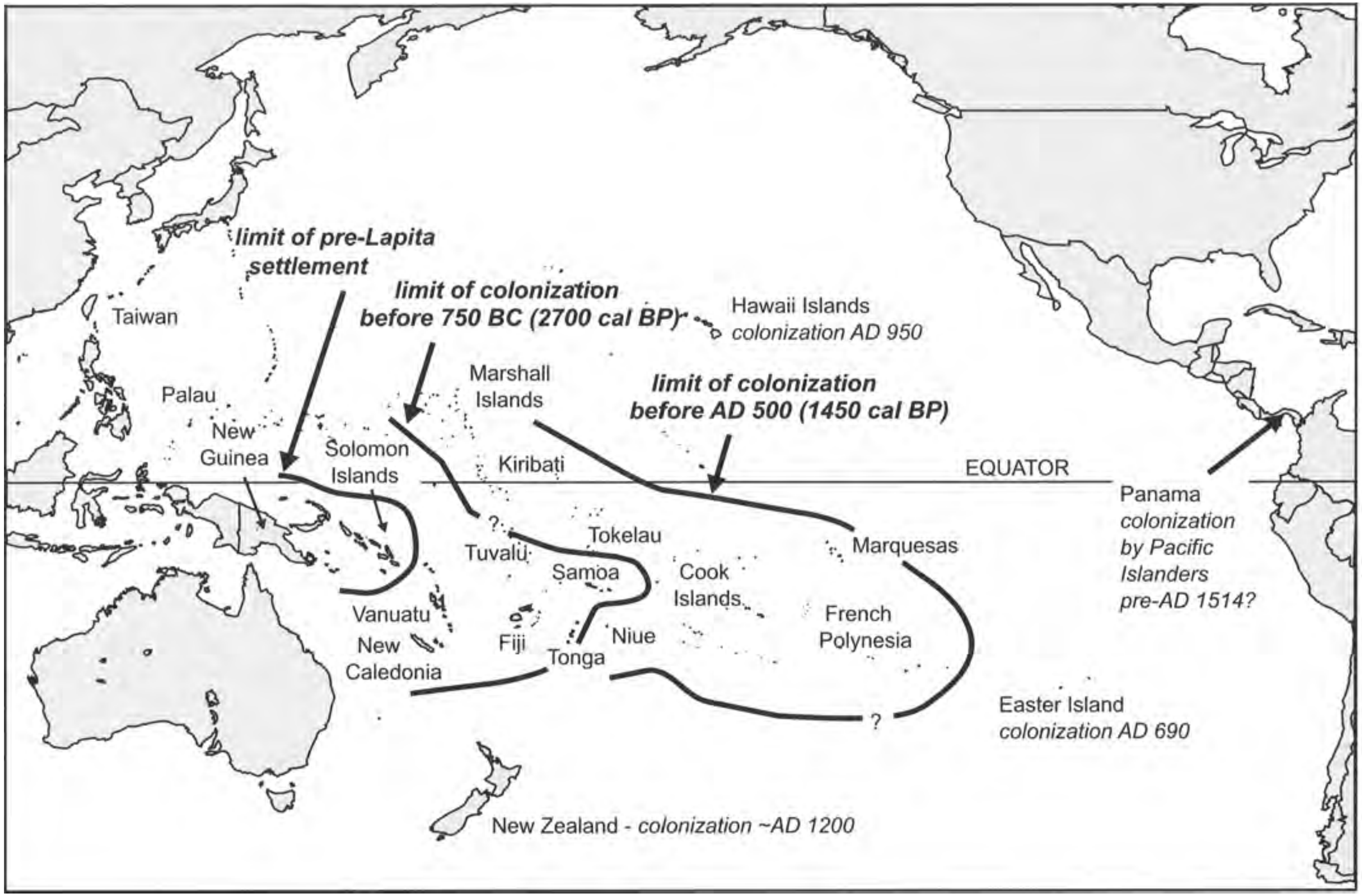


Fig. 1. The Pacific Basin showing selected groups of Pacific Islands and the history of human colonization of the region using isolines of equal earliest-known settlement age (after Nunn & Britton 2001).

the central Pacific Island Niue and discusses their provenance. The third looks at myths concerning geological hazards (with an emphasis on island flank collapses) and examines how these myths might inform more orthodox studies of such hazards in the Pacific region. The paper concludes with a discussion of future directions for this type of research in this region and beyond.

Nature of mythical data for the Pacific

There is no reason why a myth should preserve any details of past events, cultural or geological. Much of the criticism levelled at earlier, often implausibly literal interpretations of Pacific myths, made this point and argued that myths, and oral traditions more broadly defined, were often created for cultural reasons unrelated to any single historical event (Lowie 1915; Barrère 1967; Lowe *et al.* 2002). The contrary view—that some myths do preserve intelligible details of past events—has been championed for the Pacific Islands by those concerned with their cultural histories, particularly their genealogies (Buck 1954; Latukefu 1968; Gunson 1993). The interpretation of non-cultural detail, broadly classifiable into geological and environmental, has proved less controversial with several studies demonstrating the merits of certain myths globally (Vitaliano 1973) and for the Pacific (Taylor 1995; Nunn 2001, 2003).

In selecting myths for analysis, it is important to demonstrate both their antiquity and their authenticity. In the Pacific Islands, the rapid loss of cultural identity in recent decades has led concerned governments and individuals to re-create bodies of myths but these cannot necessarily be considered as ancient or long-held, and may significantly mislead people who are unaware of their recent invention (Howe 2003). Many of the earliest Europeans to settle in the Pacific Islands invented mythical details about their early history which are difficult to distinguish readily from authentic, longer-held traditions.

Although it is a challenge to demonstrate the antiquity and authenticity of particular myths among groups of pre-literate peoples, key criteria are the names of places and people used, the details of the myths themselves, and the existence of variations on the same myths recorded from neighbouring islands or island groups. Names can reveal the recent invention (or dilution) of a particular myth, such as the use of Nu'u (for Noah) in diluvian (flood) myth from Hawaii (Spence 1933). The narrative details of such myths may also reveal their 'europeanization'. Where similar yet subtly different myths exist for adjoining islands or island groups, that suggests that these myths are both ancient and authentic; examples include the origin stories associated with the demigod Maui that exist, albeit in various forms, throughout most Pacific Islands (Luomala 1949).

There have been several compilations of Pacific Island myths in which valuable information concerning geological changes can be found (e.g. Fornander 1878; Gifford 1924; Beckwith 1940). Yet, some such compilations, like many more recent accounts of Pacific Island myths, tend to focus on personalized and romantic myths, often as expressions of cultural antiquity or intended to support particular models of cultural evolution (e.g. Finnegan & Orbell 1995; Flood *et al.* 1999). More useful for extracting and understanding geological detail in Pacific Island myths are the records of those who first wrote them down, commonly the first Europeans (sailors, missionaries, colonial administrators) in the region. Most of these accounts appear comparatively uninfluenced by the prejudices of the person recording them and are considered authentic records of Pacific Islander mythical beliefs, typically around 1830–1860 (e.g. Hale 1846; Grey 1855).

Some relevant myths are regional in extent, and some of these appear to have analogues in other parts of the world and are therefore representatives of global myth-motifs. An example are the myths found in many parts of the Pacific that involve islands being 'fished up' by a demigod, thought to be representative of the global 'land-raiser' myth-motif (Oppenheimer 1998). Other relevant myths are localized, sometimes applied to only a single location, typically in recollection of a single event such as an island disappearance or a catastrophic wave impact.

A final issue of relevance to the geological interpretation of particular Pacific Island myths is whether or not they are autochthonous to a particular island or cultural group. In particular, it is important to know whether the people who claim the myth created it from what they witnessed on the island (group) where they live, or from another island (group) where their ancestors once lived. This point is illustrated by the discussion of origin myths for Niue Island, given below as a case study.

Pacific Island origin myths

Island origin myths for the Pacific generally provide excellent examples of how geological detail can be interpreted meaningfully in the light of modern processes of Earth-surface development (Nunn 2001, 2003). There are two main myth-motifs for island origins in this region, referred to here as 'fishing-up' myths and 'throwing-down' myths.

Fishing-up myths involve a god (or demigod) dropping a magic fishing line into the ocean at a place where he may know a submerged island exists, and then drawing it up above the ocean surface. It is likely that many such myths were created in parts of the Pacific where shallow underwater eruptions occurred within human memory. In such myths it is recalled that the fish struggled as it was pulled up, the water bubbling and foaming, as it does during such eruptions (Fig. 2). Sometimes the island disappeared after it was pulled up, as do many such 'jack-in-the-box' islands (Nunn 1994, 1998). Fishing-up myths are also thought to recall coseismic-uplift events, which are common on (part-) limestone islands along Pacific frontal arcs (Ota 1991; Berryman *et al.* 1992), and whose catastrophic effects are likely to have merited recollection in myth.

Throwing-down myths in the Pacific involve a god (or person of rank) flying through the air or taking giant steps across the land and deliberately dropping or spilling 'earth' from a basket or his hand onto the ground below to create an island. This is interpreted as volcaniclastic materials raining down or settling on an area following an eruption.

This section treats fishing-up and throwing-down myths separately; many of the basic data were reported by Nunn (2003) and are not repeated here. It needs to be clear that the 'heartland' of each of these particular myth-motifs is distinguishable from the area across which they subsequently diffused. The heartland is the area (or areas) within the Pacific where the myth-motif appears to have originated and, if the connections with geological phenomena suggested above are correct, then this area would be one where those phenomena occurred during human memory. Once the basic myth had originated, then the (descendants of the) people who created it dispersed to islands and island groups elsewhere in the Pacific, carrying the myth with them. So the basic myth would have been adjusted, perhaps in response to the witnessing of new geological phenomena, or would have evolved—like a biotic species isolated on an island away from the original population—into a different form from the original.

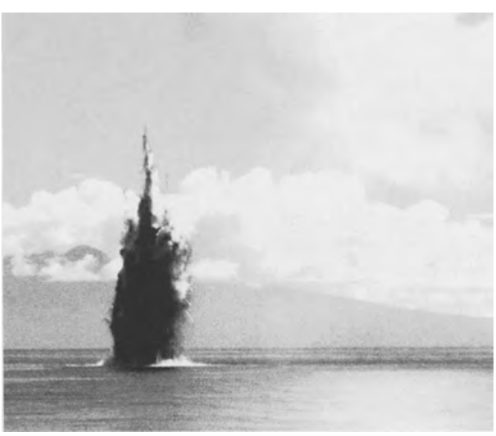


Fig. 2. The May 2000 eruption of underwater Kavachi Volcano in Solomon Islands (photo credit: Richard Arculus). Note the resemblance of the eruption plume to a huge fish, a significant detail in many island-origin myths in the Pacific.

Fishing-up myths: development

There are various ways in which the heartland of fishing-up myths can be recognized. First, by the name (or a name variant) of the fisher—commonly Maui or his father Tangaloa—and second, by the degree of consistency in the details of fishing-up myths from within the same region. For reason of progeniture, Tangaloa might be considered the earliest fisher of islands in the Pacific and, since he is named as the principal fisher only in Samoa, this might be considered the place in the Pacific where this myth-motif originated. Tangaloa is also named as a fisher of islands (alongside Maui) elsewhere in the tropical South Pacific (Fig. 3).

Since only volcanic islands exist in Samoa, it is considered that fishing-up myths here must have been created to recall shallow-water eruptions (rather than coseismic-uplift events—see above). Yet the only candidate for shallow-water eruption during the 3000 years or so that the Samoa chain of hotspot islands has been occupied by humans (Kirch 1997) is somewhere in the vicinity of Tau Island (in the Manua group of American Samoa) where an account of such an eruption around 1866 was given to Friedländer (1910). Assuming that this site, close to the probable hotspot (Nunn 1994), was active earlier in Samoa's post-settlement history, it still seems slender evidence on which to build such an enduring myth.

More probable is that the myth came to the island group that we now call Samoa from the group to the south that we now call Tonga, where there are currently numerous active shallow-water volcanoes (Nunn 1998) and many examples of coseismic-uplift events, both witnessed directly (e.g. Sawkins 1856) and inferred from the palaeoshoreline record (Nunn & Finau 1995). Tongan oral history has abundant fishing-up myths, most naming Maui as the fisher and all referring to limestone rather than volcanic islands. Since fishing-up myths from most other parts of the Pacific Islands also name Maui as the fisher and refer almost exclusively to emerged limestone islands (Nunn 2003), it

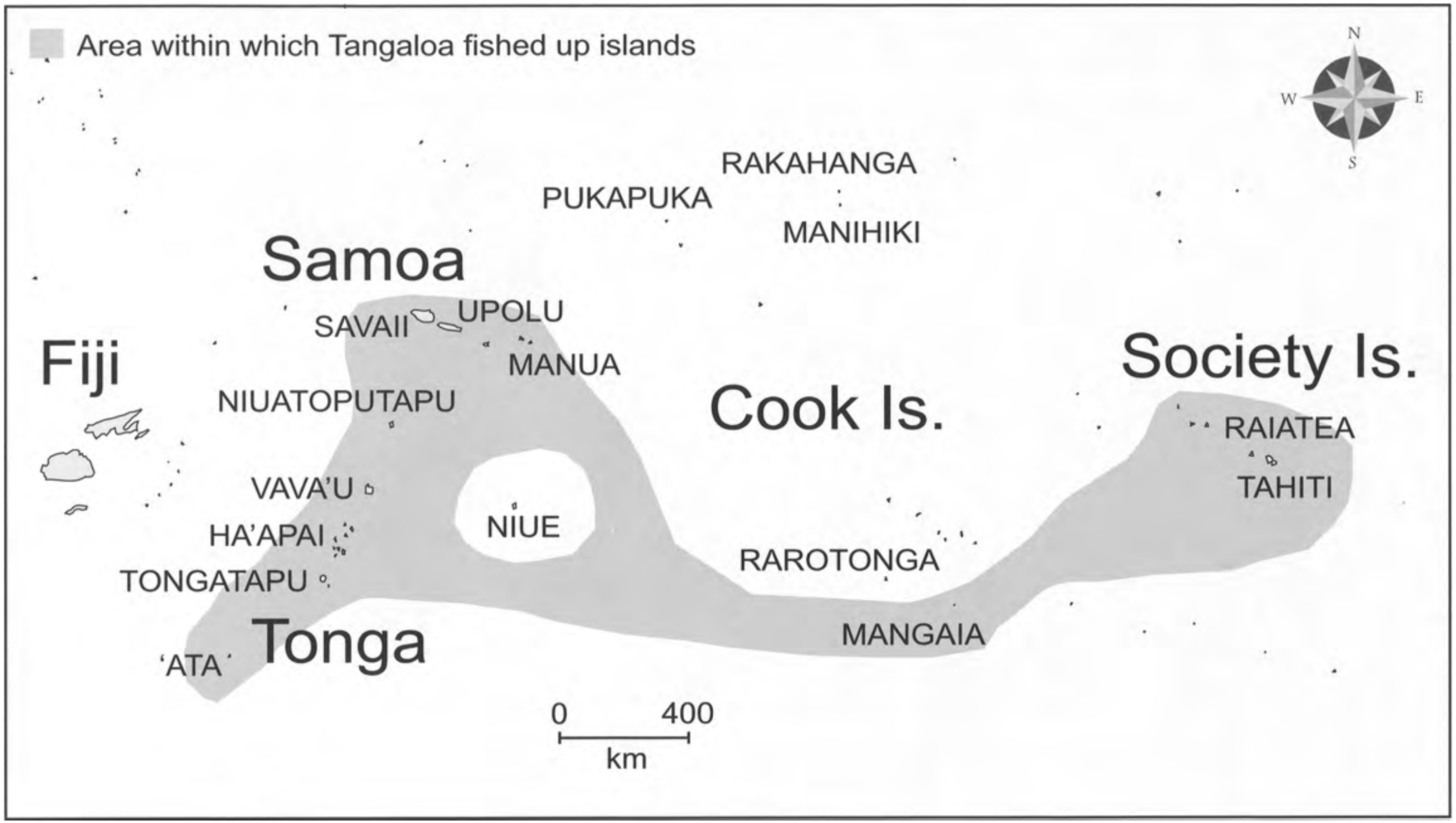


Fig. 3. The region of the South Pacific within which Tangaloa is said to have fished up islands (after Nunn 2003). Since Tangaloa was the father of Maui, the most commonly-named fisher of islands in the Pacific, this region is considered to be the heartland of the fishing-up myth motif in the Pacific. Within this region, only in Samoa is Tangaloa named as the principal fisher, suggesting that it may have been here that this myth-motif first developed.

is considered that it was from Tonga that the people carrying those myths with them diffused and came to apply them to islands they later occupied.

It is therefore assumed that the fishing-up myth-motif for the Pacific was created in Tonga and Samoa and then spread out within the immediate region (see Fig. 3). Although the only active shallow-water volcanoes in this region occur in Samoa and Tonga, there are many limestone islands which have a similar appearance to those in Tonga that experience occasional coseismic uplift. These include islands like Mangaia in the southern Cook Islands and Rurutu in French Polynesia. It is suggested that the earliest inhabitants of these islands, recognizing that they looked similar to high limestone islands in Tonga and exhibited similar lithologies, transferred the fishing-up myth to them to explain their origin. A detailed discussion of this process in reference to the island Niue is discussed in a separate section below.

The basic model outlined above for the appearance of the fishing-up myth motif in the Pacific is based both on inference from its present character and distribution and on the incidence of geological phenomena assumed to have informed the details of the myth. This procedure is far from satisfactory although the best possible interpretation given the available data. Yet it is worth considering briefly the antecedents of the development of the fishing-up myth in Tonga and Samoa. The first people in these island groups were the so-called Lapita people who arrived there around 3000 years ago (Kirch 1997). They or their ancestors had travelled through parts of Solomon Islands, perhaps also Vanuatu and Fiji, to reach Tonga and Samoa. They may well have acquired some collective memory of islands like Kavachi (see Fig. 2) erupting or parts of islands in Solomon Islands, Vanuatu and Fiji rising abruptly during coseismic-uplift events. Such memories may have informed the development of the fishing-up myth-motif in Tonga and Samoa.

Fishing-up myths: diffusion

Fishing-up myths are found throughout the low-latitude Pacific Islands, including Hawaii in the north and New Zealand in the south (Fig. 4). These myths probably reached the peripheral parts of this region by diffusion with early colonizers from a heartland in Tonga, Samoa and island groups to the east (see Fig. 3), a model consistent with what is known about the earliest human colonization of Pacific Islands (Kirch 2000). A good example of the evidence for this comes from Hawaii where many fishing-up myths speak of the islands as being 'pieces of white coral' fished up. Yet the Hawaiian Islands are almost entirely of volcanic composition, so the reference to coral is interpreted as demonstrating that the fishing-up myth is not autochthonous to these islands but reached there from islands composed of emerged coral reef.

In general, the fishing-up myths of the periphery (as opposed to the heartland) exhibit greater variation in names and narrative detail (Nunn 2003). Some of the latter could be explained by renewal of mythical detail derived from people witnessing geological phenomena, consistent with the original narrative, in peripheral areas. An example is provided by New Zealand, where fishing-up myths involving Maui are many and explicit, an improbable situation given that the first people reached New Zealand around 700–800 years ago (Anderson 1991; Hogg *et al.* 2003), more than 2000 years after the myth-motif was established. It is possible that early people travelling to New Zealand witnessed shallow-water eruptions in the Kermadec group, at Rumble III (Fig. 4), which are known to have been visibly active at the ocean surface for decades (Simkin *et al.* 1981), or at the frequently-active White Island in the Bay of Plenty (Lowe *et al.* 2002). It is also possible that some of the first settlers on the North Island of New Zealand experienced the effects of coseismic uplift, similar to those during the Wellington earthquake of 1855 and the Hawke's Bay earthquake of 1931 (Goff & McFadgen 2001; Wright 2001). Both of these experiences may have led to an increased regard for the fishing-up myth amongst the first people of New Zealand.

Throwing-down myths

Throwing-down myths are less widespread than fishing-up myths in the Pacific and appear to be confined to volcanic islands. Most throwing-down myths come from Tonga, Samoa and the Hawaiian Islands. Since the former two were colonized more than 1000 years before the latter, it seems reasonable to suppose that the throwing-down myth-motif was created in Tonga–Samoa although, given the numbers of active volcanoes in Papua New Guinea, Solomon Islands, and Vanuatu, close to which ancestral Tongans and Samoans probably passed, it may be that the antecedents of this myth-motif are farther west.

Most throwing-down myths in Tonga and Samoa refer to regularly-active volcanoes such as those on the islands of Kao, Tofua and Savaii. One refers to the centre of volcanically-active Niuafo'ou island, where there is a water-filled caldera, being stolen and dropped to form the island Tafahi, also in Tonga (Mahony 1915). At one time, the volcano Nabukelevu on Kadavu Island in southern Fiji

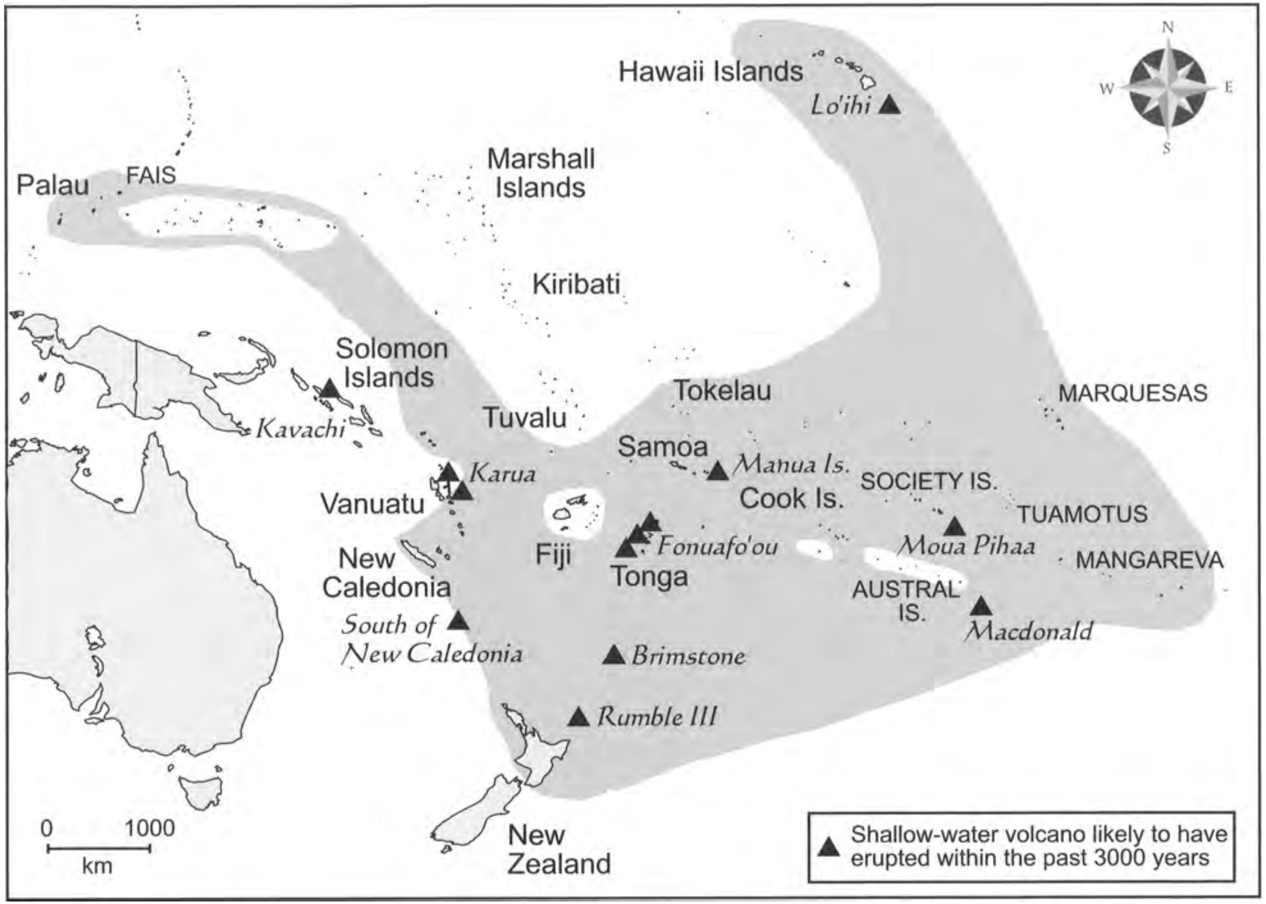


Fig. 4. Distribution of fishing-up myths in the Pacific Islands likely to recall shallow submarine volcanic eruptions and places where these are likely to have occurred within the past 3000 years (after Nunn 2003).

was thought to have become extinct well before human arrival despite the existence of myths which referred to bits of it being dropped elsewhere (Nunn 1999*b*). Taking advantage of new roadcuts, more recent investigations show that this volcano did indeed erupt within the island's post-settlement period (Cronin *et al.* 2004), bearing out the mythical narratives.

It is plausible that throwing-down myths developed in active volcanic zones of the Pacific were subsequently carried into non-volcanic regions and used there as explanations for island origins. The map in Figure 5 shows the principal diffusion pathways from Tonga and Samoa into the generally low island groups of the NW Pacific. The unconsolidated character of many islands on the atolls of this region were best explained by soil falling or being deliberately placed on the ground from a basket of earth carried by a flying being (Nunn 2003). This story is likely to be a derivative of throwing-down myths associated with volcanic eruptions.

Case study: origin myths for Niue Island

The island Niue in the central South Pacific is an isolated, 70 m high Quaternary coral-reef limestone island uplifted at average rates of 0.13–0.16 mm a^{-1} as it has ascended the lithospheric flexure (outer gravity high) associated with the subduction of the Pacific Plate along the Tonga–Kermadec Trench 275 km to the west (Fig. 6). The first people settled Niue about 1900 years ago (Walter & Anderson 1995). Their descendants at the time of European arrival in the eighteenth and nineteenth centuries recounted several groups of origin myths that can be interpreted as recalling successive coseismic-uplift events. The original data and sources are given in Nunn (2004).

The most common origin story involves two people named Huanaki and Fao arriving on Niue from Tonga and, finding the island awash at high tide, stamping on it causing it to rise and form dry land. A second stamp caused the island to rise again and led to the appearance of vegetation. A variant of this story involves the demigod Maui in a cave on the ocean floor at a time when the sea 'rolled unbroken' across Niue. Maui pushed Niue up until it became a 'reef awash at low water' and then, with a second heave, 'sent it higher than the spray can reach ... and it became a [high limestone] island like to Tonga' (Thomson 1902, 85–6).

A detail common to both these stories and their numerous variants for Niue (Nunn 2004) involves successive stamps or heaves that cause the island to rise. This is exactly what happens during coseismic-uplift events on islands along many convergent plate boundaries in the western Pacific (Ota 1991; Berryman *et al.* 1992). If coseismic-uplift ever affected Niue, then this would have been a major hazard—and could generate another major hazard in the form of a tsunami—of which the inhabitants of this island should be aware.

No historical earthquakes are known to have occurred beneath Niue, although those with epicentres along the Tonga arc, some 300 km west, are sometimes felt on the island. Yet this need not exclude the possibility of coseismic-uplift events, some of which have recurrence times of many hundred years (Ota 1991; Berryman *et al.* 1992). The evidence in favour of coseismic uplift on Niue is mythical, linguistic and geological. There are several myths that speak of the effects of earthquakes on Niue, one which attributes a great famine to the gods Futimotu ('lift up the island') and Futifonua ('lift-up-the-land') (Cowan 1923), and there are many words for earthquake in the Niuean lexicon (Smith 1901). Possible geological evidence comes from vertical series of emerged notches, similar in form to notch series elsewhere formed by coseismic uplift (Nunn 2001, 2004).

Yet Niue lies in an intraplate location of a kind generally considered aseismic, and there is no reason to assume that the island's rise up the flank of the flexure in this location has been sporadic rather than smooth. The origin myths, like those that recall earthquakes or the associated famines, might not be autochthonous to the island but transferred there from elsewhere. The cliff 'notches' might simply manifest erosion of strata of differing resistance, always a troublesome issue in cliffs of young emerged reef limestone. Niue is a high limestone island, superficially indistinguishable in appearance from high limestone islands like 'Eua, Tongatapu and Vava'u islands that rise from the frontal arc in Tonga where coseismic uplift events are to be expected and have occurred (Ota 1991; Nunn & Finau 1995). Since many Niuean myths speak of the first people arriving from Tonga, which is consistent with archaeological data, it is concluded that some of the first people to make the journey brought with them origin myths recalling successive coseismic-uplift events of Tongan islands and readily applied it to the apparently similar island of Niue (Nunn 2004).

Geohazards and myths in the Pacific

Many Pacific Island myths appear to recall catastrophic events, ranging from volcanic eruptions, earthquakes to large waves. The value of these myths to an understanding of such phenomena, particularly to the estimation of their areas of influence and their recurrence times, appears indisputable. The challenge is to interpret mythical accounts correctly.

There have been some excellent studies of volcanic (eruptive) history in the Pacific Islands

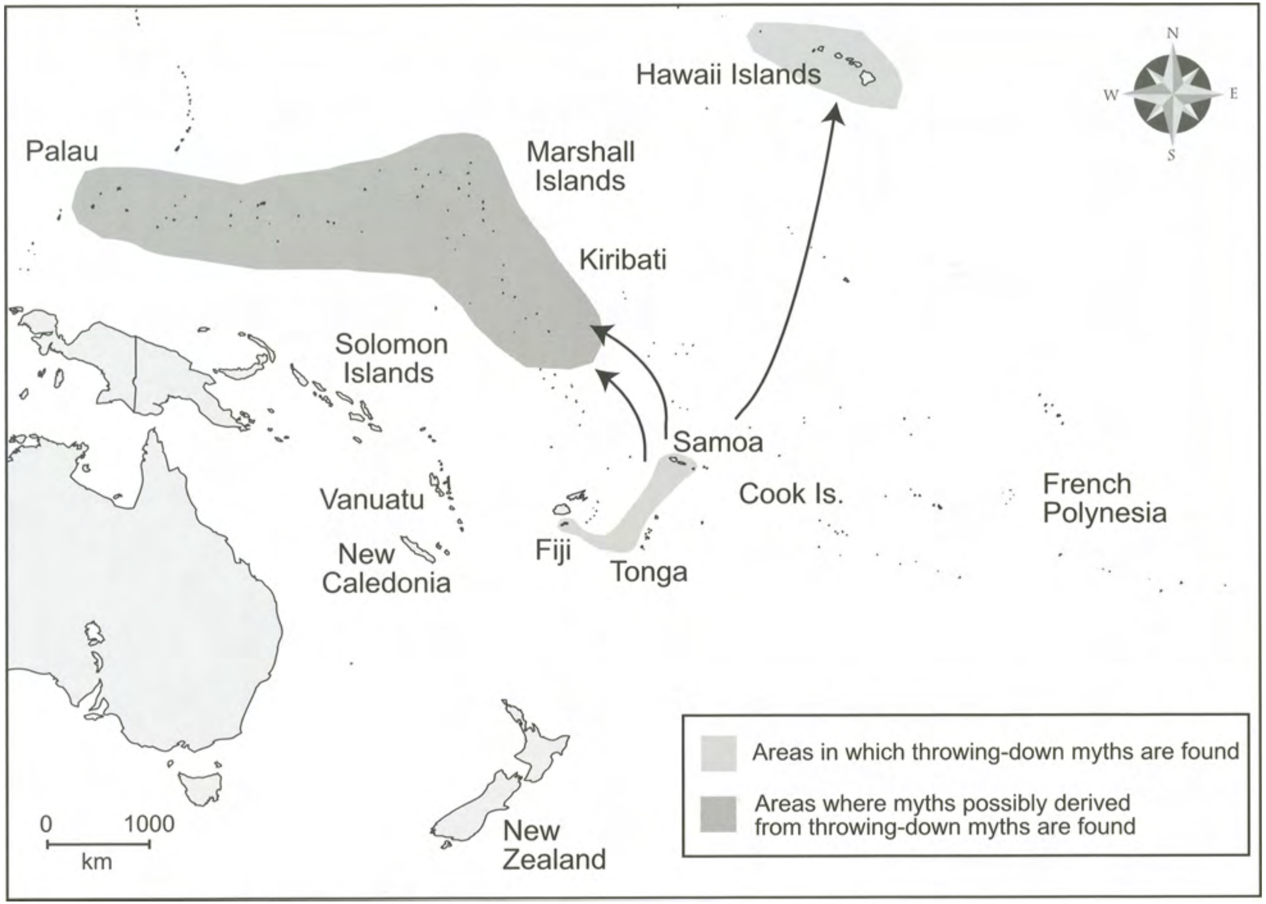


Fig. 5. Distribution of throwing-down and related origin myths in the Pacific Islands and suggested pathways of diffusion (after Nunn 2003).

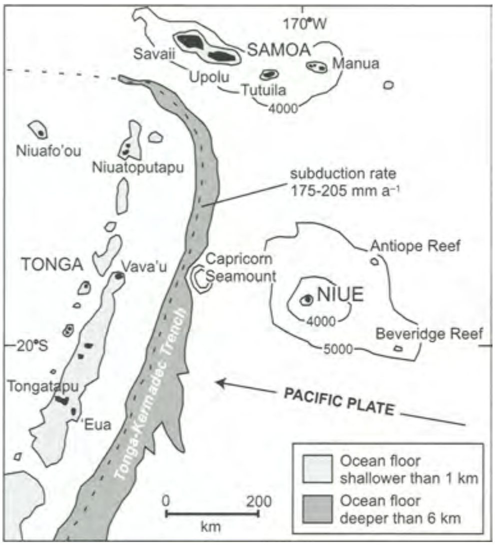


Fig. 6. Bathymetry of the Niue region. The 4000 and 5000 m isobaths are shown only around the Samoa and Niue platforms and Capricorn Seamount. Subduction rate along the Tonga Trench from Pelletier & Louat (1989) and Bevis *et al.* (1995).

(including Papua New Guinea and New Zealand) that have used autochthonous myths for purposes ranging from determining eruptive chronology and event dating to ashfall extent and societal impact (Allen & Wood 1980; Blong 1982; Taylor 1995; Galipaud 2002; Lowe *et al.* 2002). For other geohazards in the Pacific Islands, the use of myth is less common and, for this reason, this section considers some of those (non-volcanic) geohazards.

Tsunami

The 26 December 2004 Indian Ocean Tsunami has focused global attention on tsunami incidence and recurrence times. It is clear that, owing largely to their infrequency, the incidence and recurrence of large-amplitude (mega-) tsunami in the Pacific and elsewhere is poorly-known (Bryant 2001). For this reason, such tsunami provide a good example of a geohazard whose extent and recurrence can potentially be better understood with recourse to myths. Tsunami may be recalled by diluvian (flood) myths, which are among the most numerous myth-motifs in the Pacific Islands (Andersen 1928; Nunn 2001). Most tsunami in the Pacific are generated by submarine slips along one of the many steep-sided ocean trenches that mark convergent plate boundaries in the region. A mega-tsunami believed to have been generated by a large flank collapse of the Hawaiian Ridge about 105 ka ago has been held responsible for the deposition of coral gravel at levels of up to 326 m on the Hawaiian islands Lana'i and Moloka'i (Moore & Moore 1984; Moore *et al.* 1994) and also for the cutting of shore platforms 9–15 m above present sea level along the SE coast of Australia (Bryant & Young 1996).

The effects of tsunami vary depending on the proximity of the islands to the tsunami source. Thus flood myths from islands close to ocean trenches commonly recall an association between seismic precursors and tsunami. Examples where earthquakes were felt before the arrival of tsunami that they might have caused include those that regularly affect the Aitape–Sissano lagoon coast of New Guinea (Churchill 1916; Davies 2002).

Other tsunami travel across the Pacific and, without local seismic precursors, affect islands in aseismic (intraplate) regions. Examples are known from across the central tropical Pacific (Vitousek 1963; Nunn 2001); one particularly devastating tsunami is recalled in the oral traditions on Pukapuka Atoll in the northern Cook Islands as *te mate wolo* (the great death) (Beaglehole & Beaglehole 1938). Another flood-tsunami myth from the same area recalls how the atolls Manihiki and Rakahanga were once joined but severed one day when 'the sea was churned, to an angry seething mass' (Gill 1916, p. 117).

It is often not possible to use myth to distinguish tsunami from storm surges which highlights one of the dangers of using myth to reconstruct chronologies of such geohazards. Tsunami myths may include details of seismic of tectonic phenomena as precursors to the arrival of giant wave(s). Storm-surge myths often include meteorological details that indicate the associated waves were unlikely to be tsunami. One must also be sensitive to the likelihood that details in such diluvian myths may have been embellished with the passage of time. Indeed, it is possible that people who did not witness tsunami may have altered details of giant-wave myths to make them appear to have been storm-generated and therefore more credible.

Coseismic uplift

Coseismic uplift is a geohazard which is worth knowing about and yet, because of generally long recurrence times, it may be overlooked in hazard profiling based on historical records. This situation is exacerbated in the Pacific because most historical records are shorter and less complete than those for many continental areas. For this reason, it may be worthwhile interrogating myths in a search for such infrequent but large-magnitude hazards.

In the example of the island Niue discussed above, it was concluded that the origin myths for the island that involved successive stamps or heaves to raise it higher were a recollection of coseismic uplift. This is a geological phenomenon which is sufficiently memorable and infrequent to make it an ideal subject for myth.

Many coseismic-uplift events experienced by (parts of) islands along convergent plate boundaries in the Pacific have magnitudes of 1–2 m and recur every 200–2000 years. Attention has been given to reconstructing the spatial extent and recurrence chronologies of these events in some parts of the Pacific, especially the Aleutians, Japan and New Zealand (Plafker & Rubin 1978; Ota 1991; Berryman *et al.* 1992; Goff & McFadgen 2002). Yet comparatively little is known about coseismic-uplift events elsewhere—in Pacific countries straddling convergent-plate boundaries like Solomon Islands, Tonga and Vanuatu, for example—aside from the fact that they do occur (Grover 1965; Taylor *et al.* 1980; Ota 1991; Nunn & Finau 1995).

An understanding of coseismic uplift in such countries could be significantly improved were a systematic survey of pertinent oral traditions carried out alongside studies of coastal tectonics. The need for such a survey also emphasizes that much of the mythical data available at present is imprecise. On the island Efate in central Vanuatu, which is prone to coseismic uplift, it is recalled that as Maui fished up the island 'it rocked and tipped crazily in the ocean' (Luomala 1949: 122). No temporal or precise spatial information is available.

Island flank collapse

The flanks of steep-sided oceanic islands are notoriously unstable, often held in place by ocean water and peripheral sediment aprons (Menard 1983; Nunn 1994). Major flank collapses can be triggered by earthquakes, volcanic eruptions, or simply 'normal' denudational processes (Keating & McGuire 2000).

Investigations have shown that giant landslides play a major role in shaping oceanic islands (Holcomb & Searle 1991) with landmark studies in the Pacific having been made of the Hawaiian Island Ridge (Moore *et al.* 1989) and Johnston Atoll (Keating 1987). Yet for the Pacific outside of Hawaii, little is understood about either the incidence or the recurrence times of giant flank landslides. The imperative for such studies is underlined by the magnitude and extent of the associated geohazards. For the Canary Islands in the Atlantic, recent work has shown that a giant landslide on the flanks of La Palma Island is likely and that the associated wave might have a catastrophic impact on many Atlantic continental coasts (Ward & Day 2001). There is no information about a comparable threat in the Pacific.

Myth can aid the identification both of islands and island groups that are prone to flank collapses and in calculating recurrence times of such events. While there are Pacific Island myths that recall the abrupt subsidence of part of an island (Nunn 2001), the more common myths are those that refer to whole-island disappearances. The suggested process of island disappearance through flank collapse is illustrated in Figure 7.

Using oral traditions and written records, where available, it has been suggested that islands vanished within the last few hundred years in the Pacific. Examples include Tuanahe and Victoria in the Cook Islands (Crocombe 1983; Percival 1964) and Yomba in Papua New Guinea (Mennis 1981). Other examples alleged to have occurred during the last 200 years are far less well authenticated; the example of Vanua Mamata in central Vanuatu (2 in Table 1) has recently been illuminated by the collections of myths from surrounding islands (Fig. 8). But more numerous are alleged instances of older island disappearances, details of which may be preserved only in myth. These include islands like Burotu in central Fiji (Geraghty 1993). Eventually it is hoped that such persistent myths might be authenticated just as those concerning the catastrophic eruption and associated disappearance of Kuwae Island in 1453 (reviewed by Clark 1996) were used by geologists to help reconstruct the age and extent of this event (Eissen *et al.* 1994).

Case study: the distribution of vanished islands in the Pacific and its geohazard potential

This section reports a first attempt at analysing information concerning 'vanished islands' in the Pacific with reference to their value in understanding particular geohazards.

Table 1a and Figure 9a report and show the distribution of vanished islands whose existence is considered either satisfactorily authenticated or partly authenticated. By way of example, the island Tuanahe (7 in Table 1; Fig. 10) is discussed. Tuanahe in the southern Cook Islands was familiar to people on adjoining islands, including some of the early colonial administrators in neighbouring French Polynesia, traders and whalers who occasionally stopped at Tuanahe to revictual (Smith 1904; Stommel 1984). In the early days of Christian missionaries in the region, much mention was made of Tuanahe (Gill 1856, 1916; Brown 1924), and an eyewitness account of the island has come down to us today (Crocombe 1983). Yet in 1844, when a mission ship was sent to visit Tuanahe, the island could not be found

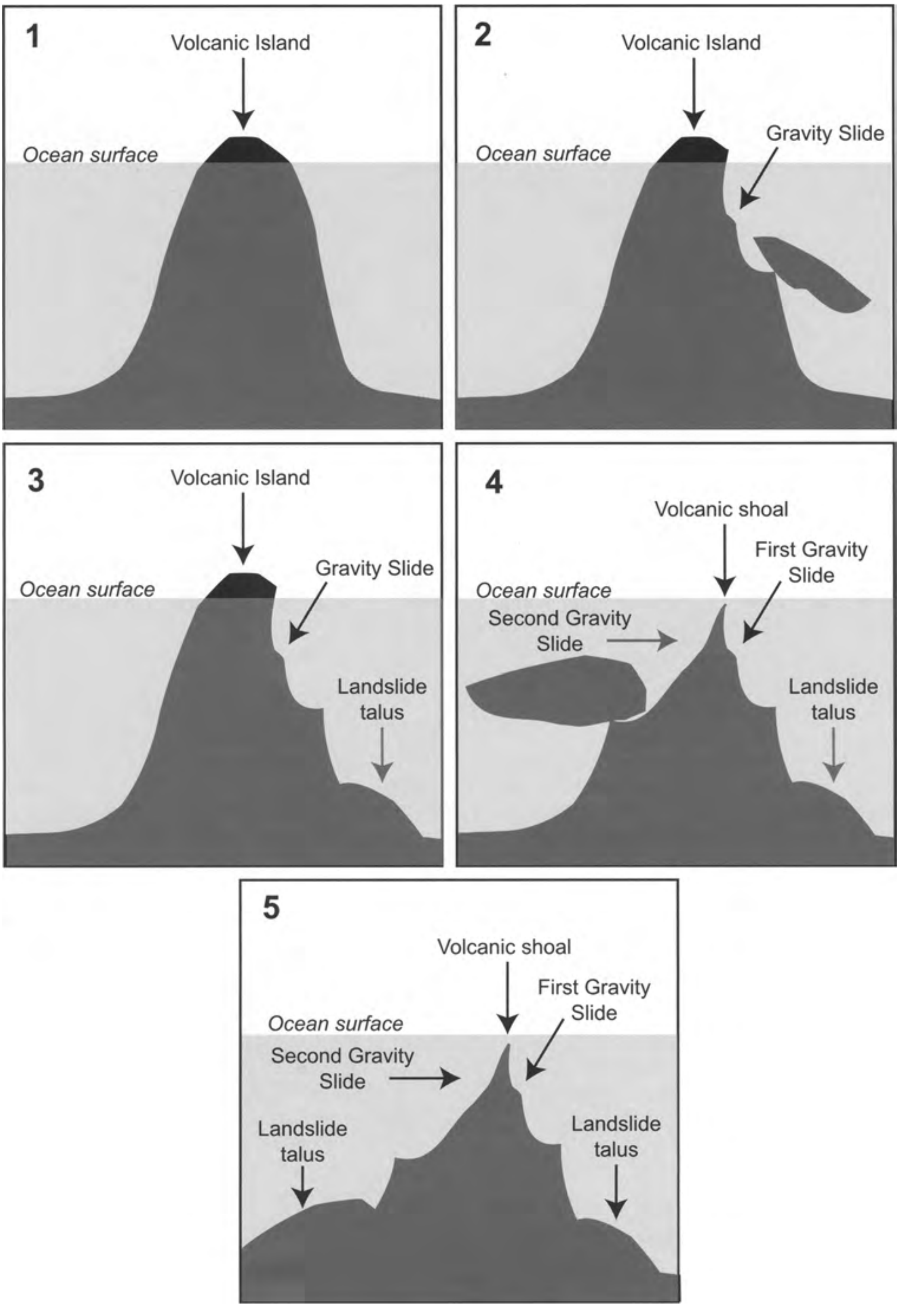


Fig. 7. Model explaining the disappearance of an island as a result of successive flank failures.

Table 1. *Vanished islands in the Pacific.*

Reference number	Island (group)	Details (principal sources of information)
(a) Satisfactorily authenticated or partly authenticated		
1.	Kuwae (Vanuatu)	Island in central Vanuatu destroyed during a volcanic eruption in 1453. Myths about this island (reviewed by Clark 1996) were used by geologists to help reconstruct its former extent (Eissen *et al.* 1994)
2.	(Vanua) Mamata (Vanuatu)	Disappearance was noted in the Remark Book of USS Narragansett, kept by Commander Meade between 1872 and 1873 (Stommel 1984). Recent oral-historical research suggests the island was named (Vanua) Mamata and disappeared long ago (Nunn *et al.* 2006; see Fig. 8)
3.	Los Jardines (NW Pacific)	Recorded by various Spanish and British ships' captains, had disappeared by the 1920s (Stommel 1984). Also Beaglehole (1966)
4.	unnamed (Papua New Guinea)	An island in the Sissano Lagoon where 2000 people lived sank abruptly (Neuhauss quoted by Churchill 1916: 13). Also (Beckwith 1940). A similar coseismic subsidence event is implicated in the July 1998 Aitape tsunami which affected the same area (Davies 2002)
5.	unnamed (Vanuatu)	Oral traditions reported by Nunn *et al.* 2006 show that the existence of an island off west Ambae (Aoba) Island is well known. According to Bonnemaison (1996) it disappeared three centuries ago at the same time as several villages in west Ambae
6.	Redfield Rocks (NE Pacific)	Reported by numerous ships' captains up until 1889 (Stommel 1984)
7.	Tuanahe or Tuanaki (Cook Islands)	Described in detail in Maretu's account of his life in the southern Cook Islands (Crocombe 1983) and referred to by many other authors (e.g. Gill 1856; Smith 1899; Gill 1916; Te-ariki-tara-are 1920) and apparently known to colonial officials and whalers (Stommel 1984). Disappeared after 1842 (Crocombe 1983). Recent unpublished research shows the former existence of the island is known to people on Mangaia Island in the Cook Islands (see Fig. 10)
8.	Victoria (Cook Islands)	Visited for 18 months by copra-cutters around 1875 and generally known at the time but had disappeared by 1921 (Percival 1964). Recent unpublished research suggests that 'Victoria' existed north of Tongareva (also known as Penrhyn in the northern Cook Islands) and was visited regularly during the 1900s for coconuts but vanished around 1930
9.	Yomba (Papua New Guinea)	Existed some 8–10 generations ago off Madang in New Guinea but is now below sea level. Numerous oral histories collected by Mennis (1978, 1981). Also Blong (1982)

(Continued)

Table 1. *Continued.*

Reference number	Island (group)	Details (principal sources of information)
(b) Unsatisfactorily authenticated		
10.	Bikenikarakara (Kiribati)	100 km east of a line bisecting Marakei and Butaritari Islands, Kiribati (Ward 1985)
11.	Burotu or Pulotu (Fiji?)	Many references in myths from Fiji, Samoa and Tonga (summarized by Geraghty 1993). Possibly located close to modern Matuku Island in SE Fiji (Geraghty 1993) (see Fig. 11)
12.	Fasu (Yap)	A large island with a high mountain, located east of Ifalik Atoll, which disappeared (Ashby 1983)
13.	Fatu-uku (Marquesas)	Near Hiva Oa Island (Christian 1895), possibly close to modern Fatu Huku Island
14.	Hiti-marama (Tuamotus)	Island north of Pitcairn 'long since swallowed in the sea' (Henry 1928: 468)
15.	Hoahoamaitu (Tuamotus)	Described as having sunk beneath the waves (Beckwith 1940)
16.	Kane-huna-moku (Hawaii)	Translated as Kane's hidden island, a sunken island where people live, precise location uncertain (Lyons 1893; Beckwith 1940)
17.	Malveveng and Tolamp (Vanuatu)	Oral-historical research suggests that these islands once existed off NE Malakula Island where shoals now exist (Nunn *et al.* 2006)
18.	many (central Pacific)	Many vanished islands are known from between Honden Island and the Hawaiian Islands (Henry 1928). Hondon [sic] is an old name for Pukapuka Island in the northern Cook Islands (Young 1898) so these vanished islands lie between approximately 10°S and 30°N
19.	Nono-kia (Tuamotus)	'a land flung down in jumbled ruins, – long since effaced from the memory of man' (Stimson 1937: 34)
20.	O'o-va'o (Marquesas)	A 'land under the sea' (Handy 1930: 115)
21.	Sipin (Yap)	Disappeared one day without warning (Ashby 1983)
22.	Tahu-uku (Marquesas)	Near Hiva Oa Island (Christian 1895)
23.	Teo (Solomon Islands)	The island near Santa Ana sank as a result of some natural disaster, with some survivors reaching Santa Ana (Mead 1973). A different version of the story names the island as Teonimanu and says that survivors went to the islands San Cristobal, Malaita and Ulawa (Fox 1925).
24.	Tonaeva (Marquesas)	The god Maui fished up Tonaeva and then let it sink. Located near Tahuata Island (Luomala 1949). May be the same as Toko-eva, now known as Clarke's Reef, 'once a populous land' (Christian 1910: 204)
25.	unnamed (Kiribati)	Near Banaba (Ocean) Island (Grimble 1972; Maude & Maude 1984)
26.	unnamed (Tongareva)	Island pushed away by god Maui which disappeared (Stimson 1937; Langridge & Terrell 1988)
27.	Uririo (Samoa)	Island which sank between Samoa and Kiribati (Newell 1895)

Reference numbers refer to Fig. 9. Note that in part (a), none of the shallow-water volcanoes which periodically erupt and form short-lived islands (particularly in Tonga and Solomon Islands) is included, although details of their distribution and character are found in Nunn (1994, 1998). Also note that no islands known to be superficial islands (like atoll *motu*; see Nunn 1994) are intentionally included in this list. All unpublished research referred to was coordinated by Patrick Nunn.

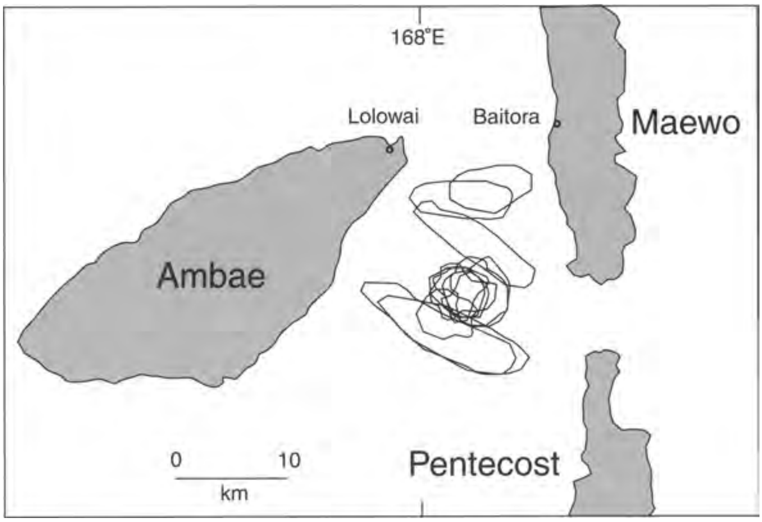


Fig. 8. Locations of the vanished island (Vanua) Mamata between Ambae, Maewo and Pentecost islands, central Vanuatu, from oral-historical information gathered from appropriate persons on these three islands. Data from Nunn *et al.* (2006).

(Gill 1856). It existed in an area of ocean where there is no other island (see Fig. 10) and it has been suggested that a rocky shoal known as Haymet Rocks is what remains of it today (Smith 1904; Stommel 1984).

Table 1b and Figure 9b report and show the distribution of vanished islands whose existence is not satisfactorily authenticated and commonly only the subject of myth. The island Burotu (11 in Table 1; Fig. 11), identified as an important homeland for many Pacific Island people (Kirch & Green 2001), was located near the island Matuku in SE Fiji by Geraghty (1993) using a variety of linguistic and oral-history data. According to recorded oral traditions, Burotu occasionally emerges and then vanishes again beneath the ocean surface. The persistence of this legend across a vast area of the Pacific Islands suggests that an island may once have vanished in this area. Although no scientific data are available, a possible candidate for Burotu lies underwater SE of Matuku (see Fig. 11).

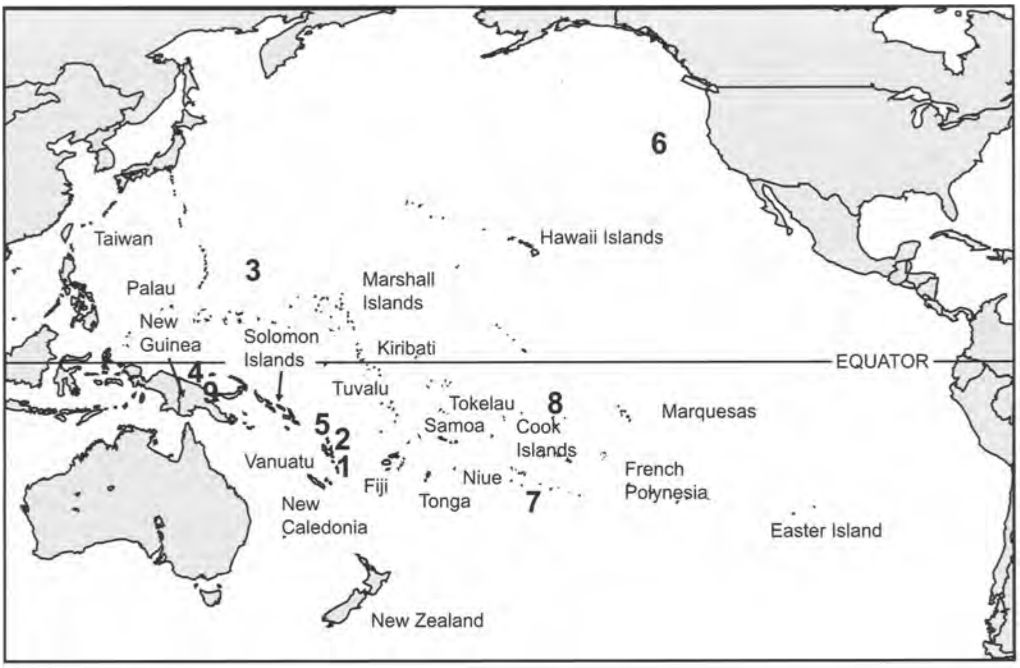
If there is some similarity between the distribution of islands in Figure 9a and 9b, then it can be assumed that there is some value in the mythical knowledge in Table 1b. This might be considered a key test of the potential value of such mythical data although, as can be seen from comparing Figure 9a and 9b, there are too few data at present to make the comparison meaningful. Yet it is also clear that the one does not contradict the other.

There is insufficient space to consider in detail the reasons for the (alleged) disappearance of every island listed in Table 1 but the locations of the main concentrations are instructive.

At least four islands are reputed to have disappeared in the Marquesas Islands (islands 13, 20, 22 and 24 in Fig. 9b), which are high, steep-sided volcanic islands known to have unstable flanks. A flank collapse of Fatu Huku Island was dated to about 1800 (Filmer *et al.* 1994) and subsequent flank slips have been recorded (Okal *et al.* 2002). Many islands in the Hawaii and Samoa island groups are similarly steep-sided and experienced many large flank collapses in pre-human settlement times (Moore *et al.* 1989; Keating et al. 2000) which, together with examples from post-settlement times (e.g. McMurtry *et al.* 2004), renders more credible mythical reports of post-settlement island disappearances here (islands 16 and 27 in Fig. 9b).

Islands are also known or reputed to have vanished at or near isolated seamounts. These include islands 3, 6, 7 and 8 from Figure 9a which may have disappeared as a result of a collapse similar to that shown in Figure 7. The credibility of this scenario is certainly stretched by noting that the most likely candidates for islands 3 and 6 are now many hundreds of metres underwater but 7 is marked by a shoal (Bryan 1940; Stommel 1984).

Several of the islands in Table 1 (including 7, 8, 14, 15, 18, 19) are perhaps also marked today by ocean-surface reefs or shoals and the possibility cannot be dismissed that they were observed by humans at a time when the sea level was lower and the islands consequently higher. This is a



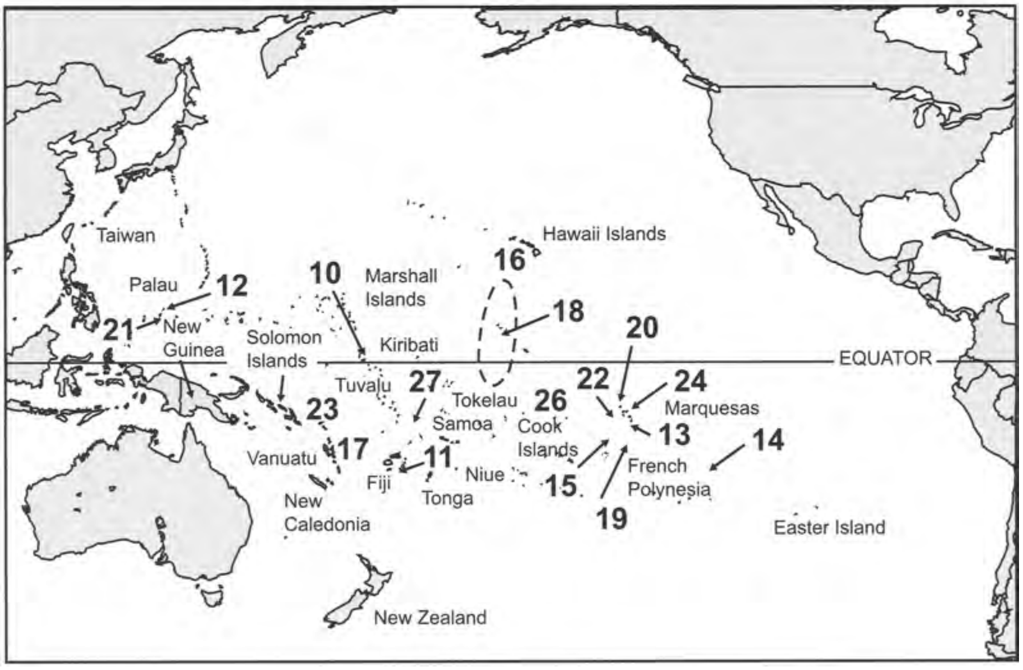


Fig. 9. Maps of the distribution of 'vanished islands' in the Pacific. (**a**) satisfactorily authenticated or partly authenticated islands. (**b**) unsatisfactorily authenticated islands. See Table 1 for details and sources.

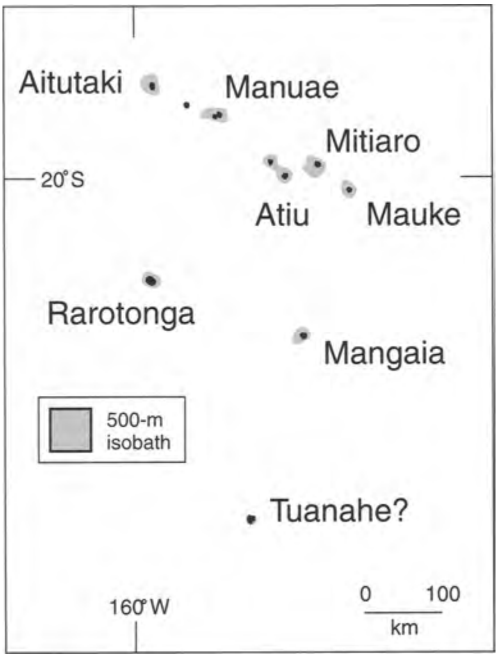


Fig. 10. Map of the southern Cook Islands showing the likely position of the island Tuanahe that apparently vanished around 1842.

radical suggestion given that sea level reached its present level in most of the Pacific about 6000–7000 cal BP (Nunn 1995) and that the earliest people known to have reached islands east of Solomon Islands did so only about 3000 years ago (Kirch 2000). It is more plausible to suppose that superficial islands (*motu*) present on some reef platforms that were encountered and recorded by humans were subsequently washed away.

There is a cluster of islands in central Vanuatu (1, 2, 5, 17) and their disappearance is likely to have been linked, like those in Solomon Islands (23), Papua New Guinea (4, 9) and Yap (12, 21), to volcanic and/or seismic processes operating along nearby convergent plate boundaries. In the cases of Kuwae and Yomba (1 and 9), explosive volcanic eruptions are implicated whereas in the cases of islands 2 and 4, coseismic subsidence and/or seismically-induced slip are likely to have been responsible (Nunn *et al.* 2006).

This is a preliminary attempt to interpret the first collection of vanished-island data from the Pacific and, as such, much more needs to be found out about most islands in Table 1 before it will be possible to use these data for practical geohazard assessment and mapping. Looking at the combined data in Figure 9a and 9b, there are 'hot spots' where the possibility of major flank collapse and the generation of associated mega-tsunami appear most likely. These include the Marquesas and Vanuatu and, to a lesser extent, Papua New Guinea and Yap. Research might also be directed to island groups that are in similar geotectonic situations to the Marquesas and Vanuatu, especially those from which at least one vanished island story comes such as Hawaii, Samoa and Solomon Islands.

Research might also be profitably directed towards investigations of individual islands which

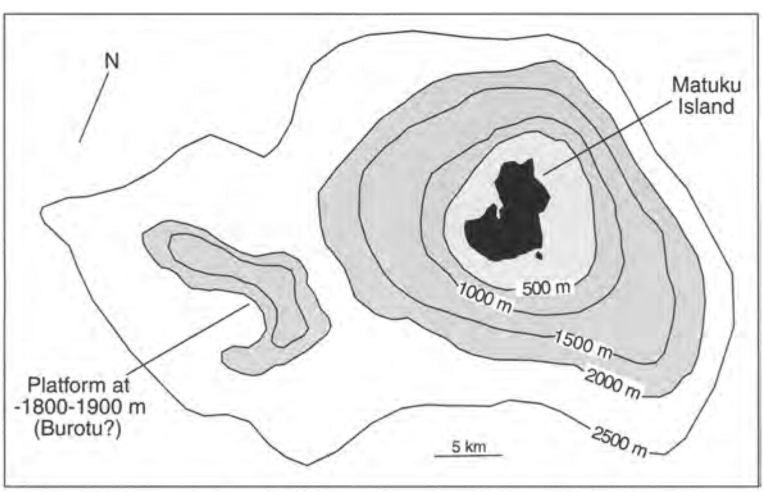


Fig. 11. Bathymetry of part of SE Fiji showing the island Matuku and the submarine platform to the SW. Myths concerning the disappearance of Burotu Island long ago are centred on the communities occupying SW Matuku, and it is possible that submerged Burotu is the submarine platform shown.

(are alleged to) have disappeared with a view to establishing times of disappearance and eventually recurrence times of large-scale flank collapses and associated mega-tsunami. Such data would be helpful to Pacific-wide geohazard assessment.

For the past 500 years, it has been estimated that worldwide there have been four structural failures of volcanic edifices each century (Siebert 1992). It has been argued that this is an underestimate (Keating & McGuire 2000). For the Pacific Islands, there are seven satisfactorily-authenticated instances of islands which have disappeared and can be interpreted as large-scale flank collapses (Table 1a excluding 1 and 9). Given that people have occupied this region for around 3000 years, this gives a crude recurrence time for such events of 430 years. Yet, if even half of the 18 unsatisfactorily-authenticated instances (Table 1) are added to the other nine, then the recurrence time becomes 190 years.

Myth and geology: future directions for research in the Pacific

This paper has shown that the wealth of Pacific Island myth can be used to make meaningful statements about the geological history and geohazard potential of the Pacific Basin. There is more that could be done.

As discussed in the previous section, the compilation and understanding of myths recalling large-scale flank collapses of Pacific islands and associated phenomena are invaluable to reconstructions of recurrence times and pinpointing hazard hot spots. In this regard, there may be many more myths relevant to this question preserved among Pacific Island peoples than have been collected and/or published. The imperative of understanding large-magnitude yet infrequent hazards in the Pacific (and elsewhere) should be enough to stimulate continued research in this area.

The best approach to such research is multidisciplinary, with social scientists and geoscientists working together to collect and interpret relevant myths. There need to be site-specific investigations of likely geohazard hot spots, such as the Marquesas and Vanuatu, and there need to be studies of the precise times of particular events.

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Exploding lakes in myth and reality: an African case study

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Abstract: In the night of 21 August, 1986, Lake Nyos, a crater lake in the Cameroon Grassfields of West Central Africa, 'exploded' and sent out a cloud of carbon dioxide that killed more than 1800 people. Ultimately the causes of the explosion were scientifically determined to have been limnological. They were part of a process, much like the opening of a champagne bottle, in which carbon dioxide that has collected at the bottom rises quickly to the top and, following the 'pop' of the cork, sends out a liquid mixture of wine and carbon dioxide. Carbon dioxide at the bottom of small Lake Nyos (roughly the size and shape of New York's Chrysler Building; 319m in height) was disturbed by an unknown force that caused it to 'pop' out as a deadly cloud about 700 m long, deep and wide. Stories about 'misbehaving' or exploding lakes had circulated in the region for many years before the 1986 explosion, and continue to circulate. This article summarizes eighty years of myth collection carried out by ethnographers, historians, administrators and missionaries who visited prior to the 1986 explosion. It also adds information about myth transformations and new folklore explanations for the Nyos explosion over 13 years following the explosion, and contributes to the discussion of implications for disaster relief in any large-scale catastrophe.

The Cameroon Grassfields region is a little-known part of Africa, but one locally renowned for its fertile volcanic soil, its sparkling crater lakes, its hospitable and delightful people. When, in late August 1986, Lake Nyos 'exploded' and killed almost 2000 people (Begley & Whitmore 1986; Browne 1986; Freeth & Kay 1987; Smolowe 1986), leaving 3000 homeless, I had been collecting stories about 'misbehaving' lakes in the area for more than five years. Soon after the Nyos explosion, I was charged by the Cameroon government with the tasks of continuing my own research and helping to find solutions to the problems of resettling the survivors. I attended the 1987 UNESCO conference on the causes of the explosion and afterward interviewed survivors, as well as many of those rendered homeless by the explosion.

Since 1986–87, I have followed not only the resettlement efforts and scientific attempts to 'degas' the lake (Giggenbach 1987; Grenier 1988; Kling 1987; Kling *et al.* 1987, 1989, 1991, 1994; Lockwood *et al.* 1987; Propper 1987; Sigurdsson 1987*b*, *c*; Tazieff *et al.* n.d.), but also the development of subsequent stories and explanations of the lake explosion (Holloway 2000, 2001; Krajick 2003; Sigurdsson 1987*a*; Stager 1987). On numerous return visits to the area, often as part of a research team that included George Mbeh, we collected new versions of the older stories, and also, in 1999, a 'brand-new' story that incorporates elements from contemporary ecology, ongoing disaster relief studies, and traditional folklore. The research reported here relates primarily to the collection of various stories that 'explain' the peculiar behaviour of crater lakes in the region, especially the motif of exploding lakes, and changes in this story motif are traced over eighty years. Further, it has been possible to document the creation of new stories and the abandonment of certain old ones concerning 'exploding' (or otherwise misbehaving) lakes in West Central Africa.

The reason the exploding lake motif is of interest is that it seems to mirror actual events, such as the 1984 explosion of Lake Monoun (37 dead) as well as the fearsome events after Lake Nyos exploded in 1986. Such mirroring invites euhemeristic interpretations of local folklore and some recent examples of euhemeristic interpretations from other parts of the world (e.g. Piccardi 2000) suggest that this is a productive mode of inquiry. A euhemerist interpretation is one in which history is believed to underlie a myth, Euhemerus (fourth century BC) was a Sicilian philosopher and theorist who believed that the mythological gods were deified mortals whose deeds had been amplified in the imagination of human storytellers (Oxford English Dictionary Online; http://www.hyperdictionary.com/dictionary/euhemerism).

Although I do not believe that all aspects of the lake stories can be explained euhemeristically, some aspects do appear to mirror actual events very precisely and are worth exploring at length. Such information may be crucial to understanding local interpretations and changes over time in accounts that originate in eyewitness testimony (LeGuern *et al.* 1992). We know that certain

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accounts have been shown to be accurate in spite of distribution over large geographic areas and many centuries. For example, Blong's (1982) study of New Guinea folklore concerning the 'time of darkness', showed that legends related to a volcanic eruption that took place more than 300 years ago were accurate over an area of almost 100 000 km^2 and throughout more than thirty language groups, and Harris's (1990) study of Klamath legends reveals considerable accuracy in folklore descriptions of what must have happened during the formation of Crater Lake in Oregon almost 7000 years ago.

In this paper, the case study materials concern what may be a more recent story or folk explanation, one that was first brought to scholarly attention in the 1940s and 1950s with mentions of strange 'behaviour' of lakes in the Cameroon Grassfields by Chilver and Kaberry. Chilver, a historian, and Kaberry, an anthropologist, were carrying out ethnographic survey research and collected several stories about peculiar 'behaviours', in this case transformations of certain of the area's many crater lakes which were said to 'shift' or disappear, occasionally to move from one location to another, to change colour, or sometimes even to explode and kill people who lived nearby. Chilver and Kaberry's search of the literature revealed that stories of this kind, but not necessarily about exploding lakes, had been recorded in administrative reports since 1912.

Similar accounts appeared in the research notes of fieldworkers during the 1960s and 1970s, as well as in newspaper reports of Lake Njupi, Nyos's 'sister' lake, which abruptly changed locations. In the early 1980s, I began ethnographic fieldwork in the former kingdom of Kom, one of the Grassfields kingdoms visited by Chilver and Kaberry. I collected similar stories about misbehaving or maleficent lakes on this and a follow-up visit in 1985–86. Before 1986, none of the researchers had attempted to account scientifically for the existence of these stories, but I did make an (unsuccessful) effort to find similar motifs by consulting folklore indices. In particular, the Motif Index of Folk Literature (Thompson 1958) includes references to exploding lakes, lakes with villages at the bottom, and lakes that misbehave spectacularly—all within Celtic folklore—but not reported in collections of African myths and folklore. These motifs likely have simply gone unreported in the literature on African myths collected by European scholars. Early on, attention focused on creation myths or otiose gods, and, more recently, on trickster figures, both foci of European theories about mythology. Very little work seems to have been done on African accounts of natural processes.

The stories

From the 1920s on, the first researchers

The earliest story collected was about Lake Oku, recorded in 1913–15 by Fr Emonts, a Catholic missionary, and reported in Chilver (1991). A quarrel over ownership of the lake took place between the Oku and Babungo leaders [*Fon*, pl. *Fons*, in Grassfields parlance] both of whom made regular sacrifices to the lake. Mawes, the lake-spirit, gave a fine robe and spear to the Babungo Fon, while whispering to the Oku Fon, whose gifts were considered to be of lesser quality. Eventually, however, Mawes awarded the lake to Oku and the Oku people pursued the fleeing Babungo. In 1963, Chilver and Kaberry collected a different version in which the quarrel was between Oku and Kijem (a.k.a. Babanki) people and began with the arrival of a stranger who asked permission to settle. The Kijem turned him away but the Oku people offered him land and after he refused several plots, they told him to choose his own and he finally settled beside the lake. When he died, his spirit-double went into the lake and invited both Fons to accompany it; they entered the lake, and the Kijem Fon was killed while the Oku Fon was rewarded with royal clothing and insignia (Chilver 1991, p. 18). In different versions also given in 1963, weeks of torrential rain accompanied the final judgment or the waters reddened with the blood of the Kijem Fon; in both accounts, the lake engulfed the Kijem people (Chilver 1991, p.18).

Early administrative reports, especially the District Officer's Reports from 1926, 1929, and 1936, do not mention earthquakes, geysers or exploding lakes; M. D. W. Jeffreys, an administrator with a geological bent, inquired as to whether there was a tradition of earthquakes in the Nyos area and was told there was not. In 1960, Kaberry and Chilver asked the same question in the surrounding areas and got the same negative result (Chilver 1991, p. 16).

The bottoms of Lake Nyos, Lake Oku and certain pools in the Kimbi River were said to provide glimpses of villages of the dead. Lake Njupi, Nyos's 'bad twin', was said to be infested with 'snakes and insects' and the crater lake at Wum (Aghem) was the final residence of two sisters, ancestresses of Funggom area matriclans, who signalled their presence by bubbles in the lake and their displeasure by sudden turbidity (Chilver 1991, p. 17). Neither Geary's 1976 materials on We (pers. comm.) nor Mbeh's (1984) on Mmen mention traditions to do with lakes.

In the 1920s and 30s, Jeffreys mentioned the Bambuto crater lakes and a story told by the Fon of Bambui: 'When we and the Bambili reached these mountains we still moved as a single group but found two lakes that were side by side and here we separated. Bambili took one lake and we the other. When we moved from Bambili to here, our lake moved to its present position' (Chilver 1991, p. 19).

Before the 1930s, an origin story with elements similar to the contemporary Kom story (retold below) was collected; it was told by the Ba'ni (also known as Chamba) whose leader, Ga Wolbe, predicted his death in battle to his queen-sister and told her how to proceed. A lake then formed over his body and eventually his spirit-double, an elephant, blazed a trail for the Ba'ni migration. In the mid-1950s, Chilver and Kaberry travelled through the Grassfields and conducted research, both together and separately, over the following two decades in numerous kingdoms of the Grassfields, including Bali, Kom, Nso', Oku, Bafut (Goheen & Shanklin 1996). Their major works include Kaberry's *Women of the Grassfields* (1952), and Chilver & Kaberry's *Traditional Bamenda* (1968). Kaberry died in 1977 but Chilver still lives in Oxford and after the Nyos explosion of 1986 she carefully reviewed both her own notes and Kaberry's for any information about lakes, other bodies of water or water-related events. In 1991 she published a summary of these findings and, like my own data in the 1980s, many stories about lakes came from accounts of (clan) migrations from other places.

Chilver also found a lake rite recorded in 1934 by R. Newton: the sacrifice was addressed to the dead and it was believed that once accomplished, women would bear many children and the wicked would die (Chilver 1991, p. 19). A similar lake sacrifice was witnessed and photographed by Michael Rowlands (pers. comm. 1985) at the Awing (also known as Bambulewe) crater lake, famous for ensuring conception. A recent Awing story concerns a disappearing lake, which became annoyed after a woman threw her menstrual bed/cloth into it, polluting it, and causing the angry lake to move. Later however, Mba'nka, an early leader of Awing, met some elders who asked for palm wine, which he served them. The leader then introduced himself as the ancestral keeper of the lake and gave Mba'nka instructions in case he wished to recall him or the other ancestors. Mba'nka told his Fon of this incident and the Fon went to the site, where he found a huge pool of water (Lake Awing). He and Mba'nka called the elders, who came and took the Fon and his followers into the lake for the necessary sacrifices. Later, they returned home without looking behind them and since that time, sacrifices (which may or may not be accepted, i.e. bring about the desired outcome) have been conducted annually, before the new year (Mbangwana pers. comm. 2001).

A different (Bafut) version of the origin of the Bambulewe lake has it that as the people were crossing, they made a rope bridge across a big water and sent people across. But some had to return to fetch a powerful calabash containing water; a queen and others crossed the bridge with the calabash but the bridge broke behind them and they lost touch with their other people. As they neared Bambuluwe, the exhausted queen dropped the calabash on a stone and then came a flood, in which Lake Bambuluwe was formed. At the time of Kaberry and Chilver's fieldwork in 1963, there was a good deal of reticence about the rites performed at lakes so information was difficult to gather, a problem I also experienced two decades later, although lake stories were not hard to find.

Chilver quotes my (1980s) account of the Kom story (Shanklin unpublished field notes 1990), outlined below, and notes that a similar story was present in Bum but instead of a python, the deceased Fon took the form of a leopard. The lake mentioned in the Bum version is not a crater lake but a seasonal swamp lake; another lake, Ngwo, was the scene of the emergence of the first Fon of Bambalang and his councillors.

One point worked out in discussions with Chilver has to do with the general dread of bodies of water in most cultures in the region. The likelihood must be noted that, before the Europeans arrived at the end of the nineteenth century, some groups did not bury their dead but threw corpses into nearby streams or pools. Chilver (1991; pers. comm. 2004) has recently confirmed that Zintgraff (1895), the first colonial explorer into the Grassfields, mentions that he saw corpses in bodies of water on his way through Kom. Chilver remembers reading this before her eyesight began to fail; she does not now have the reference but is sure that it is contained in Zintgraff's account.

Chilver mentions other recurrent themes in stories involving rivers and lakes: first, the notion of spirit-doubles; and second, the association of numinous powers with waters, sometimes benevolent, sometimes wayward or punitive, and adds that:

> It is hard to resist the conclusion that both the underworld of the dead, reached through deep water or holes, and the upper world of sorcerers or sky-travellers, contain elements seen as necessary to life and reproduction, which may be cut off and must be sued for. If this is right, deep waters in high places offer a highly charged symbolic site. So the ambivalent emotions attached to them do not necessarily reflect past traumatic experiences: deep waters may be seen to contain punishment as well as fecundity and treasure, high places, rain, as well as sorcery and storm (Chilver 1991, pp. 21–22).

Seeming somewhat doubtful as to whether these stories actually recall specific historic events, she concludes with this useful thought:

> In searching for evidence of past volcanic activity or gas explosions in oral sources I suggest what we might look for are items which seem foreign to the usual run of motifs or redundant to narrative frameworks. For example, is the behaviour of the lakes after torrential rain a signifying item? Was the earthquake which destroyed Nto's dwarf cows predicted according to well-established convention, a just-so story, or was it an event transmitted over many generations, later ensconced in a familiar story-telling framework? Is a waterspout necessary to the separation of linguistically related groups with so many other familiar gambits to choose from? ... (Chilver 1991, pp. 21–22).

The 1960s and 1970s research in the post-Independence era

R. and P. Ritzenthaler (1962, p. 125) reported that although they found no evidence of a supreme being among the Bafut, there were sacred dwelling places reserved for dead Fons including trees, rocks and four pools in a river at which offerings are made:

> The actual dwelling places ... of the dead are believed to be within the four sacred pools. Each of the first four Fons occupy a different pool, the last four share a pool with one of the first four ... The dead Fons move together, at one time staying in the sacred pool, another time in one of the sacred trees, and another time in one of the sacred rocks. If the sacred pool partially dries up, it is said that the spirits have left, and a deeper, darker pool in the river is sought as the new home of the deceased gods (Ritzenthaler & Ritzenthaler 1962, pp. 125–126).

They add that just prior to the annual dance, a pilgrimage is made to the sacred pools, together with a series of offerings, and, during the annual dance, members of an important ruling body, *kweyifon*, make another pilgrimage and offer sacrifices at the most important pool.

> A small band of the *kweyifon* march out, for example, to the sacred pool, about six miles from the Fon's compound, throw a calabash of palm wine into the pool, slit the neck of a goat and throw that in, all as an offering to the dead Fon.... In former times they went to Menchem Waterfall, where there was an altar and where the dead Fon lived, but this is too far now, so they visit 'lake' Achum. The *kweyifon* then report to the Fon upon their return and the power brought by their pilgrimage strengthens the Fon (Ritzenthaler & Ritzenthaler 1962, p. 129).

A version of the Kom legend was published by Nkwain & Briggs (1958), and in it the story of the lake is told but in terms slightly different to those I was told in the 1980s. Much as in Jeffreys' account, quoted above (Jeffreys 1951; Chilver 1991), Nkwain says that the lake 'swallowed' the Bamessi people.

The early 1980s

In Nkwi & Warnier's *Elements For a History of the Western Grassfields* (1982), there is little mention of indigenous religion or practices to do with lakes and sacred pools, but at the beginning of the book, Warnier makes an important point:

> The Grassfields peoples had a common stock or repertoire of social institutions, elements of political organisation and beliefs. Each of them drew on that stock to give shape to a specific organisation of its own, depending on convenience and local conditions. This repertoire operated like a basic vocabulary—a vocabulary that different people use in different ways to say different things, but that everyone can understand (Nkwi & Warnier 1982, p. 54).

It may be fair to suggest that lakes and sacred pools were part of the symbolic repertoire of the Grassfields, and further, that much of this repertoire drew on local observations. Warnier's observation about the repertoire operating like a basic vocabulary is one that the reader might want to recall as we continue the survey of folklore and legends surrounding northwestern lakes.

The Kom origin story contains an exploding lake and I collected nearly fifty versions of this during ethnographic fieldwork in 1980–81 (Shanklin unpublished field notes 1990). In Kom, it is said that the ancestors arrived at Laikom, the site of the Fon's palace, after following the track of a python. All versions agree that the Kom were settled for a time in Bamessi on the Ndop Plain and that they left there because of a trick played by the Bamessi Fon, who was beginning to fear that Kom people were becoming too numerous and might soon take over his kingdom. He devised a plot in which all the young Kom men were killed and when the Kom Fon discovered it, he vowed revenge. He called his sister to him and told her that he would soon hang himself, that no one was to cut down his body, that a lake would form where his body fluids dripped down, and soon the people of Bamessi would go into the lake to catch the fish that would flourish there. No Kom person was to enter the lake, he said, and they should be ready to leave Bamessi forever on the day that was set for catching the fish. All happened as the Fon predicted and Kom people watched as the Essi people entered the lake—which sank or imploded, most variants say—and died, leaving their Fon sitting alone, watching helplessly as all his people drowned. Kom people, led and instructed by the Fon's sister, settled at Laikom, in a new (lakeless) territory east of Bamessi, and when the Fon's sister delivered a son, he was anointed Fon.

One informant who told me this story used a different word than the one I have translated as 'imploded'; he said the lake had exploded, and when I asked how a lake could explode, he answered that since I was a scientist, I might wish to explain how lakes explode, but he, as a storyteller, did not have to explain this.

A final point about this story: in Bantu philosophy, as I understand it mainly from Kom people, all living entities have dual natures, good and bad, or beneficent and maleficent 'sides' that can cause strange events. Duality occurs, too, in non-living entities in pairs, e.g. a good rain versus a bad rain. A 'good' lake, such as Nyos, also had a 'bad' counterpart, Lake Njupi, which by local accounts is full of leeches and has also transferred from one place to another, according to newspaper accounts from the 1970s. I read about this in Cameroonian newspapers stored in the Buea Archives. There were at least two stories that mentioned this strange 'transference' and I collected many similar stories from informants who lived in the area. In the oral accounts, no particular significance is attached to these transfers, apart from the usual human motivations attributed to lakes—the lake didn't like its neighbours, didn't approve of the actions of an important person in the area, or wasn't satisfied with the quality of the sacrifices offered.

The stories I collected along the roads and in my travels to other kingdoms were of a similar order, except when the lakes expressed their preference for 'belonging' to one ethnic group or another by causing the death of members of the 'other' ethnic group in order to make this desire clear. (In 1981, I asked the question in Bamessi, where I went to see the place where the lake 'imploded' or sank in the Kom story, and sent the Kom on their way to the area they now occupy. There seemed to be no Bamessi story corresponding to the Kom one.)

Other traditional story motifs involving lakes collected before 1986 by myself and others included:

- A Fon who was displeased after his death because his funeral was not sufficiently lavish, so he punished survivors for failing to comply with his explicitly-stated wishes about cattle to be sacrificed. This was a very common motif prior to 1986, reported to me in 1981 and 1985 (Shanklin 1980s, unpublished field notes);
- Conflict over land/lake ownership between two competing groups whose leaders are sent into the lake. Only one emerges alive, thus demonstrating the lake's wishes as to its ownership; indigenous sources, including such other ethnic groups as Oku and Aghem (Bah 2000; Shanklin 1980s, unpublished field notes);
- Conflict between the locals and an outsider whose behaviour is strange; after the outsider dies, the lake behaves oddly towards the locals, positive proof of the outsider's powerful sorcery; indigenous sources found in several ethnic groups, (Shanklin 1980s, unpublished field notes);
- An implicit motif in many lake stories is that agricultural and human fertility is threatened by illicit human manoeuvres, regardless of the source, which might be witchcraft, conflict or ancestral anger over some slight (Shanklin 1980s–1990s, unpublished field notes).

Post-explosion 1986 motifs

Soon after the 1986 explosion, Paul Nkwi, then professor of anthropology at the University of Yaoundé, headed a team that went into the Nyos area with the intent of learning about the ethnicity of the survivors. The team, that included Nkwi's then-student, George Mbeh, who later revisited the camps with me, collected various explanatory stories (Nkwi *et al.* 1986; Nkwi 1988).

In 1986, explanatory motifs included a neutron bomb and a nuclear testing conspiracy, plus three other motifs for the 1986 explosion: 1) Mami Wata; 2) strange Europeans; and 3) a manifestation of 'Allah's will' or 'Allah's lesson', an explanation some Fulanis advanced but did not defend when asked what lesson Allah was teaching by this means. Most acknowledged that the third motif was unsatisfactory and went on to discuss other stories they had heard.

The 'Mami Wata' motif involved a (Nigerian) folk belief in a female demon who inhabits pools and other bodies of water and, when she emerges, is always destructive. This motif was contributed by American Peace Corps worker, Steve Tebor, who told me at the UNESCO conference in Yaoundé that after the explosion he was asked repeatedly to explain what had happened and eventually he opined that a 'Mami Wata' had come out of the lake and killed all the people and animals (pers. comm. 1987). Although common in 1986 and 1987, this foreign variant seems not to have lasted very long; in 1999, there was no trace of it. I do not know when or why it disappeared. I can only speculate that since demon spirits inhabiting lakes were a common motif throughout the region prior to the Nyos explosion, this import may have found some immediate favour, but since traditionally demon spirits were *not* considered to be exclusively female, traditional explanations may have overridden this one.

In 1986–87, there were many stories about local people who had predicted the Nyos explosion; most of the ones George Mbeh and I heard in 1987 centred around either the man who kept the Nyos guest book or another, a well-known healer, whose predictions were based on a particular wild plant that grows in the area and was said to turn red to signal a lake explosion. (No one was able to point out this plant near where we interviewed them.) Both men died in the explosion. The Cameroonian press began another panic about prediction, misreading American George Kling's scientific notation in the guest book that Nyos was a crater formed by an explosion as 'explosive', and therefore as a prediction, but most of the people we interviewed in 1987 had not heard or read about this particular bit of misinformation. The second motif, one that George Mbeh and I heard in 1987, had much more staying power and was eventually incorporated into the 1999 story I collected. This was that heavy-set, menacing-looking Nordic or European motorcyclists were seen in the area either days or hours before the Nyos explosion (the terrain around Lake Nyos is very rough, in most seasons too rough even for most all-terrain vehicles but a skilled motorcycle driver could make it to the lake, as several Peace Corps workers had apparently done shortly before the explosion). Sometimes these people were said to be part of the American/Israeli/Peace Corps connection, and sometimes not, but their presence was usually accompanied by a question mark in informants eyes, aware that they were speaking to an American. When I remarked that I'd never heard of delivering bombs by motorcycle, and I didn't think the American government was likely to do it that way, people often said that there was reportedly a large parcel on the motorcycle, not necessarily a bomb, and then changed the subject.

The stories I collected before the Nyos explosion and those mentioned above by Chilver in publications following the Nyos explosion were quickly 'overridden' by new stories that used different elements, some modern, some traditional, to explain the disaster at Lake Nyos. One of the first people to go into the area after the explosion was a Dutch priest, Father Fred tenHorn, who contributed a new 'modern' element, the neutron bomb. When interviewed by the international press, Fr tenHorn was quoted in *Time International* as saying 'it was as though a neutron bomb had exploded' (Smolowe 1986, p. 7). The 'as though' part of the former statement was quickly dropped and neutron-bomb-as-cause became a major explanatory motif among the educated, reading public (but not so much among the locals in 1987, Shanklin & Mbeh 1987). Other modern elements were added to give credence to the story: a diplomatic visit to Cameroon by the Israeli prime minister, Shimon Peres, coincided with the discovery of the Lake Nyos victims and the Israelis quickly provided equipment and supplies to the survivors, with the result that one 'modern' explanatory variant was that the US and Israel had entered on a pact to explode the neutron bomb, the newest weapon in the American arsenal, an experiment conducted on behalf of Israelis, who wished to see it demonstrated for possible use against Palestinians. A different version held that members of the American Peace Corps who had visited Lake Nyos on their motorcycles and remarked in the visitors' book about the beauty of the lake, had urged their country to test the neutron bomb at Lake Nyos in order to clear the countryside for their own eventual settlement.

It is worth mentioning the rumours that circulated after the 1984 explosion at Lake Monoun, near Bafoussam in the Western Province suggesting that these deaths were part of an attempted coup organized by or on behalf of the former dictator, Ahmadou Ahidjo. For this purpose, Ahidjo or his allies had dispatched a plane that crashed into Lake Monoun in the dead of night, causing the deaths of 37 people in the vicinity (why the bodies were spread along the roadside while the plane was in the lake was not explained). Eyewitness accounts of the Monoun events were considered worthless in the face of such spectacular conspiracy theories, but they are none the less very interesting and convincing ('JAK' 1986). In one version, collected by geologists studying the events, two men were given a ride by the local priest who had set off on his rounds early in the morning, just before daybreak, when the gas cloud could not be seen (the Nyos photos from a day or two after the explosion also show a wispy off-white residue that is hard to see even in the full daylight in which the photos were taken). When they saw bodies scattered along the road, the priest stopped and got out of the car, going downhill either to help or to administer last rites. Both his passengers also came out of the vehicle when they heard him coughing and choking but they soon realized there was nothing they could do for him. The two ran in opposite directions, one uphill and the other down and the one who ran uphill lived to tell the tale. We now know it was the release of carbon dioxide, not the crash of a mysterious plane, that caused the deaths at Monoun.

Murphy provides a semi-digested account of the 1987 UNESCO conference and her own trip around Lake Nyos, during which she admits to being lost or disoriented most of the time. She notes in her bizarrely-named chapter, Trapped by Lake Nyos, that 'In Cameroon the spirits of Fons and other important religious and military figures dwell in lakes, which also have their own powerful tutelary spirits ...' (Murphy 1990, p. 232) but does not elaborate.

A final comment on the 1986–87 variants: after our trip around the Nyos resettlement camps, George Mbeh and I returned to Kom, where we were closely questioned about our findings, especially about the causes of the lake explosion. In Kom at the time, there seemed a general feeling that Lake Nyos was particularly volatile and apt to remain so, even in 1987, seven months after the explosion. However, my suggestion that the 1986 Nyos explosion might have been like that of the Bamessi 'lake' in the Kom story was greeted with derision. The Kom lake, formed from the body fluids of their Fon, was said to be a 'supernatural' or 'spiritual' lake, not a 'real' lake as Nyos was, and I was politely but firmly told that the two had nothing to do with one another (Shanklin & Mbeh 1987).

Conspiracy theories of 1994

In a brief trip to Kom in 1994, I asked questions about the explanation for Lake Nyos and was told much the same stories I had heard immediately following the explosion; little was added that was new. The conspiracy between the Israelis and the Americans seemed to have gained ground, and the 'Mami Wata' version was not mentioned at the time. Since this trip was largely for personal reasons, I spent a fair amount of time with (literate) people who were friends rather than my usual Kom informants, who are older and mostly illiterate. Many friends worked in various cities around the country and were quite familiar with the conspiracy theory of the explosion and readily discounted the traditional explanations, with dead Fons and such. When I did have a chance to ask my Kom informants and to mention the exploding lake version of the Kom origin story, they universally dismissed the possibility of any similarity between events at Nyos and those of Bamessi. By and large, many Kom people were convinced by the conspiracy theory in 1994, though they knew fewer details and there was some variation in terms of which governments were considered responsible.

The 1999 version: collecting a new explanation

In 1999, I returned to Cameroon to investigate the latest stories and explanations and spent several months in and around the North West Province. On one trip to Buea, I encountered a young man who was selling plastic shoes on the street and, as we were walking in the same direction, he joined me and introduced himself as a Nyos survivor. After I convinced him that I was not going to buy his wares but would be happy to buy him a drink in return for his story, we continued our conversation over drinks on his girlfriend's porch. He told me that he was actually not a Nyos survivor but had friends from school who were and he gave me what he said was one friend's version of the explanation for the explosion.

On my next trip to Wum, I tracked down this friend and heard the story for myself. Because I am writing a book on this subject, I will not recount the full story here, either as I heard it or as it has changed since I first heard it. But the motifs involved will give a fair idea of the story: a deceased Fon who lives in Lake Nyos emerges for two reasons—first, to warn people that the lake is about to explode, and second, to take with him back into the lake any local endangered species in need of his protection. Heavy-set European-looking motorcyclists are present, and they have come to collect a somewhat mysterious object, an object said to have been in the lake as long as the indigenes have been in the area. The object represents local fertility and is dualistic, having both creative and destructive powers. The outsiders are not successful in their attempt to remove the object from the lake and something goes wrong, causing either the detonation of an explosive device (which is not necessarily a neutron bomb and is never called such in the story) or the detonation of the object itself, resulting in the devastating explosion the Fon predicted.

Several things are of interest in this version of events: first, in recent versions, the deceased Fon is a generic Fon, not a specific one; it was sometimes suggested to me in 1987 that the enraged deceased Fon was a Fon of Nyos, the ethnic group that inhabited the area prior to Independence and 'owned' the lake, but in 1999, no one gave the deceased Fon an ethnic identity of any sort—he had become generic. I asked the present Fon of Nyos (who was on the throne in 1986) if any such events might have happened in Nyos to inspire this story and he said emphatically not. Recalling the earlier story about a Fon enraged because his choice of slaughter animal was ignored, I also asked if Fons in the vicinity kept cattle and again was told no, in no uncertain terms. In 1999, no one volunteered accounts of people who had predicted the lake explosion and when I asked, I was told, somewhat vaguely, that there were such people 'somewhere' but no one could identify them precisely.

Now to say something about the 'author' of this story. He is a young man, 20 at the time of the interview in 1999; he is also a 'survivor' of the Nyos explosion but was away at school when the explosion occurred and killed nearly all his family. He had to leave school soon after, since there was no one to pay his school fees, and he took up a trade in the town of Wum, where he now lives and enjoys a modest success, although his trade does not engage him, he says, as his studies did. Probably he would have been a gifted English teacher had he continued in school. When our team first located him, he told us that most of the story was something he had heard from his father. Later, after several sessions in which we discussed the details of the story (I bought him breakfast over the course of a week's stay in Wum), he admitted that he had made up the story and begun telling it in 1994 or so, that his father had never discussed the Fon who was supposed to live in the lake, and that he had pieced his story together from various elements that interested him (including, for example, a study he'd read of endangered species in the Wum area).

To me the most surprising thing about the story is that its 'author' was so young. As a result of these interviews, my image of Homer has changed forever; the books I read as a child pictured Homer as an old, blind man, being led from one place to another by a young apprentice. Now my image is that it is the young man who is the storyteller, the one capable of keeping audiences spellbound with his visual imagery and his careful, psychologically-nuanced descriptions. Probably if he were questioned strenuously about one detail or another, he (and his audience) would have deferred to the older man's authority. Further, the story was spread, my young African Homer said, not in the courts of nearby Fons, but in off-licences in Wum where he told the story after a long day's work and was sometimes given food and/or drink in return. He mentioned that while 'singing for his supper', he noticed that most people preferred the traditional story elements, not the modern ones, so he had modified his story in traditional directions. Also, most people especially liked (and did not question, as we did) the part about his father's telling him the events as if he'd seen them in a dream. But mostly those who repeated to me the story told by my young storyteller did not mention its 'source' in the dream he claimed was recounted by his father, and that may have been another modification made by his audience. My African 'Homer' might be the catalyst but he is not necessarily the final arbiter of the story elements.

Oddly, to me, neither he nor his listeners made any attempt to link this story with the deaths at Lake Monoun but the explanation may lie either in a local liking for the conspiracy theories that link Monoun to an abortive coup attempt or, more likely, to a local preference for local explanations. In Kom, at least, if someone's child dies in a foreign country, the ultimate cause of the death is always considered to be local, normally a local malefactor with the power to cause, say, an auto accident in a distant land. Monoun, about seventy miles away, may simply be too distant, too different in cultural terms to be considered.

Conclusions

This study suggests conclusions in two directions: those to do with changes in myths or legends and those related to disaster relief. Because the former are of less interest to a geological audience, I will briefly sketch out those conclusions and then concentrate on the disaster relief implications.

Changes and transformations in myth

Clearly, definitional distinctions between story/legend/myth that scholars wrangle over—wrangles omitted here for reasons of space limitations—are pretty much useless in this context, as the new story being told around Nyos fits the definition of a myth in every respect except that its author acknowledges that it is a 'new' story composed of several traditional elements. We know that the 'new' story was being formulated, moulded, and retold in the Wum area from 1994 onwards. This point is sometimes corroborated in careful anthropological accounts of story-telling and suggests that successful stories, legends, or myths are often formulated in collaboration with an audience, especially audiences composed of energetic questioners and active listeners.

The main conclusions about myth transformation in this case can be illuminated with a series of (journalistic) questions to do with the *who*, *what*, *where*, *when* and *why* of storytelling and myth development. This case study reveals a good deal about the process, a fair amount of it anti-commonsensical. First, who are the mythmakers? Here it was not the old men, musing about their childhoods or dreaming over their cups who imagined this new version. Instead, the mythmakers of the 1986 Nyos incident are often young men, as witness the Peace Corps man who introduced, albeit briefly, 'Mami Wata' and the priest, who mentioned a neutron bomb, in passing as he thought. My version of Homer—in response to audience 'demand'—set his brand-new account in traditional frameworks so that after a while, the 'new wine' he added to old bottles began to seem indistinguishable from traditional stories usually considered ancient. In a decade or so, a foreign collector might not recognize either the new elements or the traditional motifs and might consider this an ancient story, especially when the recently-invented neutron bomb becomes a powerful explosive device that is not an artifact of modern technology.

Further, a second supplementary answer to 'who' is that those who recount the stories that circulate *are* more apt to be older people, at least in gerontocratic societies like those in the Grassfields, where older men, especially, have more leisure and money to spend in off-licences or Fons' courts. This is a guess on my part, based on my questions in off-licences and Fons' courts, where elderly men predominate and where younger men may not even speak, as a sign of respect.

What—the content of the story's motifs—is probably more apt to be up to date if the mythmakers are young men, as illustrated in the inclusion of elements such as endangered species or, in some versions, commentaries on too rapid social change, but much of this content was and is revised substantially in the course of the storytelling according to the audience's appreciation or distaste for certain motifs. Here it is necessary to know something of the audience's proclivities and in the Northwest Province, it is usually older men who deplore rapid social change, and younger, literate men who follow newspaper and radio stories about new scientific discoveries or revelations.

Where, in this instance, is nearly always the area around the North West Province's many crater lakes, as we know from Nyos and Monoun, and from folklore attached to many of the other lakes in the region.

The answer to when these explosions took place was invariably during the rainy season and at night, as I knew from collecting information in Kom, as well as from passengers on long car journeys, but this is valuable information when putting together a programme to train people to respond to these emergencies.

Why these events take place—a question asked of me over and over when I was interviewing survivors—belongs very much in the realm of faith and scientists must leave large portions of it there, although why certain people died and not others can be answered to some extent both architecturally and culturally. Architecturally, those who slept at the back of a room that had windows in the front or behind a barricade of some sort were more likely to survive than those near the front or where access to the house openings was unimpeded. Culturally, Grassfields men usually have their sleeping quarters at the back of a compound because as important people, they are supposed to be less accessible, but in the event of an emergency, the head of the household will go out to make inquiries or meet whatever danger exists. Women and children usually huddle indoors until the situation is resolved. This explains why so many men died outside when they and their families heard loud noises or saw strange lights coming from the lake. But why this particular night at Nyos and not the more densely populated market night, why one individual and not another survived his entire family, the answers to those questions remain within the realm of faith.

Lessons about disaster relief

First, local folklore about geological features might be studied in more detail than has previously been the case, with particular attention to the features that prove deadly in local myth, e.g. there are 46 lakes in the Grassfields region, a majority of which have attached legends recounting circumstances in which numbers of people (or very important people, such as a *Fon*) were 'slaughtered' in or by the lake. This folklore concerning natural hazards needs to be studied and evaluated or assessed according to whether it suggests that such hazards exist and exhibit recurring patterns, e.g. in the folklore, the explosion of crater lakes in Cameroon's Northwest Province seems always to happen in the rainy season and always at night, two factors that must be pointed out to local inhabitants in counselling on these matters. In my retelling of the story in a forthcoming brochure (Shanklin *et al.* 2007), I added another element of emergency preparedness training. In my version and on the cover illustration, the deceased Fon advises people to run uphill. I did this after seeing a high government official solemnly proclaiming on television that in the event of another such emergency people should run downhill. Carbon dioxide, which is heavier than air, flows downhill, like water, so those who run downhill increase their chances of dying whereas those who run uphill increase their survival chances.

Second, there is much to be learned from this case study about wrong directives or mistakes in contemporary planning; e.g. if, instead of moving down into the valley at government behest, the people who lived in the area around Lake Nyos had continued their traditional pattern of dispersed hillside settlements, there would have been far fewer casualties in the explosion of 1986 (Shanklin 1988*a*, *b*). This mistake was repeated in the resettlement camps, some of which were built in valleys adjacent to Lake Nyos, and for the same reason that the road through Nyos village was built where it was. That is, it is easier to build a good road in a valley than through a series of winding hills, but when the cost could well be counted in human lives, the economic savings perhaps should not be the primary consideration. My own suggestion, that people be allowed to farm in the valleys during the day but not to spend the night there, was made with this precaution in mind.

Third, there is also much to be learned from this case study about solutions to the problems of refugees, chief among which is that the 'natural' resettlement pattern advocated by the resident Catholic clergy, pairing up parents who had lost children with children who had lost parents, worked best (Shanklin 1988*a*), though this strategy was not universally successful and was particularly unsuccessful in the case of older adults, who, in several instances, lost their entire social support system in one night. For example, one of my 1999 informants was an older man, away from home on 21 August, who lost three wives and more than 20 children; when he developed a series of ailments from living alone and eating poorly, there was no one

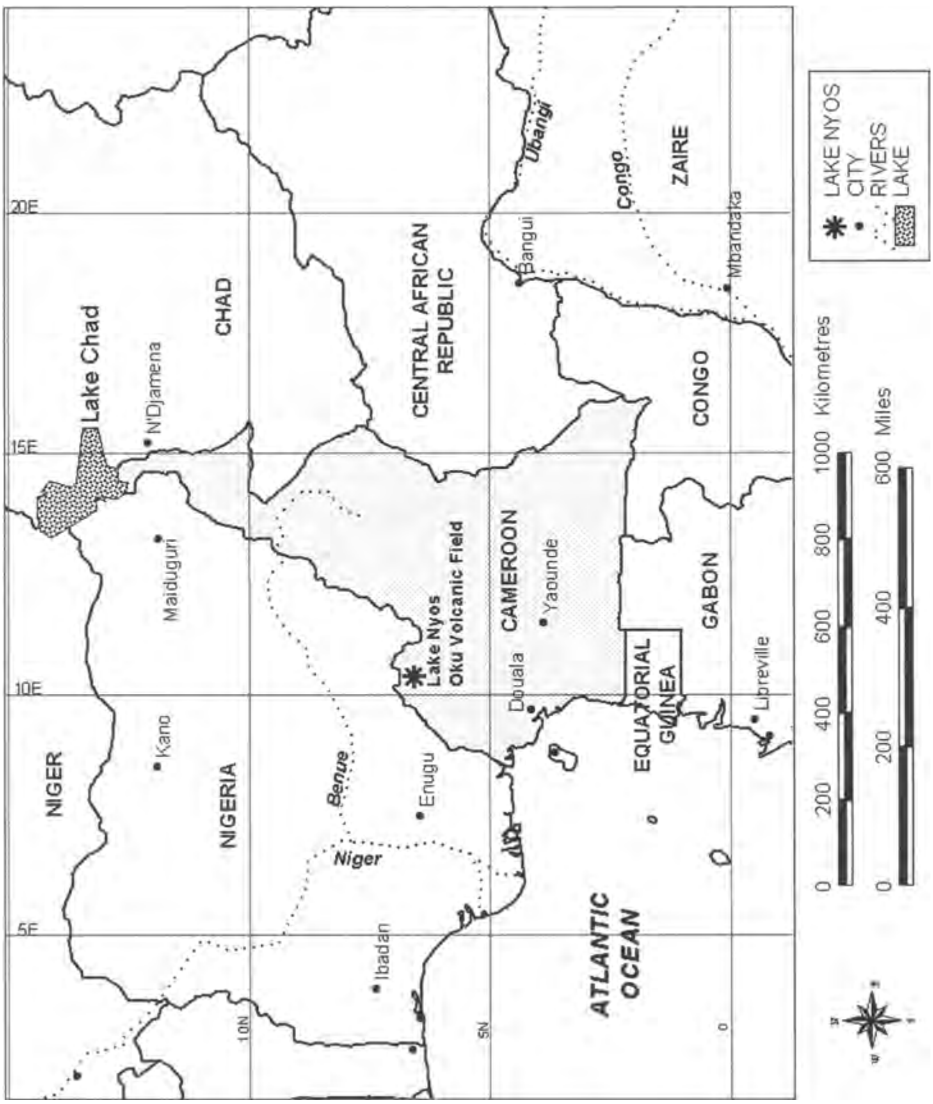

Fig. 1. Lake Nyos and environs.

to take him to the hospital, a service our team provided. What happens to such people when we or our equivalents are not there? Other strategies must be developed to include those survivors who are left out of the 'normal' resettlement strategies. What worked least well was the strategy of resettling refugees in uninhabited areas lacking one or more natural resources such as good farm land, water, etc (Shanklin & Mbeh 1987; Shanklin 1989). We knew the latter lesson already; as yet the former has not been so well established or its nuances studied closely enough to permit generalization (cf. Erikson 1994).

Finally, I agree with Leonard and McClure's wise summation, 'Like an onion, a myth has many layers ... Euhemerism permits us to remove one layer of the myth-onion, the comparative method another, the structuralist and functionalist approaches further layers, and psychological and literary analyses still others' (2004, p. 28) and they conclude that at the core, there is 'no *single* all-encompassing explanation' of myth but the effort of studying the many layers is its own reward. Better proofs of the 'euhemeristic' explanations advanced by geologists and those interested in the formation of geomythology lie in the compilation of more long-term studies of the ways in which such myths and stories change and develop. I believe that collaborations between geologists, folklorists and anthropologists would benefit all disciplines, that merely drawing attention to the question of stories involving natural phenomena would increase our awareness of both natural events and the (social) processes by which those events are accounted for. Anthropological fieldwork techniques have changed in recent decades and long-term studies, once very rare, are becoming commonplace. This kind of study is promising for increasing our understanding of the development of many phenomena, including myths or folktales and other cultural responses to geological processes.

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Myth and catastrophic reality: using myth to identify cosmic impacts and massive Plinian eruptions in Holocene South America

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Abstract: Major natural catastrophes such as floods, fire, darkness, and 'sky falling down' are prominently reflected in traditional South American creation myths, cosmology, religion, and worldview. Cosmogonic myths represent a rich and largely untapped data set concerning the most dramatic natural events and processes experienced by cultural groups during the past several thousand years. Observational details regarding specific catastrophes are encoded in myth storylines, typically cast in terms of supernatural characters and actions. Not only are the myths amenable to scientific analysis, some sets of myths encode multiple catastrophes in meaningful relative chronological order. The present study considers 4259 myths, including 284 'universal' (perceived in the narratives to be worldwide) catastrophe myths, from 20 cultural groups east of the Andes. These myths are examined in light of available geological, palaeoenvironmental, archaeological, and documentary evidence. Our analysis reveals three likely major Plinian volcanic eruptions in Columbia and the Gran Chaco. We also identify a set of traditions that are probably linked to the well-known Campo del Cielo iron meteorite impact in northern Argentina around 4000 years ago, along with a separate set of traditions alluding to a possible airburst in the Brazilian Highlands. These impacts apparently triggered widespread mass fires. There are hints of cosmic impacts in the mythologies for other locations in South America.

South America is a vast and physically diverse region, occupying some 17 819 000 sq km, approximately 12% of the world's overall land mass. South America was seemingly the last of the inhabited continents to be colonized, a process beginning by at least 12 000 BP. Prior to European contact in the sixteenth century, a wide range of societies developed and flourished throughout South America, ranging from simple migratory hunter-gatherers of Patagonia and Tierra del Fuego to well-known state-level societies of the central Andes and adjacent coastal plains of Peru and Chile. The Inca, the Chimu, and the Moche continue to impress archaeologists and historians with their monumental architecture and their mastery of irrigation and general water management. In between these two extremes were semi-sedentary and sedentary village horticulturalists and various small independent chiefdoms relying heavily on agriculture and maritime resources.

The distinguished anthropologist Julian Steward identified a total of 178 named different tribes for South America (Steward 1946–1959; Steward & Faron 1959). It is readily apparent that thousands of additional 'tribal' names are present in historical documents, and that much confusion exists due to synonymy and language uncertainties. Early explorers and missionaries had no systematic way to classify the various groups of people they encountered. There are at least 65 known language families in South America with estimates of the numbers of individual languages ranging between 400 to as many as 3000 (Bierhorst 1988, p. 17). This uncertainty is compounded by the fact that many of these languages and the groups who spoke them have become extinct during the past several hundred years.

Despite these conditions, South America has a rich legacy of oral traditions and mythologies. South American mythology has been the source for some of the most creative and comprehensive studies of mythology performed to date (e.g. Lévi-Strauss 1969, 1973, 1978, 1981; Bierhorst 1988). Of particular value for our study is the set of 4259 myths published during the period of 1970–1992 by the University of California at Los Angeles (UCLA) as part of the monumental 24-volume series entitled *Folk Literature of South American Indians* (Wilbert & Simoneau 1992). The distribution of the 'UCLA collection', representing 20 different cultural groups east of the Andes, is depicted in Figure 1.

We hypothesize that 'great' or 'worldwide' catastrophic events appearing in South American Indian

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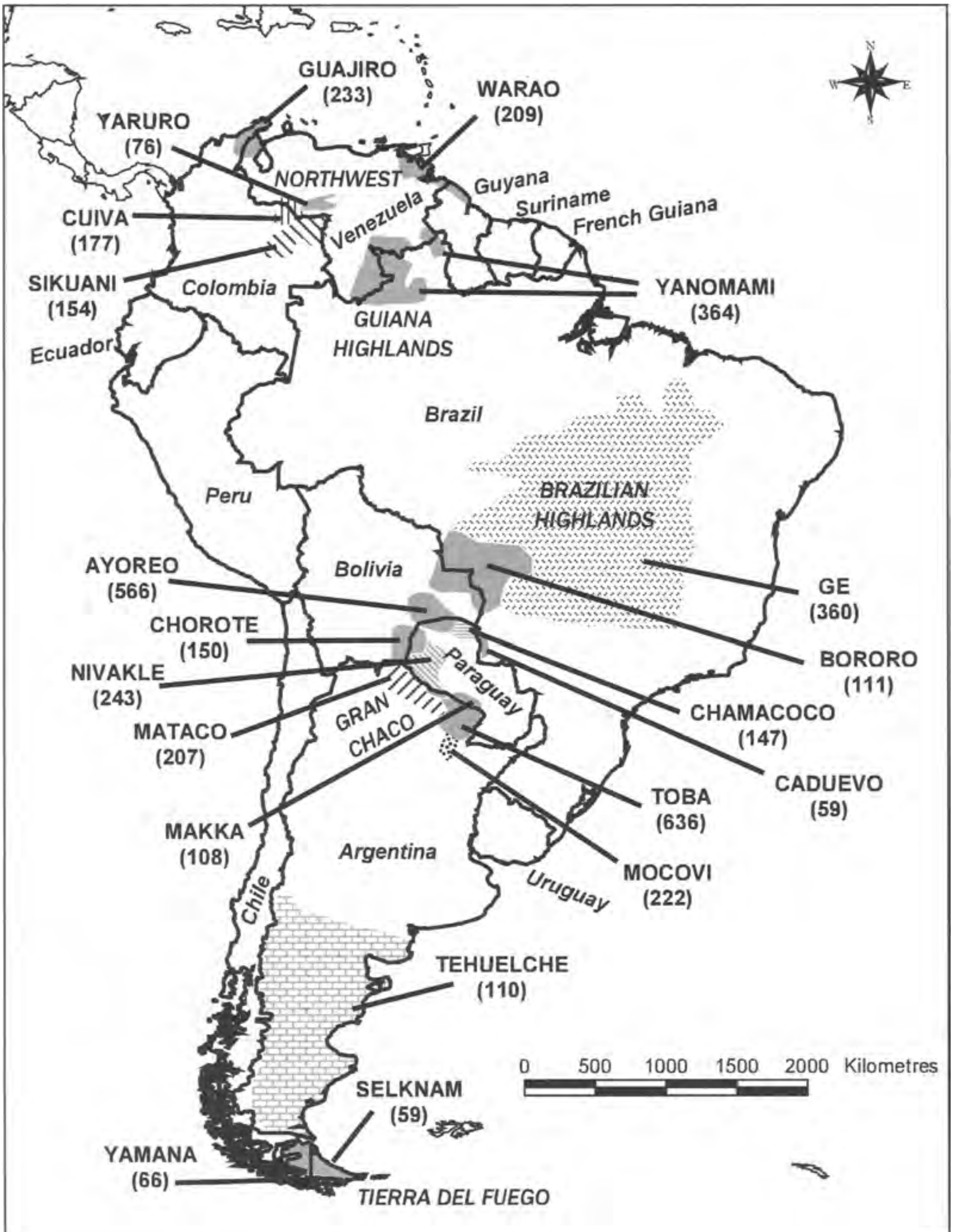

Fig. 1. Map of South America depicting countries (e.g. Paraguay), geographic regions (e.g. Gran Chaco) and cultures with their total numbers of myths in the UCLA collection (e.g. Toba with 636 myths).

mythologies are based on actual large-scale natural events identifiable in the geological and archaeological record. These include Plinian volcanic eruptions, cosmic impacts, and mass fires potentially caused by cosmic impacts.

We are not the first researchers to attempt to use myths to elicit historical information about South American catastrophes. A century ago Adolph Bandelier (1905, 1906) attempted to determine the historicity of myths along the western coast of South America relating to earthquakes, volcanic eruptions, and possible impacts by meteorites. Based on Spanish archival accounts and associated Native American oral traditions, Bandelier surmised that a number of South American volcanoes likely had significant eruptive events prior to Spanish colonization. Although several of his named volcanoes cannot be matched with their modern counterparts, Bandelier's list includes the Ecuadorian volcanoes of Capacurcu (?), Cayambe, Chimborazo, Cotocachi (?), Cotopaxi, Gugagua Pichincha, and Tungurahua; the northern Peruvian volcanoes of Guallollo (?) and Pariacaca (?); the southern Peruvian volcanoes of Coropuna, Huaynaputina ('Omate'), Misti, Quimsachata, and Solimana (?); and the Chilean volcanoes of Planchon-Peteroa and Villarrica. Of the 11 certain identified volcanoes for which Bandelier found oral traditions supportive of significant pre-Spanish volcanic activity, only that of Planchon-Peteroa has yet to provide documented physical evidence of such pre-Spanish Holocene activity (Siebert & Simkin 2005). Bandelier specifically looked for, but failed to find, evidence for either historic or pre-Spanish Holocene volcanic eruptions in the Bolivian Andes.

Native American oral traditions gathered and cursorily evaluated by Bandelier were all from Andean and coastal cultural groups not represented in the UCLA collection. We build on Bandelier's precocious suggestion that myth storylines and the spatial distributions of myth elements and motifs represent a logical and relatively accurate record of catastrophe and its impact on both humans and the environment. A systematic comparative analysis of environmental and geophysical data contained within the UCLA collection reveals patterns that appear to reflect the physical nature of the catastrophe, including the type, location, intensity, and duration.

In order to set the stage for our hypothesis and to identify potential specific catastrophes, we first examine aspects of the Holocene geological and environmental record of South America, including known Plinian volcanic eruptions, data pertaining to climate, regional mass fire events, and the record of known and hypothesized cosmic impacts.

South American Holocene physical environment

The Andes and Holocene volcanism

The subduction of the Nazca and Antarctic plates along the western continental margin has uplifted and folded the Andes into the longest range of mountains in the world, extending 8900 km from Columbia in the north to Tierra del Fuego (Fig. 2). At least 203 volcanoes with Holocene (*c.* 11 000 BP to present) activity have been identified, based on radiocarbon and tephrachronological dating and on observed glacial activity on older volcanoes. Holocene volcanism is divided into four main zones controlled by segmentation of the subducted plates along pre-existing zones of weakness. The volcanoes typically range in height from 4000 m to nearly 6000 m in the two northern zones, and are progressively lower in the two southern zones.

Unless otherwise noted, the details listed in the following discussion are obtained from *Volcanoes of the World* (Simkin & Siebert 1994), *Encyclopedia of Volcanoes* (Sigurdsson 2000), and Smithsonian Institution's '*Global Volcanism Program*' website (Siebert & Simkin 2005). Reference to the Volcano Explosive Index (VEI) for pertinent eruptions is from the Global Volcanism Program website. Figure 2 illustrates the locations of South American volcanoes highlighted below, presented in order of descending latitude. Thirty-eight Plinian eruptive events have been documented in South America (VEI $= 4$), along with 14 probable ultraplinian events (VEI ≥ 5). Plinian eruptions are characterized by voluminous eruptions of many cubic kilometres of magma, resulting in eruption columns generally ranging in height between 11 and 40 km. The column is composed of magmatic gases and tephra (fragmental volcanic ejecta), including pumice (frothy low density particles) and ash (glass shards, minerals, and rock fragments less than 2 mm in diameter). Stratospheric winds fan out the tephra column creating an effect commonly referred to as an umbrella cloud. Prevailing winds can distribute pumice tens of kilometres from volcanoes; ash can be distributed hundreds or even thousands of kilometres away. Hot pyroclastic density currents (flows) also are a common feature of Plinian eruptions. Many of the Andean volcanoes are covered in ice and snow, and pyroclastic flows often create destructive mudflows (lahars).

The Northern Volcanic Zone (NVZ), comprising more than 300 volcanic structures, is bounded by the Bahia Solano–Macarina mega shear-zone in central Columbia at the northern edge and extends

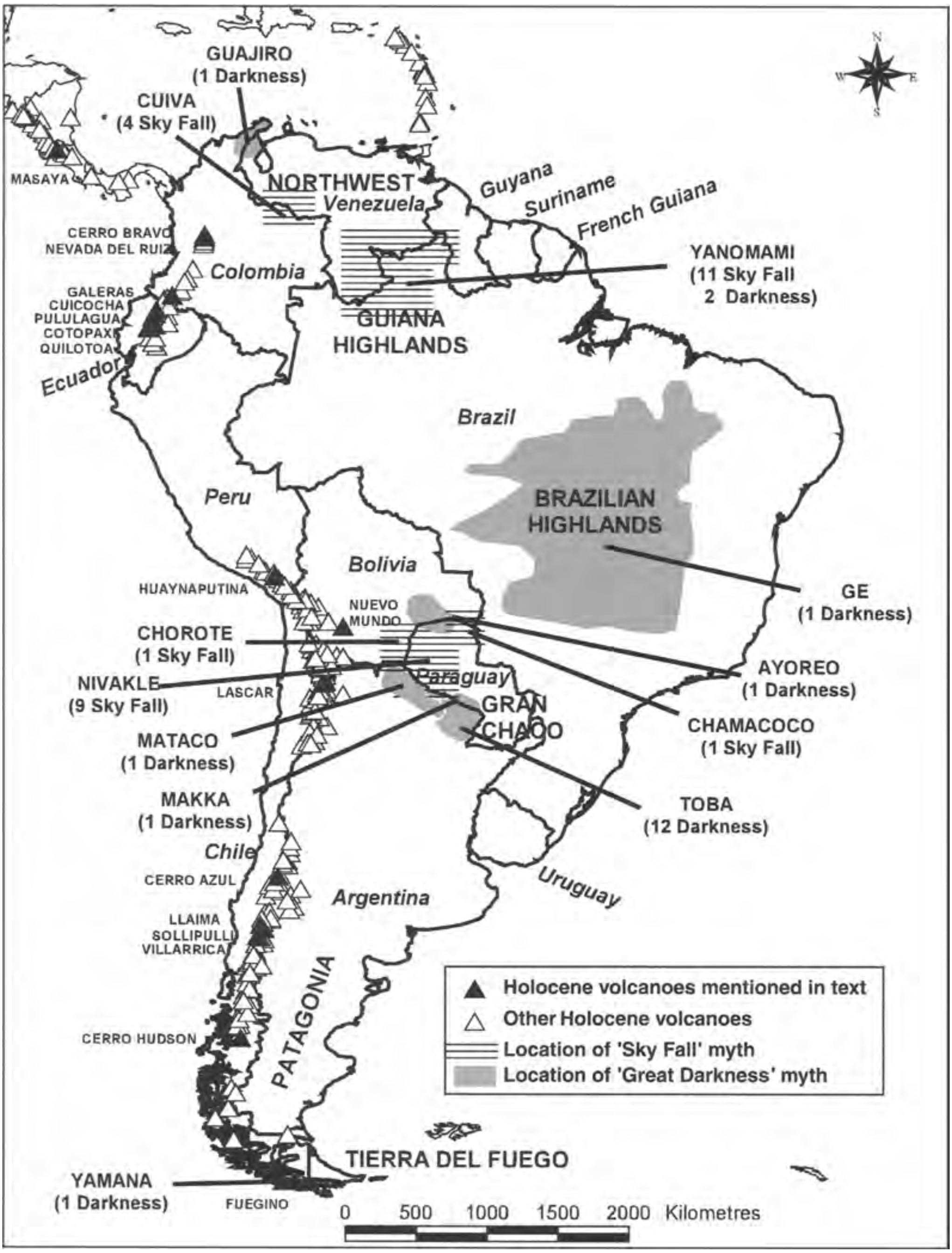

Fig. 2. Map of South America depicting the distribution of 'sky fall' and 'great darkness' catastrophe myths from the UCLA collection in relation to Nuevo Mundo volcano and known late Pleistocene and Holocene period cosmic impacts.

south 1100 km terminating at the Amotape mega shear-zone in southern Equador. Stratocones, clusters of monogenetic cones and several andesitic shield volcanoes dominate the NVZ, many capped by perennial snow or glaciers.

Cerro Bravo is the northernmost active stratovolcano with seven Plinian eruptive phases beginning approximately 6280 BP (Lescinsky 1990). Nearby Nevado del Ruiz stratovolcano has four documented Holocene Plinian eruptions since 2850 BP (Pierson *et al.* 1990; Thouret *et al.* 1990; Voight 1990; Simkin & Siebert 1994). In 1985, a Nevado del Ruiz subplinian eruption (VEI = 3) and associated small pyroclastic flows melted approximately 10% of the summit ice. A series of devastating lahars, including one that travelled 100 km, killed 23 000 people. Complex volcano Galeras has exhibited frequent, modest Holocene subplinian eruptions (Calvache *et al.* 1997; Banks *et al.* 1997). Charcoal evidence of ignited fires has been found 6–8 km from the crater. Cuicocha is a 3 km wide caldera formed during an explosive ultraplinian event in 1150 BC. An estimated 5 km^3 of pyroclastic material was ejected.

Stratovolcano Cotopaxi is the highest active volcano in the world (5911 m) and the site of perhaps the most catastrophic event to have occurred in the Holocene (Barberi *et al.* 1995; Mothes *et al.* 1998). Around 4640 BP a small sector collapse (2 km^2) of the upper north and NE slope caused an avalanche of ash debris into the valley below. This formed hummocks and a run-out field extending 25 km northward. Pyroclastic flows melted part of the icecap; the meltwater mixed with ash debris and formed an immense lahar. The lahar descended the western flanks of the Andes, entering two parallel river systems. It attained depths of 200 m, finally merging to create an 11 km wide flood front ending 326 km from its origin, emptying into the Pacific ocean. A portion of the lahar descended the SW flanks of Cotopaxi forming a 2–3 km wide path 30–40 m deep, eventually emptying east into the Amazon headwater region.

West of Cotopaxi, Quilotoa volcano generated a major ultraplinian eruption (VEI = 6) around 850 BP, creating a 3 km wide caldera. The eruption produced large pyroclastic flows; lahars reached the Pacific Ocean more than 160 km to the west. It also produced one of the largest airfall-tephra deposits of the northern Andes. Regional human impact is unknown, but is surmised to have been great.

Prehistoric pottery has been found at the base of the Cotopaxi lahar flow, and it is assumed that local cultures would have been greatly affected. A more definitive impact on past Andean cultures was created by the massive caldera-forming Plinian eruption of nearby Pululagua volcano around 2700–2500 BP. The eruption devasted Formative period archaeological cultures in western Ecuador, and led to major shifts in settlement systems and political alliances (Zeidler & Isaacson 2003).

The seismically active transverse Albancay Deflection shear zone is the northern boundary of the Central Volcanic Zone (CVZ) and is 1600 km south of the NVZ. More than 600 volcanic structures extend southward 1100 km. The southern boundary coincides with a subduction of the Sala y Gomez ridge hotspot track. Andesitic stratovolcanoes predominate.

Huaynaputina stratovolcano produced a small explosive eruption around 5750 BP, and then remained dormant with occasional mild fumarolic activity for the next 5300 years. Early Spanish documents note the Indian population would ascend Huaynaputina to perform appeasing sacrifices. The Huaynaputina eruption that began on 19–20 February 1600 was the most violent ultraplinian event to have occurred during historical times in South America, producing about 30 km^3 of ejecta (de Silva & Francis 1991; Adams *et al.* 2001; Thouret *et al.* 2002). The initial explosive event lasted 13–16 hours; a sustained eruption column ascended to 35 km at around 30 $m\,s^{-1}$. Strong east winds above the Tropopause formed an umbrella cloud and dispersed pumice fragments 50 km to the west. Thick pumice falls and ash blanked an area of 4900 km^2. The ultraplinian phase ceased abruptly as pumice debris choked off the vent. A series of vent-clearing explosive events occurred on February 20–22 producing extensive ashfalls. From February 22–24 the volcano was quiescent. Ashfalls began again on February 25 forming 'complete darkness' for around 40 hours. Strong earthquakes on 26 February caused the collapse of a cathedral and many houses. A loud explosion was heard on 27 February; pyroclastic flows and surges covered an area of about 950 km^2 and dammed the Rio Tambo Canyon forming two temporary lakes. The subsequent breach of these dams released large saturated debris flows down the valley into the Pacific Ocean 120 km to the west. Periodic explosions, ashfalls, and pyroclastic surges continued until March 15 when Huaynaputina again became dormant.

The Huaynaputina eruption has been assigned a VEI level of 6, at least equalling the 1883 Krakatau, Indonesia event. Ten villages were buried, more than 1500 people were killed, and the regional economy was devastated for 150 years. The atmospheric acid spike from the Huaynaputina eruption is documented in ice core samples from Greenland as exceeding the spike produced by Krakatau and may have affected world climate for decades.

The stratovolcano Lascar is the most active volcano in northern Chile. The Plinian eruption of 1993 produced pyroclastic flows extending more than 8 km. Tephra fell over large areas in Uruguay, Brazil, Paraguay and Argentina. Buenos Aires, 1500 km distant from Lascar, received light ashfall. (de Silva & Francis 1991; Matthews *et al.* 1997). The 1993 eruption (VEI = 4) demonstrates that moderate Plinian eruptions can distribute tephra over vast regions. Seasonal weather occasionally distributes ashfalls from the Andes into the Gran Chaco, Pampa, and the southern Brazilian Highlands.

The Southern Volcanic Zone (SVZ) is bounded in the north by a fault zone extending from the Galapagos Rise and is a continuous, little studied, volcanic belt extending 1400 km that terminates where the Chile Rise intersects the continent.

Cerro Azul stratovolcano has been historically active from the Quixapu vent on Azul's northern flank. In 1932 the Quixapu vent was the source of one of the most violent ultraplinian eruptions in the twentieth century producing more than 9.5 km^3 of tephra. Llaima stratovolcano has evidence of Holocene ultraplinian events in 8880 BP and 7290 BP. It has remained moderately active since 1640. Sollipulli caldera erupted violently from the SW rim in an ultraplinian event at 2920 BP (Gilbert *et al.* 1996). The stratovolcano Villarrica rises from a 2 km wide caldera formed in 3730 BP which itself occupies a 6 km wide Pleistocene caldera. Several ultraplinian events are identified from the late Holocene with pyroclastic flows extending 20 km. Frequent historical Plinian eruptions have melted glacial cover and have damaged several towns on its flanks.

Cerro Hudson stratovolcano (1905 m) is the southernmost volcano in the SVZ. Its base is greater than 300 km^2 and a 10 km ice-filled caldera occupies its summit. It was not recognized as a volcano until its first twentieth century eruption in 1970. An ultraplinian event in August 1991 produced an estimated 4 km^3 of pyroclastic ejecta (Naranjo & Stern 1998). It is now known that a caldera-forming event in 6700 BP deposited more than 10 cm of tephra 900 km south in Tierra del Fuego. A bulk volume of greater than 18 km^3 is estimated for this event. A second massive eruption in 3890 BP approached the magnitude of the 6700 BP event. Both eruptions have been assigned a VEI of at least 6 and are said to have exceeded the 1991 Cerro Hudson event (VEI = 5+) and the 1932 eruption of the Quizapu vent on Cerro Azul (VEI = 5+) in explosive force and tephra bulk volume.

Beginning 290 km south of Cerro Hudson five widely separated stratovolcanoes comprise the Australandean Volcanic Zone (AVZ), defined where a portion of the Antarctic plate descends beneath the continental plate. Three volcanoes have been observed distantly or by aerial means, including the Volcán Fueguino lava domes, but none has been studied systematically.

Tanguy *et al.* (1998) have attempted to put a human face on volcanic eruptions by creating a worldwide database of the causes of documented death from volcanoes between 1783 and 1997. Of the more than 221 907 victims, the following causes were deduced in decreasing order of significance: Post-eruption famine and disease (30.3%); pyroclastic flows (26.8%); lahars (17.1%); volcanogenic tsunami (16.9%); debris avalanche (4.5%); ashfall (4.1%); and lava flows (0.3%). Most of the volcanic eruptions discussed above for South America are notable for pyroclastic flows, lahars, famine and disease, and to a lesser degree debris avalanches, and ashfalls. However, as one moves east of the Andes, the effects of ashfalls and associated famine take on a heightened role. These proportional relationships can be identified in sky fall and darkness myths.

Climate and fire regimes in the Gran Chaco and Brazilian highlands

Dominated by oceans, the atmospheric circulation in the southern hemisphere is primarily zonal and is disrupted by the north–south interposition of the South American continent and the continuity of the Andes Mountains. Distinct pressure zones are the intertropical low and subtropical high with air mass movement from east to west. Within the intertropical low the NE and SE trade winds merge forming the Intertropical Convergence Zone (ITCZ) and at convergence the moist air is pushed aloft resulting in a band of heavy precipitation. This band moves seasonally, always being drawn toward the area of most intense solar heating, or warmest surface temperatures. The band of subtropical high pressure forms two distinct cells east and west of the Andes. Temperate low pressure, and polar high pressure air mass movement is west to east. Seasonal fluctuations of these semipermanent pressure systems and their interactions are responsible for the various major climate regimes. Climate is further influenced by seasonal insolation producing local and regional high-pressure zones.

East of the Andes broad natural vegetation zones have developed in direct relationship to the amount and season of rainfall and altitude. Tropical vegetation predominates from 10°N to 10°S. The Amazonian lowlands are occupied by dense rain forest. Extending south and east of the rain forest boundary is the *cerrado* (*c.* 2 000 000 km^2) of the

Brazilian highland, characterized by savanna grasslands and low, dense savanna forests of 5–15 m tall evergreens. In the *cerrado* the trees are gnarled and twisted and have a thick, fire-resistant bark—perhaps an adaptation to the many lightning induced natural fires from frequent thunderstorms. The *cerrado* has been termed 'the natural epicentre of Brazilian fire' (Pyne *et al.* 1996, p. 685). Temperate vegetation in the Pampa of southern Brazil and Uruguay (327 000 km^2) changes to a vast tall grass prairie. The rainfall is greater than 1000 mm and is suitable for forests. High evaporation, low water tables, and frequent regional fires inhibit their growth (Clapperton 1993). West of the Rio Paraná and west of the 1000 mm rainfall isohyet is the Gran Chaco (609 600 km^2), an immense region of dispersed deciduous thorn forests and grassland. Intense evaporation, low rainfall, and very hot summers predominate; lightning induced local and regional wild fires are frequent. South of the Gran Chaco the full effect of the Andean rain shadow, and high steady winds characterize the Patagonian plateau (770 000 km^2). This semi-arid desert is colonized by short drought-resistant shrubs and grasses in the north and in the far south, forests occupy lower Andean slopes in the west and grassland steppe on the plateau to the east.

A synthesis of palaeoenvironmental data suggests that the early to mid-Holocene was drier than now (Ledru *et al.* 1998; Salgado-Labouriau *et al.* 1998; Behling *et al.* 2001; Marchant *et al.* 2001; Sifeddine *et al.* 2001). Swamps dried up, peat formation was absent, lake levels were lower or dried up, and sedimentation decreased. The ITCZ remained seasonally further to the north. Climate zones moved northward and vegetation became more xerophytic. Savannas in tropical lowlands expanded; temperate forests evolved into *cerrado*. Frequent fires have been identified in lacustrine core samples. The dating of the arid episode varies from site to site and was gradual; no sudden climate changes have been identified. Reported dating of this transition vary widely and range between 7000 and 3800 BP. The return of the ITCZ further southward brought increased precipitation and a climate and vegetation transition to current regimes. At 5000 BP in Columbia, cores disclose degraded vegetation with the presence of *Zea mays* pollen and charcoal, evidence of farming and the use of fire as a forest clearing technique (Marchant *et al.* 2001).

Flammable plant material and an ignition source is all that is necessary to start a wildland fire. If flammable material is contemporaneous with the presence of drought or dry winds, fires can grow to regional proportions. The 1997–1998 El Niño event delayed rainfall to the NW portion of Brazil, a region already suffering from an extended drought. Once wildfires started, they consumed over 20 000 km^2 of highland savanna in 1997 and 40 000 km^2 in 1998. Drought and fire was worldwide; the popular media defined 1998 as 'the year the Earth caught fire'.

Ignition may originate from several sources. Lightning is the primary igniter and is pervasive throughout South America starting hundreds of fires annually. It is particularly prevalent in the Pampa and Gran Chaco regions in summer when the southwesterly flow of dry air from Patagonia converges with westward flowing moist air from the SE trade winds forming vast frontal systems accompanied by intense cloud-to-ground lightning (Clapperton 1993). Fire ignition can be volcanogenic. Pyroclastic flows, incendiary bombs, and lava flows can produce local and regional burning (Calvache *et al.* 1997).

Anthropogenic fires can be purposeful or accidental. Amerindian hunters may have used fire regularly as early as 8000 BP to herd or flush prey (Goldammer 1993). In recent times the Toba people in the Gran Chaco commonly set bush and grass fires to procure game, and the burnt ground was searched for injured and dead animals (Métraux 1946, p. 13). There is strong evidence for Mid-Holocene agricultural burning (Marchant *et al.* 2001), although natural causes cannot be ruled out. Frequent charcoal occurrences have been identified between 7000 and 4000 BP (Santos *et al.* 2000). It has been suggested that intensified El Niño events occurred beginning around 5100 BP causing worldwide drought and regional fires comparable to the 1997–1998 event (Haberle & Ledru 2001). Modern examination of controlled burns over single and multiple seasons are helping to document the progression of biotic recovery and can be used to model past events (Bóo *et al.* 1996, 1997).

Late Pleistocene/Holocene cosmic impacts

The record of cosmic impact is not as well known for South America as that for other parts of the world (University of New Brunswick 2005; Masse 2007). A total of only seven impact structures have been documented to date, two of which are located in Argentina and are of potential significance to our discussion (Fig. 1). One, Campo del Cielo, dates back to the Holocene period. The second, Rio Cuarto, has been dated to the Holocene period, but both its nature and dating is suspect as is discussed below. A third probable impact structure, Iturralde in northern Bolivia, may date back to the end of the Pleistocene. In addition, there are several glass melt strewn fields dating to the Quaternary period that may relate to either airbursts or to impacts for which the craters have yet to be documented. One apparent airburst in the vicinity of Rio Cuarto has been dated to the middle Holocene and probably produced ground fires.

The 8 km diameter depression referred to as the Iturralde Structure (Araona Crater) was initially identified from 1984 LandSat images. Despite two expeditions by NASA Goddard in 1998 and 2002, its expected meteorite impact origin is not yet confirmed (Wasilewski *et al.* 2003). Both expeditions were hampered by the logistics of site location within the Amazon rainforest. The geological context of the structure indicates a formation date of around 30 000–11 000 BP, possibly too early to have been witnessed by humans unless occurring between about 15 000–11 000 BP.

The Campo del Cielo 'Field of the Sky' crater field in northern Argentina was first mentioned in Spanish colonial reports from 1576 and variously since then. This portion of the Gran Chaco is semi-arid, hot, very flat, and covered equally by savanna, scrub, and dense thorn forests. Reconnaissance of the site in 1961 supported the theory of meteorite origin and the National Science Foundation awarded grants to study the site beginning in 1962. The depressions were confirmed to be impact craters formed from the impacts of multiton silicated iron (IAB) meteorites.

The Campo del Cielo crater field contains at least 26 small, elongated impact craters within a north-trending ellipse, 3 km wide and 19.2 km long. The in-fall angle was calculated at 9° from the horizon (Cassidy *et al.* 1965; Cassidy & Renard 1996). The main concentration of craters is at the southern end of the ellipse. A strewn field extends 60 km beyond the craters, and meteorites have been recovered all along the path. Two craters were studied extensively. Three sizeable charcoal specimens were recovered for ^{14}C dating and the impact event was estimated at around 4000 BP. Impact velocities have been calculated ranging from 1.7–4.3 km s^{-1}. An analysis of impact effects yielded a pre-atmospheric entry velocity of 22.8 km s^{-1} (Cassidy & Renard 1996), a diameter greater than 3.0 m (Cassidy *et al.* 1965; Liberman *et al.* 2002), and mass minimally at 840 000 kg (926 tons) (Liberman *et al.* 2002). No impact glass melts have been recovered from the Campo del Cielo crater field, indicative of the small size and relatively slow speed of the impactors.

Cassidy & Renard (1996, p. 443) cite and translate traditional information, published by medical doctor and historian Antenor Álavarez in 1926. They suggest this information may relate to the impact and its aftermath as witnessed around 4000 years ago:

> The meteorite of the Chaco was known since earliest American antiquity through stories from the Indians who inhabited the provinces of Tucumán. (These Indians) had trails and easily traversed roadways that departed from certain points more than 50 leagues away, converging on the location of the bolide. The indigenous tribes of the district gathered here in useless and vague veneration to the God of the Sun, personifying their god in this mysterious mass of iron, which they believed issued forth from the magnificent star. And there [Campo del Cielo] in their stories of the different tribes of their battles, passions and sacrifices, was born a beautiful, fantastic legend of the transfiguration of the meteorite on a certain day of the year into a marvelous tree, flaming up at the first rays of the sun with brilliant radiant lights and noises like one hundred bells, filling the air, the fields, and the woods with metallic sounds and resonant melodies to which, before the magnificent splendour of the tree, all nature bows in reverence and adoration of the Sun.

Giménez Benítez *et al.* (2000) have conducted a detailed review of the Álvarez information to determine what relationship it may have to the Campo del Cielo event. They question aspects of the findings and suggestions of Álavarez, particularly the notion of a widespread solar cult. However, Giménez Benítez and his colleagues note little archaeological work has been done around Campo del Cielo but that it needs to be done. They also note that there has been little meaningful dialogue between anthropologists and planetary scientists regarding the myths and the physical aspects of the impact site.

Rio Cuarto, in central Argentina, graced the cover of the journal *Nature* (Shultz & Lianza 1992) and was proposed as a Holocene shallow angle meteorite impact zone containing at least 11 elongated craters. The largest is about 1.1 × 4.5 km. Schultz & Lianza (1992) noted that these putative impact structures could be interpreted to be of aeolian origin due to the geological setting; however, they also pointed to the presence of impact glass melts in and around some of the putative craters.

Further laboratory testing and aerial mapping have provided alternate interpretations (Bland *et al.* 2002; Cione *et al.* 2002). Bland *et al.* (2002) suggest that the Rio Cuarto structures are part of a widespread set of several hundred elongated aeolian depressions associated with parabolic sand dunes that formed in the Argentine Pampas during the mid-Holocene. They did support the impact origin of the Rio Cuarto glasses; their interpretation was that the glasses represented the distal ejecta of an impact occurring several hundred kilometres away, that was Pleistocene in age, around 480 ka.

Cione *et al.* (2002) likewise support a non-impact origin for the Rio Cuarto structures, and state that Argentine geologists have long supported the aeolian formation of these structures, pointing out that the alignments match prevailing wind patterns during the period(s) of their formation. Cione *et al.* (2002) argue that the glass melts are unlikely to be of impact origin, rather they suggest that natural and anthropogenic fires, such as the burning of fields as part of the agricultural cycle, can produce the glass melts described by Schultz *et al.* (2004) and Bland *et al.* (2002). This seems unlikely because of recent detailed studies of the glasses and because of the physics of wildfire.

Schultz *et al.* (2004) have conducted an exhaustive analysis of melt glasses from the Pampas. They identified glass melts from five separate Quaternary period cosmic impacts with four of the impacts dating to the Pleistocene period between 570 ± 100 ka (corresponding to the material identified by Bland and his colleagues) and 114 ± 26 ka. Of significance is the robust documentation of the age of the Holocene impact glasses by three dating techniques: 4–10 ka based on geological context (stratigraphy and preservation state); 2.3 ± 1.6 ka by fission track dating; and 6 ± 2 ka by radiometric $^{40}Ar/^{39}Ar$ dating. The combined suite of dating techniques implies a date for the impact of approximately 3–6 ka, similar to that for Campo del Cielo. No impact craters were defined for any of the five glass melt horizons, but the Holocene Rio Cuarto glass melts are traceable along a corridor extending at least 150 km to the SW, suggesting a sizable impactor. Schultz still favours an impact origin as originally defined for the Rio Cuarto structures; however, he concedes that the Holocene impact glasses could conceivably result from an airburst (Schultz *et al.* 2004; P. Schultz, pers. comm. 2004).

We still have much to learn and understand about airbursts—cosmic impacts by objects that explode and release their energy in the atmosphere above the Earth's surface—such as the well-known 1908 Russian Tunguska event. The frequency and the range of magnitude of large airbursts and all other classes of cosmic impacts are still critical topics of research (Bland & Artemieva 2003; Morrison *et al.* 2003). Most magnitude estimates of Tunguska range between 10–15 megatons (MT), approximately 500 times more energetic than the estimated energy release of the atomic weapons that destroyed Hiroshima and Nagasaki. Recent modelling (Bland & Artemieva 2003; Wasson 2003) suggests that airbursts can be created by objects much larger and therefore much more energetic than that of Tunguska. Objects and resultant airbursts smaller than Tunguska also produce devastating local Earth surface effects. In 1930, an apparent airburst half the magnitude of Tunguska devastated several hundred square kilometres in Brazil's upper Amazonian rainforest, creating widespread wildfires (Bailey *et al.* 1995). Similarly, a poorly documented apparent airburst may have occurred over Guyana in 1935 (Steel 1996).

Petrological and electron microprobe analyses of the Argentine glass melts by Schultz *et al.* (2004) indicated that temperatures in excess of 1700 °C were necessary to completely melt all constituents including quartz grains. The specimens indicated rapid quenching of the melt and is stratigraphically restricted in occurrence. Together with the high temperatures for melt productions, this strongly implies an airburst origin.

Aspects of the physics of wildland fire argue against human burning of fields as the origin of the glass melts suggested by Cione and his colleagues. Pyne *et al.* (1996, pp. 20–23) note that the theoretical maximum temperatures that can be achieved by the burning of combustible gases generated from wildland fuels is around 1900–2200 °C. Most wildland fires, however, are more likely burn at average temperatures of between 700–980 °C with the maximum actually measured for an exceptionally intense fire being not much greater than 1650 °C. The burning of fields in preparation for agriculture, including the presence of smoldering fires, would typically yield temperatures lower than the average wildland fire due to the differences in fuels. These data are also in accord with our first-hand experience with assessing the impacts of wildfire on soils and archaeological sites in the North American Southwest (e.g. Nisengard *et al.* 2002).

Mythology

Our view of the nature and meaning of mythology, along with the structure and utility of oral tradition, is discussed earlier in this volume (Masse *et al.* 2007*a*) and other publications (e.g. Masse 1995, 1998, 2007; Masse & Espenak 2007; Masse *et al.* 2007*b*). This differs considerably from the manner in which myth is portrayed by most contemporary anthropologists and mythographers. We recognize that myths do have important psychological and structural aspects, in addition to the basic fundamental values given to myths within their traditional cultural settings; however, we chose to emphasize that myth can represent a coherent form of historical narrative.

The UCLA collection

Our environmental analysis of South American mythology is indebted to the efforts of Wilbert and Simoneau in putting together and publishing *Folk Literature of South American Indians* (Wilbert & Simoneau 1992). A total of 4259 myths from 31 South American Indian societies representing 20 major cultural groups were assembled and reproduced along with a detailed classification of the complex motifs contained in each story. These myths are the contribution of 111 authors, translated into English as necessary, and published over the course of 20 years as a set of 23 separate volumes. The cultural groups themselves are widely dispersed: five from the 'Northwest' region of Columbia and Venezuela at the northern tip of the continent, one from the Guiana Highlands along the border of Venezuela and Brazil, two from the Brazilian Highlands of central and eastern Brazil, nine from the Gran Chaco of northern Argentina, Paraguay and eastern Bolivia, one (now extinct) from Patagonia in southern Argentina, and two (also extinct) from Tierra del Fuego at the southern tip of the continent (Fig. 1).

Although there are many societies and myths not included in the UCLA collection, the coverage is sufficiently widespread and diverse to permit our preliminary attempt to draw inferences from the distributions and regional patterns of myth motifs. The sample is particularly robust for the Gran Chaco region. The 4259 myths do not represent all recorded stories for each cultural group and cannot be used to achieve absolute quantification of motifs for each culture and between cultures. The editors deliberately attempted to include as many substantive story variants as possible to provide a qualitative sense of story and motif prevalence.

A single person, Simoneau, is responsible for the motif classification and indexing of 22 of the 23 volumes. This gives the whole body of work a uniformity of approach and consistency unparalleled by any other large regional body of myths. A total of 54 637 motifs were identified, divided into 23 motif groups and 135 subgroups. The motif groups include the following categories: mythological motifs, animals, tabu, magic, the dead, marvels, ogres, tests, the wise and the foolish, deceptions, reversal of fortune, ordaining the future, chance and fate, society, rewards and punishments, captives and fugitives, unnatural cruelty, sex, the natural life, religion, traits of character, and humour. The mythological motif category contains a total of 11 958 motifs or approximately 22% of all motifs. Within the mythological motifs are the following subgroups: creator, gods, demigods and culture heroes, cosmogony and cosmology, topographical features of the earth, world calamities, establishment of the natural order, creation and order of human life, creation of animal life, animal characteristics, origin of trees and plants, origin of plant characteristics, and miscellaneous explanations.

Any given myth can of course contain dozens of motifs, and any specific motif subgroup, for example 'world calamities,' can occur as a minor theme within the context of other subgroups and groups. Our focus in this paper is on the motif of 'world calamities'.

South American catastrophe myths

A small but persistent motif within the mythologies of the 20 studied cultural groups is 'world cataclysm', in which most people of a particular tribe and their neighbouring tribes, or typically all people worldwide, are said to have died. Wilbert & Simoneau (1992, p. 27) provide insights regarding the possible aetiology of such catastrophe myths:

> Accounts of universal or local catastrophes are told by all our sample societies except the Caduveo, whose failure to do so may be attributable merely to the limited size of the collection. Many tribes describe a number of disasters, some ordered by a supernatural being as punishment for perceived offenses, others simply regarded as spontaneous events which the myths attempt to rationalize. Whatever their source, such cataclysms play a major role in shaping the world as we know it today. The Flood motif and the Great Fire are the most common, but the Long Drought, the Wave of Cold, the Fall of a Meteor, the Great Darkness, and the Collapse of the Sky also appear. Doubtless many such tales reflect the environmental hazards faced by the Indians, as long-gone natural disasters, dimly preserved in tribal memory, tie in with creation or other myths to explain the present natural order.

Wilbert & Simoneau (1992, p. 54, 353–357) identified a total of 685 individual motifs within the world calamity subgroup. Some of these variables are what we suggest to be environmental observations contained within the myth storylines.

We have chosen five categories of world calamity for our environmental and geological analysis of South American mythology (Table 1). These are the 'great flood,' the 'great cold,' the 'world fire,' the 'sky falling down' (sky fall) and the 'great darkness'. These are the most prevalent cataclysms, being mentioned in 284 of the 4259 myths. There is some indication, particularly from the Gran Chaco, that cultural groups placed these stories into relative order: the flood and cold occurred first, the world fire in the middle, and sky fall and darkness occurred most recently, but still prior to European colonization in the early 1500s.

Regrettably, the relative order of disaster myths has not been a specific topic for investigation by most ethnologists and collectors of mythologies, nor was this apparently the case for the editors of the UCLA collection, thus much potentially valuable relative chronological information has been compromised or lost in the recording of these myths. In those few cases in the Gran Chaco where relative information is provided, the flood is consistently singled out as the earliest of the worldwide disasters. It is notable that the flood is

Table 1. *Number of individual UCLA Folk Literature Collection myths containing specified 'world calamity' motifs for each cultural group in the collection.*

Culture & location	Great flood [earliest in myth cycle]	Great cold [after flood myth]	World fire [middle of myth cycle]	Sky fall darkness [latest in myth cycle]	Great darkness [latest in myth cycle]	Total
Northwest						
Cuiva	13	–	–	4	–	17
Guajiro	9	–	–	–	1	10
Sikuani	10	–	–	–	–	10
Warao	3	–	–	–	–	3
Yaruro	10	–	–	–	–	10
Guiana Highlands						
Yanomani	17	–	–	11	2	30
Brazilian Highlands						
Bororo	4	–	1	–	–	5
Ge	11	–	6	–	1	18
Gran Chaco						
Ayoreo	17	–	2	–	1	20
Caduevo	–	–	–	–	–	0
Chamacoco	10	–	1	1	–	12
Chorote	10	–	7	1	–	18
Makka	2	–	–	–	1	3
Mataco	12	–	5	–	1	18
Mocovi	7	–	3	–	–	10
Nikvale	6	1	6	9	–	22
Toba	24	5	27	–	12	68
Patagonia						
Tehuelche	2	–	–	–	–	2
Tierra Del Fuego						
Selknam	1	–	–	–	–	1
Yamana	3	1	2	–	1	7
Total	171	7	60	26	20	284

by far the most prevalent of the disaster myths. In this regard, the prevalence of the myth of the great flood in South America matches that for virtually all other regions of the world and as such represents the one truly universal human myth not traceable to a common source (Frazer 1919; Dundes 1988; Dang Ngheim Van 1993; Masse 2007). The flood myth lies beyond the scope of this paper, but is subjected to similar environmental analysis elsewhere (Masse 1998, 2007).

'Sky fall', 'great darkness' myths and Plinian volcanic eruptions

Motifs about the 'sky falling down' (sky fall) are common in mythology worldwide, and logically could allude to several different natural phenomena. Intense rain, large hailstones, smoke from mass fires, volcanic ashfall, and debris from tornadoes and waterspouts could provoke images of the sky falling, as could airbursts and meteorite falls such as have been documented at various places throughout the world in virtually every decade throughout the twentieth century (Lewis 2000, pp. 14–25, table 1.1). A period of intense darkness during daytime hours could logically result from several phenomena, including solar eclipses, dust storms, smoke from mass fires, volcanic ash plumes, or the stratospheric dust loading from the coma of a dusty large near-Earth comet as has been hypothesized for an extended period of worldwide diminished sunlight beginning in AD 536 (Baillie 1999; Gunn 2000).

Figure 2 illustrates the distribution of 'sky fall' and 'great darkness' myths in our sample of 20 cultural groups. 'Sky fall' and 'great darkness' myths are most prevalent in the Gran Chaco region, and also occur in substantial numbers for several cultures in the northwest and the Guiana Highlands. The myths themselves provide a number of substantive clues as to the nature of the observed natural disaster(s).

Gran Chaco 'sky fall' and 'great darkness' myths. In the Gran Chaco (Fig. 2), there are nine 'sky fall' myths for the Nivaklé, with single stories found also for the neighbouring Chorote and Chamacoco tribes. Pertinent environmental details contained in the 11 Gran Chaco 'sky fall' myths are presented in Table 2. It is evident that all eleven stories refer to the same event—ashfall from a Plinian eruption. The following Nivaklé story is representative (Chase-Sardi, in Wilbert & Simoneau 1987*a*, pp. 101–102, story no. 35):

Now I am going to tell you about the time, long ago, when the sky fell. A heavy rainfall began, until finally the sky began to descend. The people were very frightened and asked the shamans to order the rain to stop. But not even those who sang to the rain could do anything. The next day they saw the clouds falling. 'Now the terrible moment has come,' said the people. Among them was one man who now warned everybody to take refuge under a *molle* [Brazilian Peppertree, *Schinus mole*] tree, for the sky would fell all the other trees. Only the *molle*, could not be either crushed or felled. All the people who stood under the other trees would be smashed; only the *molle* could support the weight of the sky. The men ran toward the forest where they found some *molle* trees to take refuge under. They had with them their wives and children, and a few sheep which they had been able to round up quickly.

The sky crushed the huts, killing all those who were sheltering inside. It was very heavy. Intense darkness covered everything, and the people could no longer see one another. Disoriented, they did not know what to do. They tried to cut through the sky with their knives and axes, but in vain; it was very hard, seemingly impenetrable. They did not know what to do, and were terrified. It was not like daytime; they could not see, for it was darker than during the night. 'Are you still alive?' some would ask. 'Yes, I am alive,' others would answer. In the meantime it dawned. One of the men remembered some tuco-tuco teeth [incisors of the burrowing rodent *Ctenomys*] which he had kept for many years inside a rolled-up piece of string. This saved them. Quickly he started cutting the sky with the tuco-tuco teeth. Suddenly it opened above him. He ran to the other people and distributed his tuco-tuco teeth among them, and everyone worked to cut through the sky that covered them. Soon it opened, and once more they could see the day. They were happy. For many years we heard the old people saying that the sky was going to fall, and that is how it happened. All those people died who had taken refuge under the white quebracho, the red quebracho, and the other trees, which were all smashed by the sky. Only the *molle* trees survived, and with them those people who were sheltering beneath them. It was the owner of the tuco-tuco teeth who saved the members of his clan. He had had those teeth for a long time. Every time he caught a tuco-tuco he kept its teeth, for he used to hear the old people saying: 'Be sure to save the teeth of the tuco-tuco, and keep them ready for when the sky falls.' When the sky was cut it suddenly turned into smoke and rose upward. For they say it was fairly thick when it fell. The only place where it did not fall was over a stream. The people from all the villages died, except the ones near the man who had the tuco-tuco teeth. All those years he had kept them. Those people were the only ones who were saved. Some time after this had happened the men went to look at the other villages, or the places where they used to be. They found nothing. Nothing remained of them, not even the bones of the people who had died. There was only grass, covering everything. Since that time the people always save the teeth of the tuco-tuco and keep them handy. But since then the sky has never fallen again.

In addition to the 'sky fall' myths there are a number of 'great darkness' myths that, while not alluding to actual ashfall, generally appear to articulate with the 'sky fall' myths. A dozen such myths are associated with the Toba, along with single examples each by the Ayoreo, the Makka, and the Mataco. The following two Toba 'great darkness' myths are typical:

Darkness came over the sky. At noon the sun was covered and the people beat trees and yelled, making all the noise they could. Those who had gone to pick up *mistol* were lost; others who were fishing could not see to return home. In the evening the darkness moved toward the north. Twenty men were missing. They had been eaten by jaguars (Métraux, in Wilbert & Simoneau 1982*a*, pp. 94–95, story no. 39).

People had many different kinds of power then. When they all got together, there was a clash of power, and that is why the world was plunged in darkness. All the shamans knew it was coming, and they stockpiled food. There was one person who was always warning: 'Store away food, and see to it that your children don't wander too far away.' Suddenly it came. One could see a cloud descending which got darker and darker. People put their things away and stayed in their houses. Whenever they did come out they only spoke to one another in very low voices because they were afraid. If they spoke loudly, dangerous animals might come, like jaguars that were out hunting. The jaguars came out of the ground and down from the sky. People were singing and praying, and were very careful not to go out of their houses. If anyone went out, he would surely be eaten by the jaguars. People stayed inside very quietly, and, if someone wanted to eat, he would touch another person and ask him to feed him. It went on like that for several days. Sometimes it was dark for a little while, and there was danger outside because animals came out of the ground and ate people. Everyone prayed and sang a great deal, and as they did so, the darkness began to dissipate, little by little. As time went by people were separated. Some women and children were eaten by jaguars. It was very sad .... Finally the darkness vanished and people began to sing and to jump and to make [collective ritual magic]. The darkness had lasted fifteen days. When things like that happen, all the shamans come together and sing and talk. They help each other, their sons and grandsons. Those things are terrible, but the darkness finally came to an end (Téran, in Wilbert & Simoneau 1989, pp. 98–99).

Based on the characteristics of studied historic Plinian eruptions (e.g. Blong 1982; Baxter 2000; Cioni *et al.* 2000; Schmincke 2004, pp. 163–176), the picture that emerges from the Gran Chaco 'sky fall' and 'great darkness' myths is of a major Plinian ashfall event, with the eruption column and associated ashfall being sustained and persisting for approximately two days. (The 15 days noted in the second Toba myth quoted above is considered an outlier, as noted in our discussion of Blong's work in Papua New Guinea). The myths lack details indicative of lahars, pyroclastic flows, lava flows, or aerial bombardment by large stones. This suggests that the observers were probably a considerable distance from the volcano at the time of the eruption.

Assuming that the modern distribution of Gran Chaco cultures (Fig. 1) reflects their approximate

Table 2. *Environmental details contained in Gran Chaco sky fall myths from the Chorote (Wilbert & Simoneau 1985), Nikvaklé (Wilbert & Simoneau 1987a), and Chamacocco (Wilbert & Simoneau 1987b).*

	Chamacoco (Story 38)	Chorote (Story 18)	Nikvalé (Story 10)	Nikvalé (Story 22)	Nikvalé (Story 33)	Nikvalé (Story 34)	Nikvalé (Story 35)	Nikvalé (Story 37)	Nikvalé (Story 38)	Nikvalé (Story 39)	Nikvalé (Story 164)
Earthquakes before or during sky fall event	X										
Loud earth or sky sounds heard before or during sky fall event	X	X									
Sky—clouds fall, celestial vault collapses	X	X	X	X	X	X	X	X	X	X	X
Rainfall associated sky fall		X					X		X		
Duration of Darkness		?	2 days		8 days	2–3 days	?		2 days		
Survivors protected under hard tree		X			X	X	X		X		
Houses crushed							X				
Vegetation—landscape crushed, covered, or otherwise altered and destroyed		X			X	X	X		X		
Starvation during or after sky fall event					X	X					
Numbers of human survivors		1 family			5 people	1 village	1 village		9 people	None	

distribution at the time of the Plinian eruption, the resultant distribution of myth motifs (Figs 2, 3) reveals a strongly patterned situation that mirrors the characteristics of historic Plinian eruptions. There is a central corridor of 'sky fall' (ashfall) and associated 'great darkness' myths stretching from the west to the east surrounded by stories of 'great darkness' without an explicit 'sky fall' motif. The presumed west–east nature of the ash cloud and tephra fallout plume, due to sustained winds moving toward the east, would effectively block out sunlight for cultures living on either side of the central ashfall corridor; the ash cloud generally followed the ecliptic path of the Sun. The Nivaklé are situated much closer to the Andes, therefore it is consistent with our Plinian eruption model that they would have received greater densities of ashfall and thus have more associated 'sky fall' stories than would the Toba living to the east. Similarly, of the two cultures with stories of the distant sounds of explosive volcanism caused by atmospheric sound waves, one, the Chorote, is the closest of the Gran Chaco cultures to the Andes and is best positioned to feel and hear such sensory volcanic phenomena. The Chamacoco story of an earthquake and volcanic sounds does not fit this pattern given their location to the NE of the Nivaklé.

The Gran Chaco 'sky fall' and 'great darkness' stories largely mirror the 'time of darkness' myths collected by the geologist Russell Blong (1982) in his exquisite study of the seventeenth century pre-European eruption of the Long Island volcano off the coast of Papua New Guinea. Blong found that the length of the period of volcanic darkness was occasionally exaggerated in the Papua New Guinea myths, similar to the Gran Chaco myths, due to the combination of the disorienting nature of extended darkness and the fear that such an event would produce. Despite the potential for exaggeration, the typical stated duration of the Gran Chaco 'sky fall' and 'great darkness' event is a very realistic 'two days' (see Table 2), interpreted here as roughly 36–48 hours. This duration and the level of associated destruction suggest an eruptive event similar to that of the Long Island eruption with a VEI of approximately 6, equalling or exceeding that of the 1991 eruption of Mount Pinatubo in the Philippines. The Gran Chaco myths are not as richly detailed as the Papua New Guinea myths. This may reflect the greater antiquity of the Gran Chaco myths. Based on the archaic style of the myths and the general lack of identifiable references to the Spanish and other historic peoples, the observations were made long before the arrival of the Spanish in the early sixteenth century.

The Nuevo Mundo lava dome complex (de Silva & Francis 1991, pp. 144–147) is an obvious candidate as the source for the Gran Chaco 'sky fall' and 'great darkness' stories. Nuevo Mundo (5438 m) is the single extra-Andean volcanic centre with Holocene activity, and derives its magma from the descending Nazca Plate. As such, it represents the closest known Holocene volcano to the general Gran Chaco region, approximately 500 km to the west (Fig. 2). Viscous dacitic lava flows emerged along a north–south fault forming coulées that overlay moraines in the NE and developed minor ash and block flows to the east. Sometime after the coulée implacement small cinder and ash cones developed.

A recent Plinian eruption deposited fresh tephra and ash, blanketing the area between Nuevo Mundo and the town of Potosi about 200 km to the NE (Fig. 3). There is no historical record of the event, so it must be older than regional Spanish settlement. Field inspection of Nuevo Mundo indicated that the Plinian event was '... younger than a few thousand years old on the basis of preservation' (de Silva & Francis 1991, p. 186). These observations suggest a late Holocene date perhaps in the range of 2000 to 1000 BP. The geographic propinquity and eastward orientation of the Nuevo Mundo ashfall are strongly suggestive. This relationship is evident in Figure 3, which for comparison overlays the area covered by the distribution of ash from Mount Pinatubo after a period of 36 hours. The distance of the Gran Chaco cultures from Nuevo Mundo (500+ km) is not a significant problem if we consider that, originally, they may have lived somewhat further to the west. It is also possible that the ashfall behaved similarly to the 1980 Mount St Helens eruption. The thickness of the Mount St Helens ashfall decreased to less than 5 cm abruptly between 100 and 250 km from the eruptive column, beyond which it increased to a thickness of up to 12 cm (Schmincke 2004, p. 173, fig. 10.26).

Most of the volcanoes in the CVZ are remote from population centres and have not received adequate study, and volcanic eruptions other than the late Holocene Nuevo Mundo Plinian eruption cannot be excluded from consideration as the source for the Gran Chaco 'sky fall' and 'great darkness' myths.

Northwest and Guiana Highlands 'sky fall' and 'great darkness' myths. A large number of 'sky fall' and 'great darkness' myths are found with the Yanomami of the Guinea Highlands (Fig. 2):

This happened in the direction of the Waika region but well beyond it, on the savanna, where the tapirs go to rub themselves against the *tokori* trees. It happened beyond the region inhabited by the Yanomami. They occupied a vast area of this land, but this happened in a place where one does not meet them, in an uninhabited region, where the celestial disk is as fragile as an old tree.

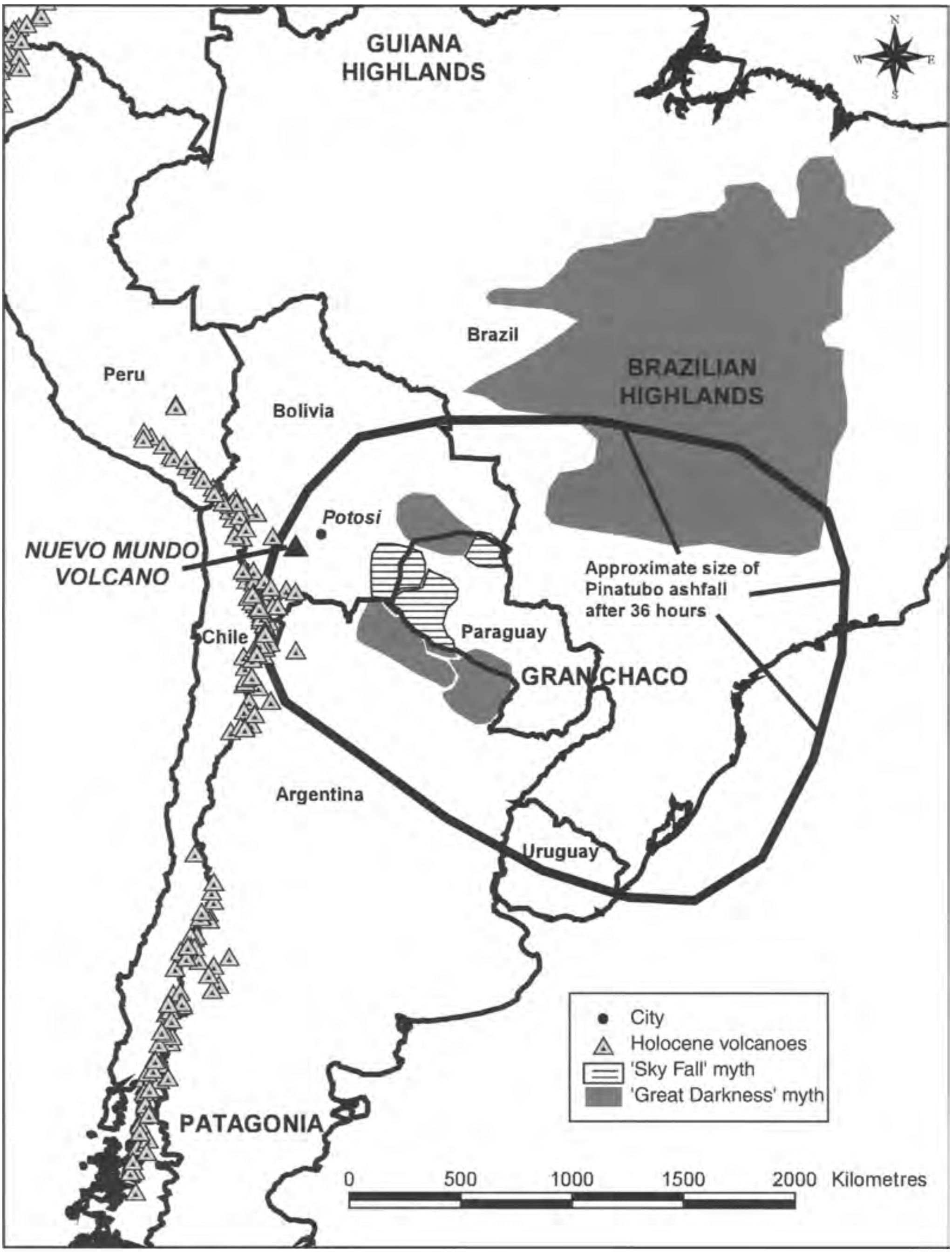

Fig. 3. Map of the Gran Chaco geographic region depicting the distribution of 'sky fall' and 'great darkness' catastrophe myths from the UCLA collection in relation to Nuevo Mundo volcano. These are compared with the size and shape of the 1991 Pinatubo (Philippines) Plinian ashfall distribution after 36 hours.

This land, which is as ancient as an old man, and its celestial disk as ancient as the land, this area is haunted by supernatural beings. Those were the beings that fell on the people of long ago. Those were the ones! They are spirits! Then the people were carried far away by an irresistible force: the sky broke above their heads. In vain the shaman pronounced propitiatory formulas, in vain they invoked their protective spirits; the sky broke in spite of everything. Our ancestors truly witnessed extraordinary events. But how did it occur to them to seek refuge under the canopy of the great cacao tree? Nevertheless that was where they ran when the celestial disk broke. The cacao tree bent under the weight but managed to support it. The sky, which was very close to their heads, emitted unbearable heat, and the people were complaining. But they knew what to do, and using their axes they opened a passage through the sky. Thus our ancestors found refuge under the cacao tree. Afterward they became underworld creatures, *amahiri* (Lizot, in Wilbert & Simoneau 1990, p. 44).

These myths are similar to but uniformly less detailed than those from the Gran Chaco, and suggest a longer period of oral transmission. It is clear from the storyline that the ancestors of the Yanomami were living NW of their present location at the time of the hypothesized Plinian ashfall event. The storyline suggests that the eruption may have been a deciding factor for migration away from the area; the area of original occupation was considered haunted and cursed.

Presumably the ancestors of the Yanomami originally lived close to the flanks of the Andes, perhaps near Cerro Bravo and Nevada del Ruiz (Fig. 2). The shift southward of the ITCZ permits eastern movement of air masses into Columbia and NW Venezuela and ashfalls originating in the Columbian Andes can blanket this region. There also is a remote possibility that the NE trades will carry ash from eruptions in the West Indies into central and southern Venezuela. We cannot dismiss the possibility that the original homeland of the Yanomami was instead relatively close to the very active arc of Caribbean volcanoes to the north.

The Cuiva along the Venezuelan and Colombian border have a remarkable set of 'sky fall' and 'great darkness' stories that are distinct from those of the Yanomami:

At the beginning there was only daytime, for the sun did not move but remained stationary at the center of the sky. At that time men wore clay medallions around their necks. The women, laughing at this style, told the men the medallions were awful and should be thrown away. The men, refusing, said women knew nothing about the medallions, which belonged to the grasshopper ... and to the black ant .... Women kept on laughing and telling men to throw them away. But the men always refused. Then one day the women took the medallions from the men and broke them into pieces either with their fingers or by throwing them to the ground. At that very moment the sky fell on their heads, and with the pieces of sky falling everywhere and injuring people, down came gigantic grasshoppers and black ants. They were enormous; they had large teeth, and they began to eat people. It was dark everywhere, as the ground was buried under a huge pile of sky. The grasshoppers and the ants were eating people, especially women's vaginas. The dead bodies that were all around created quite a stench. Many of the women who had been so foolish as to break the medallions were now lying dead, their tongues sticking out. This situation continued until the pygmy kingfisher ... and the dragonfly ... reassembled the sky by carrying back into place all the fallen pieces of sky. They needed to make many trips to the sky. They also took back the grasshoppers and the black ants which, even today, live up there. 'We told you so,' said the men to the women, who were no longer laughing. There were bodies all over the ground, ribs without skin or flesh. It is since then that we sleep at night. Since then the sun no longer remains still in the center of the sky, and there is a day and a night (Arcand, in Wilbert & Simoneau 1991, p. 29).

Formerly there was no night. People could not sleep because it was always daylight, and the daylight never ended. Then a woman went crazy, perhaps because she had eaten too much. Perhaps her gluttony caused her to go mad. She broke the sky. Her husband was a shaman, and he had a dream. He had warned her: 'Don't you go and break the sky; it belongs to the locusts.' The woman paid no attention and threw a stone at the sky. She broke it because it was made of clay. Immediately darkness fell and many locusts came flying. They were enormous, as big as iguanas. The locusts pecked out the eyes of all the people, of the women and children. There was only one person whose eyes they did not peck out: the shaman's. Then the swallows repaired the sky. They are very hard workers and can carry heavy loads. They took earth and repaired the sky. That is why the days are short now (Ortiz, in Wilbert & Simoneau 1991, p. 31–32).

The fantastic images of giant grasshoppers/locusts and ants are much further removed from the more realistic images of eruptive ashfall represented by the Gran Chaco and Yanomami stories. There is enough descriptive detail, such as the sky being made of clay and the darkness associated with the sky fall event, to associate the Cuiva myths with a Plinian tephra/ashfall event, presumably from the vicinity of Cerro Bravo and Nevada del Ruiz. The description of giant grasshoppers descending from the sky is not so fantastic if the Cuiva were close enough to the source volcano to experience the fall of pumice lapilli (pyroclastic particles between 2–64 mm in diameter).

South American meteor and meteorite myths

Meteorite falls rank with Plinian volcanic eruptions as being among the most spectacular natural events that can be witnessed by people (Masse 2007; D'Orazio 2006). Meteor storms have been known to evoke strong reactions, such as was the case across North America during the great Leonid storm event of 1833 (Littmann 1998; Masse & Espenak 2006).

Meteors and meteorite falls play a prominent role in South American myth and culture. For example, two related Gé myths from the Brazilian Highlands tell of the lethal fall of a single small meteorite:

At a water-hole two Indian women who were collecting piaçaba palm nuts in the steppe found a callow young bird the size of a chick. They took it home and raised it, letting it bathe in a gourd bowl. Then they saw that the water in it was boiling as it came out. As it grew larger, they filled a mortar with water, which also began to boil as soon as the bird had bathed in it. At last it grew as large as a domestic fowl. The feathers, however, were pink like those of the spoonbill. One day the Indians put on paint and went out to catch fish with timbó. After a while the women said: 'Let us also go there and see whether they have already caught many fish!' They went, taking the bird along. But when they got near the fishing-grounds and the bird saw the water glittering through the trees, it flew up and straight into the water. There was a loud clap of thunder, and all of the Indians who happened to be in the water at the time at once fell dead. Then the bird rose to the sky and the people recognized it as a meteor (Nimuendajú, in Wilbert & Simoneau 1984, p. 45).

Meteors (*akrá*), which luminously descend at night, are evil demons who assume human or animal shape on the earth.

The youths of a village were once bathing in a deep rivulet. Then they noticed two boys at the bottom of the water. 'Look, there are two boys!' they cried, 'let us get them out!' Several dived in, but as soon as they touched the two there was a stroke of lightning that killed the divers, for the two boys were akrá (Nimuendajú, in Wilbert 1978, p. 125).

There are no meteor or meteorite stories for the Bororo of the southern Brazilian Highlands in the UCLA collection; however, ethnologists have recorded a remarkable set of ritual behaviours (*aroe butu*) pertaining to loud atmospheric bolide impacts and the witnessed impacts on the Earth of small meteorites (Crocker 1985, pp. 216–220). This is the only circumstance that brings together the shamans from all related villages for collective ritual appeasement. Such an event causes great alarm and commotion among the general populace, as it is believed such impactors steal possessions and souls (Crocker 1985, pp. 217–220):

Everyone, women and children down to young toddlers, sets off a chaotic uproar. People scream urgently, fire off guns, beat on pots, pans, and logs, crash rolled-up mats against the ground .... In the single *aroe butu* I witnessed the din was impressive, and nearly everyone was acutely anxious, on the verge of panic. Even the *emijera*, the titled subclan chiefs, always self-possessed and calmly dignified, were obviously very worried and led the noise-making, which struck me as having the quality of a cathartic outbreak. The women rushed to gather in a few houses within each moiety, while the children screamed with fear .... There can be no question that the Bororo feel their society acutely threatened by the noise of a 'falling star'.

This culturally ingrained dramatic response to meteorites suggests that the Bororo witnessed one or more devastating cosmic impacts at some point within their culture history. It is noted that neighbouring cultures in the Gran Chaco to the south and their Gé neighbours to the north both apparently experienced major consequences from meteoritic airbursts.

There are also possible meteorite impact myths from Ecuador and Peru as noted by Bandelier (1905, 1906). In the sixteenth century, Spanish historian, Juan de Bentanzos collected many detailed stories relating to the rulers and their gods, including one about the deity *Con Ticci Viracocha* who caused fire to fall from heaven burning a mountain range near Cuzco (de Bentanzos 1996, p. 10). Bandelier (1906) suggests that the myth relates to a pre-Spanish eruption of isolated Quimsachata volcano. Although Bandelier does not suggest a cosmic impact explanation for the *Con Ticci Viracocha* story, he does suggest such an explanation for a seemingly similar worded myth about the destruction of a race of giants, alleged to have taken place near the city of Puertoviejo in Ecuador (Bandelier 1906, p. 52).

'World fire' myths and cosmic impacts

Distribution of 'worldfire' myths. The UCLA collection identifies three separate regions containing a total of 60 myths about a great fire that destroyed humankind. These include the fire-prone Gran Chaco, the Brazilian Highlands, and Tierra del Fuego (Fig. 4).

It is not unexpected that myths about devastating mass fires are identified. What is surprising, however, is the stated cause of the mass fire for each region. In the nine myths actually specifying a cause for the fire (four each from the Gran Chaco and Brazilian Highlands, and one from Tierra del Fuego), all point explicitly to a cosmic rather than an earthly cause. This link with the sky is even implicit in several of the remaining 51 myths: 'The fire, when it burned everything here on the earth, was made by Fitzököjíč [a creator demiurge present at the great flood, the great fire, and the sky fall events]; he did the burning. He alone did it. The entire earth was burned, even the water in the lagoons. Even the sky burned' (Wilbert & Simoneau 1987*a*, p. 84). Fitzököjíč is thought by the Nivaklé to live in the sky (Wilbert & Simoneau 1987*a*, p. 85).

Gran Chaco 'world fire' myth details and their potential relationship to the Campo del Cielo and Rio Cuarto cosmic impacts. Álvarez was the first to claim a connection between the Campo del Cielo impact and the generation of a mass fire event (in Giménez Benítez *et al.* 2000, p. 337): '[T]his tribe (toba) ... also tell the tradition ... 'that, one day the Sun had fallen from the sky, setting on fire the forests and that the tribes survived becoming caimans [alligators]; legend that was born, without a doubt, because the fall of the superb meteorite'. Giménez Benítez *et al.* (2000) have raised reasonable doubts about the connection between the 'world fire'

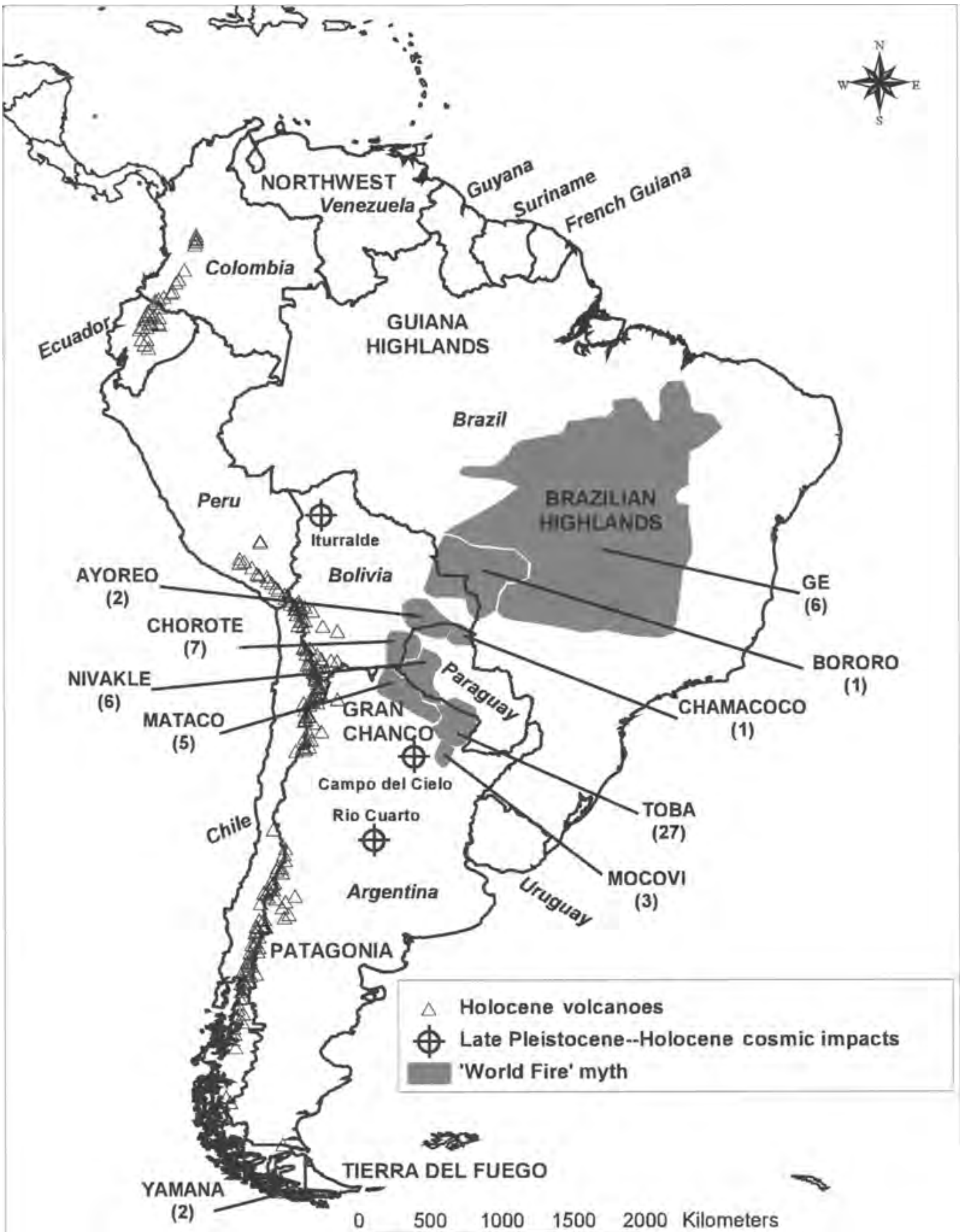

Fig. 4. Map of the Gran Chaco geographic region depicting the distribution of 'world fire' catastrophe myths from the UCLA collection in relation to known cosmic impact locations (e.g. Campo del Cielo).

myths and the Campo del Cielo impact; however, it is possible to build an equally reasonable case for supporting Álvarez's hypothesis based on a thorough analysis of the myths.

The UCLA collection contains a total of 51 Gran Chaco myths about a single catastrophic 'world fire,' representing seven of the nine cultures in the region (Table 1, Fig. 4). The two cultures lacking such myths, the Caduevo and the Makka, are also the two cultures with the smallest numbers of total myths in the collection (Fig. 1). The rapidity of the spread of the fire and the extent of its destruction is captured in the following Mataco myth (Fock, in Wilbert & Simoneau 1982*b*, p. 126):

Once, a very long time ago, the life-style of the Mataco developed into near anarchy. Wives left their husbands and lived with other men for a year or so, and then they lived with still others. The people spent all their time drinking beer, dancing, and shouting. All was chaos. Then one day a big black cloud gathered in the south, and lightning and thunder began. When the cloud had covered the entire sky it began to rain a bit here and there, but the drops that fell were not like rain but like fire. The people tried to jump into the river to save themselves, but the water was boiling. Tokhuah was among them, but he saved himself because he could go wherever he wished, and he decided to go underground. All died but a very few, and they did not know why they had survived. Bits of fire continued to fall from the sky and everything, including the entire forest, burned; nothing remained except a few people here and a few there. They did not understand why they were still alive and what they were to do next.

Volcanoes have the capacity to start wildfires; however, the great distance of the Gran Chaco cultures from Holocene volcanoes and the absence of other volcano motif indicators in the 'world fire' myths, suggests a likely meteoritic origin for the 'rain of fire,' such as a Tunguska-like airburst or perhaps the rain of small meteorites associated with the Campo del Cielo impact event. The distribution of a number of South American meteorite myths is depicted in Figure 5.

The likely meteoritic origin for the 'world fire' myths is more clearly spelled out in several Mocoví and Toba Pilagá myths, including the following:

When the sun once fell from the sky a Mocoví was so moved to pity that he devised a way to raise it: he tied it so that it would not fall again. The same accident happened to the sky, but the clever strong Mocoví lifted it with sticks and put it back in its proper place. The sun fell a second time, either because the knots were not tight enough or because they had been weakened in the course of time. Waves of fire spread everywhere, the flames consuming trees, plants, animals and men (Guevara, in Wilbert & Simoneau 1988, p. 100).

The people [Toba Pilagá] were all sound asleep. It was midnight when an Indian noticed that the moon was taking on a reddish hue. He awoke the others: 'The moon is about to be eaten by an animal.' The animals preying on the moon were jaguars, but these jaguars were spirits of the dead. The people shouted and yelled. They beat their wooden mortars like drums, they thrashed their dogs, and some shot at random with their guns. They were making as much noise as they could to scare the jaguars and force them to let go their prey. Fragments of the moon fell down upon the earth and started a big fire. From these fragments the entire earth caught on fire. The fire was so large that the people could not escape. Men and women ran to the lagoons covered with bulrushes. Those who were late were overtaken by the fire. The water was boiling, but not where the bulrushes grew. Those who were in place not covered with bulrushes died and there most of the people were burned alive. After everything had been destroyed the fire stopped. Decayed corpses of children floated upon the water (Métraux, in Wilbert and Simoneau 1982*a*, p. 68).]

The occasional intrusion of minor details about post-European material objects and animals into ancient myths, such as the presence of guns (noted above), horses, and cattle, is not uncommon in oral transmission (Barber & Barber 2005), and should not be construed as obviating the reality of the basic myth storyline. Such practice simply reflects the considerable importance that such initially alien objects and animals have come to assume in the storyteller's culture.

The meteoritic cause of the 'world fire' is most explicitly stated in Toba cosmology (Métraux 1946, p. 19):

Moon . . . is a pot-bellied man whose bluish intestines can be seen through his skin. His enemy is a spirit of death, the celestial Jaguar. Now and then the Jaguar springs up to devour him. Moon defends himself with a spear tipped with a head carved of the soft wood of the bottletree . . . . which breaks apart at the first impact. He also has a club made of the same wood which is too light to cause any harm. The Jaguar tears at his body, pieces of which fall on the earth. These are the meteors, which three times have caused a world fire.

It is possible that these stories simply reflect the coincidental observation of a spectacular individual meteor or meteor shower at approximately the same time as a mass fire generated by lightning or anthropogenic means; however, the details of the stories argue against such coincidence. The Mataco story cited above and a number of Toba great fire stories about people saving themselves in 'holes in the ground' stated to be several metres deep is suggestive of the Campo del Cielo impact event given that the meteorite strewn field lies immediately to the south of the present geographic distribution of the Mataco, and that the associated crater field is composed of both large explosive craters and a number of craters in which the meteorite fragment burrowed into the ground, leaving holes and tunnels that would have been visible to people for a number of years following the impact (Cassidy & Renard 1996).

There has been considerable debate as to the capacity of meteorite impacts to trigger ignition fires (e.g. Jones & Lim 2000; Jones 2002; Svetsov 2002; Durda & Kring 2004). So far, the discussion has been geared to large impactors. However, in contrast to the conclusions of Jones and Lim, it

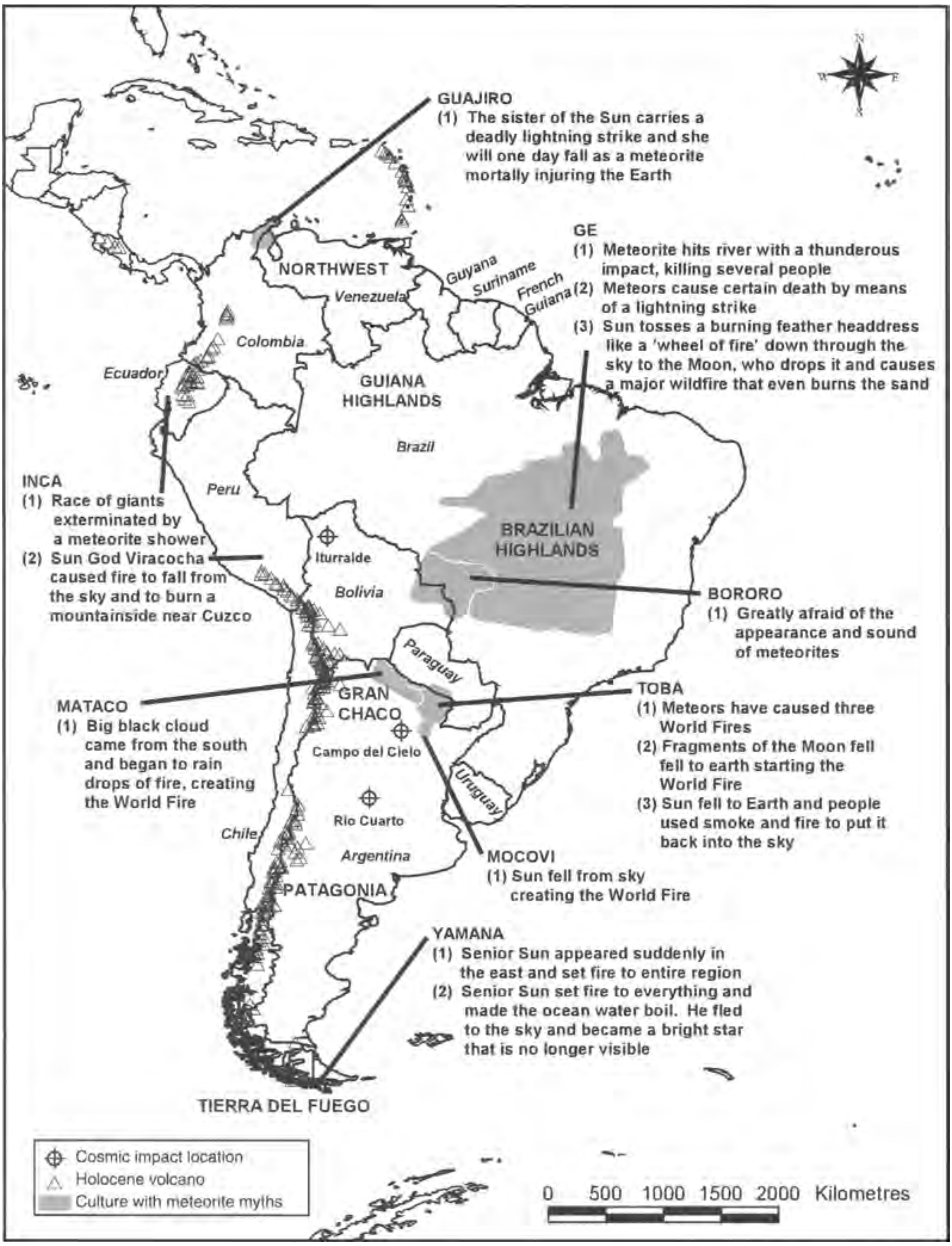

Fig. 5. Map of South America depicting cultures with myths about explicitly stated or inferred meteorite impacts, or the potential effects of meteorite impact upon humanity.

would appear that eye-witness accounts of falls, the limited archaeological record of impact sites, and the myths discussed here indicate that wildfires are indeed associated with at least some smaller impacts (Masse 2007). A key, of course, is the availability of fuel and suitable weather/climatic conditions, which in places such as the Gran Chaco and the Brazilian highlands should not be an issue.

An impact scenario can be developed for Campo del Cielo, which would fit most of the myth and scientific details. A bolide greater than 3 m in diameter entered the atmosphere about 1000 km SW of the crater zone. As bright or brighter than the Sun it blazed brilliantly from ionized gases, a long swath of ablation smoke trailing the 'fireball'. If weather permitted it could have been viewed from the Andes in the west to the Atlantic shore, and northward past the Gran Chaco. Descending slowly, it would have had an atmospheric time greater than 2 minutes. Early in its descent, compressed air against the meteoroid face facilitated fragmentation along existing cracks or across silica inclusions. It would suddenly have become brighter; the surface area available for ablation increased by the breakup. A sparkling trail would have formed adjacent to and behind the 'fireball' when air drag differentially slowed the smaller to tiny fragments. Late into the flight the meteoroid would have slowed sufficiently to end ionization and the brilliant light would have faded out. Unless immediately adjacent, the impact itself would have been anti-climatic—a series of loud thuds, small explosions of loess ejecta carried a few tens of metres and ignition of small fires. The sonic booming and rushing sound of the meteoroid flight would finally have caught up. Within the strewn field, small meteorite fragments would rain down. Local fuel loads and weather conditions may have permitted the fires to grow into regional conflagrations.

The Gran Chaco 'world fire' myths may also encode an airburst event other than that of Campo del Cielo. The Holocene Rio Cuarto airburst probably occurred too far south of the Gran Chaco to be the model for the Gran Chaco myths. The event defined by Schultz *et al.* (2004) would have resulted in a mass fire greater than that associated with the Tunguska event. Another still to be discovered airburst may be responsible for the myths, or a combination of these possibilities may have occurred. It is sobering to note that recent archaeological and palaeoenvironmental research has identified a likely major population replacement that took place in the SE Pampas of Argentina at some point between about 1500 and 4000 BC (Barrientos & Perez 2005). The possibility that Holocene cosmic impacts played a significant role in such replacement should be considered in future studies of regional culture history.

It is unfortunate that Métraux did not further pursue the meaning and context of the Toba statement that meteors had on three separate occasions been responsible for a world fire event. Of course, the best way in which to determine if a mass fire was associated with the Campo del Cielo impact event is to conduct additional microstratigraphic investigations where feasible in and around the crater and strewn fields (Masse 2007). Similar studies should be attempted for the Rio Cuarto airburst defined by Schultz *et al.* (2004). At the very least, this should provide more definitive dates for the impacts.

Brazilian Highland 'world fire' myth details regarding a potential airburst. There are seven stories of a 'world fire' in the Brazilian highlands, six associated with the Ge and one with the Bororo. These include a series of elaborate myths regarding Sun and Moon in which Moon is jealous of the feather ornament that Sun has obtained from the red head feathers of Woodpecker. The ornament subsequently falls to Earth and causes a world fire. Wilbert (1978 p. 15), in analysing these myths, likens the ornament to a 'wheel of fire'. One of these stories, from the Craho band of the Ge, is presented here in detail (Schultz, in Wilbert 1978, pp. 40–41):

Pud [Sun] then said to Pudleré [Moon]: 'Friend, you stay here. I'm going over there.' They were at the foot of the sky, seemingly walking close to it. Pudleré went home and waited at his house for Pud. Pud went to the foot of the sky and plucked a hat from the head of a woodpecker, the bird with a red head (the informant made a gesture, passing his hand over his head)—'no, not a hat, an adornment.'

When Pud came back with it, Pudleré saw the plumes and said: 'Friend, give me that headdress so that I can wear it.' But Pud said: 'No, I won't give away my headdress! I found it and I'm going to wear it. I'm going to sing while wearing it.' Pudleré said: 'Let's go back there; I want one too.' Pud went with him to the foot of the sky and arranged the woodpecker's feathers on his head. He then seized the adornment and spoke from above to Pudleré below: 'Well, here it is. Catch the plumes and don't let go of them!' And he added: 'Look now, if you let go of them you are going to see something!' Pudleré said: 'No, I'll catch them.' Pud replied: 'Look here, friend, when I throw the plumes to you, don't move, but grab them. Don't let them fall to the ground. If you do you're going to see something.' Then he threw the feathers to Pudleré, and with them came a lot of hot coals. He hadn't mentioned the coals before, when he was getting ready to throw the plumes, but had just said: 'Look here, catch them and don't drop them. If you drop them you're going to see something!' As he threw them, with the coals inside, he was saying: 'Come on, grab it, grab it!'

But when the headdress came near Pudleré he could not catch it. He pulled his hand away and the feathers fell to the ground. The sand caught fire and everything was burning. All the sand in the world, or almost all of it, was burning.

Burning sand is an unusual myth motif, and is absent from Gran Chaco world fire myths. The statement that 'almost all of the sand in the world was burning' may reflect the creation of a large region of impact glass melt in the Brazilian Highlands by a sizeable airburst at some point during the Holocene. This interpretation is consistent with the findings by Schultz *et al.* (2004) regarding the glass melts in the Argentine Pampas loess, and with our discussion above regarding the general inability of most wildfires to create and sustain temperatures hot enough for the formation of soil silica melts.

Tierra del Fuego 'world fire' myth details regarding a potential oceanic impact. Two Yamana myths from Tierra del Fuego describe a 'junior' and 'senior' Sun in which the senior Sun creates a world fire by appearing suddenly in the east and making the ocean boil and burning down the forests. He then changes into a bright star that eventually disappears (Gusinde, in Wilbert 1977, pp. 17–18):

In those days there lived a man here among the first families who was of evil nature. He was not only unfriendly toward all, but quite openly hostile, always intent on hurting everybody else. Everyone despised him, which angered him the more, and made him try even harder to do everybody harm. He was extremely powerful and wielded great authority. Once, in a rage, he set fire to everything within reach, for he made the water of the ocean boil by bringing forth intense heat. Also all the forests burned down, and from that time to this very day the mountaintops have remained bald and bare. All this happened because at the height of his fury he produced tremendous heat.

This may be a somewhat confused rendering of a hypothesized oceanic comet impact described elsewhere (Masse 1998, 2007). Alternatively, it may represent an impact witnessed by the Yamana in the waters near Tierra del Fuego. Volcán Fueguino is yet another possible source of Yamana myth. A group of andesitic, columnar-jointed lava domes and pyroclastic cones up to 150 m high on Isla Cook mark the southernmost Holocene volcanoes of the Andes (Fig. 2). The closest Holocene volcano occurs 420 km NW, at Monte Burney. The volcanoes, known as Volcán Cook or Volcán Fueguino, occupy a broad peninsula forming the SE end of Isla Cook. The lava domes and pyroclastic cones are possibly emplaced along north–south trending faults. Passing navigators observed possible eruptive activity in the direction of Cook in 1712 and the eruption of incandescent ejecta in 1820. Unfortunately, since the Yamana are now extinct, there will be no future chance to clarify the details of their myths.

Conclusions

Past cultural groups in South America typically led rich and full lives, as did their counterparts elsewhere in the world. Catastrophic drought, floods, famine, volcanic eruption, and even rare cosmic impacts also played a significant role in their cultures, either as witnessed events or as cautionary stories of such events passed down through the generations.

These cultures were no less gifted observers of their natural world than we are today. They differed from modern western society primarily in the lack of our technology and through the their use of a holistic approach by which to deal with the world around them. It was a dangerous beautiful world populated by animistic creatures and supernatural powers, filled with competing beneficent and malevolent forces.

It was not a random and unstructured world. The creation of myths served past societies as a tool to categorize and explain natural phenomena and spectacular and catastrophic events unfolding around them, and facilitated the transmission of events and lessons to be taught to subsequent generations. This structure permits us as geologists, archaeologists, anthropologists, historians and even astrophysicists to examine and analyse catastrophe myths systematically, and to discern the very real natural events that are their foundation. The selected UCLA collection catastrophe myths presented here are only a fraction of the overall myths of South America that can be studied systematically from a geological and historical perspective.

Myth by itself can rarely be used to prove the existence of a specific catastrophic natural event. However, myths do allow us to model plausible or hypothetical events such as the Plinian eruptions, cosmic impacts, and mass fires outlined and hypothesized above. It is only when we bring to bear the full force of our scientific knowledge of the regional setting, the geology, the climate, the palaeoenvironment, and the archaeological and cultural context, and use these disciplines and their analytical techniques to explicitly test these models of myth, that we can transform myth back into the catastrophic reality that our ancestors so earnestly sought to pass onto future generations.

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Cosmogenic mega-tsunami in the Australia region: are they supported by Aboriginal and Maori legends?

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Abstract: Mega-tsunami have affected much of the coastline of Australia over the past millennium. Such catastrophic waves have left an imprint consisting predominently of bedrock sculpturing of the rocky coastline and deposition of marine sediments to elevations reaching 130 m above sea level. One of the largest of these events occurred in eastern Australia in the fifteenth century. This event may be related to the Mahuika impact crater found at 48.3° S, 166.4° E on the continental shelf 250 km south of New Zealand. A comet at least 500 m in diameter formed the crater. Maori and Aboriginal legends allude to significant cosmogenic events in the region, while Aboriginal legends about tsunami are common along the eastern Australian coast. Evidence for legends that could describe the impact of a cosmogenic tsunami also exists in NW Australia. Here geological evidence of a single mega-tsunami as recent as in the seventeenth century covers 1500 km of coastline. We term this event Wandjina after the artwork related to the legends. More attention should be given to oral traditions in searching globally for other sites of significant mega-tsunami.

> Then the sky moved ... heaved and billowed and tumbled and tottered. The moon rocked. The stars tumbled and clattered and fell one against the other ... The great star groups were scattered, and many of them, loosened from their holds, came flashing to the earth. They were heralded by a huge mass, red and glowing, that added to the number of falling stars by bursting with a deafening roar and scattering in a million pieces which were molten ... Burragorang/Illawarra legend (Peck 1938, p. 202–203)
>
> He had never before seen the sea, and he did not know what it was. He believed it to be a great sky ... and that the sky had fallen down .... It was that a great ancestor had left the earth and had gone up into the sky .... He tried to return but the hole that he had made was closed up. Yet he did not give up hope, and by beating upon it he loosened it and it fell. *What Makes the Waves* (Peck 1938, p. 119)
>
> The Moa disappeared after the coming of Tamaatea who set fire to the land. The fire was not the same as our fire but embers sent by Rongi [the sky] (Hill 1913, p. 331)

These legends—the first two Aboriginal from the coast of New South Wales south of Sydney and the third Maori from New Zealand (Fig. 1)—describe natural events or processes with a cosmic origin not usually invoked as being significant in the modern geological literature. If the large object in the Burragorang legend had struck the ocean, it would have had the potential to generate a regionally devastating tsunami. The impact would also have injected billions of tonnes of water into the atmosphere as superheated vapour that would have fallen subsequently as torrential rain that would have exceeded historical levels and produced catastrophic flooding. Research along the east coast of Australia since 1989 (Bryant 2001; Bryant & Nott 2001) indicates that a mega-tsunami struck and eroded the shores of Lord Howe Island and the rocky coastline of New South Wales over a distance of 600 km around AD 1500 (Fig. 1a). A comet impact in the region is the most likely cause of such a large and widespread event. The location of a possible impact has recently been discovered (Fig. 1b, c), lying in 300 m depth of water on the continental shelf 250 km south of New Zealand at 48.3° S, 166.4° E (Abbott *et al.* 2003). The crater is 20 km in diameter and could have been produced by a comet 0.5–1.05 km in size travelling at a speed of 51 km s^{-1} (calculations based on Marcus *et al.* 2005). When it struck, it would have generated an earthquake with a magnitude of 8.2 on the Richter scale. The lack of sediment that normally settles over time from the ocean suggests that the crater is less than 1000 years old. The comet has been named Mahuika after the Maori God of fire. Tektites found in sediments to the SE indicate a trajectory for

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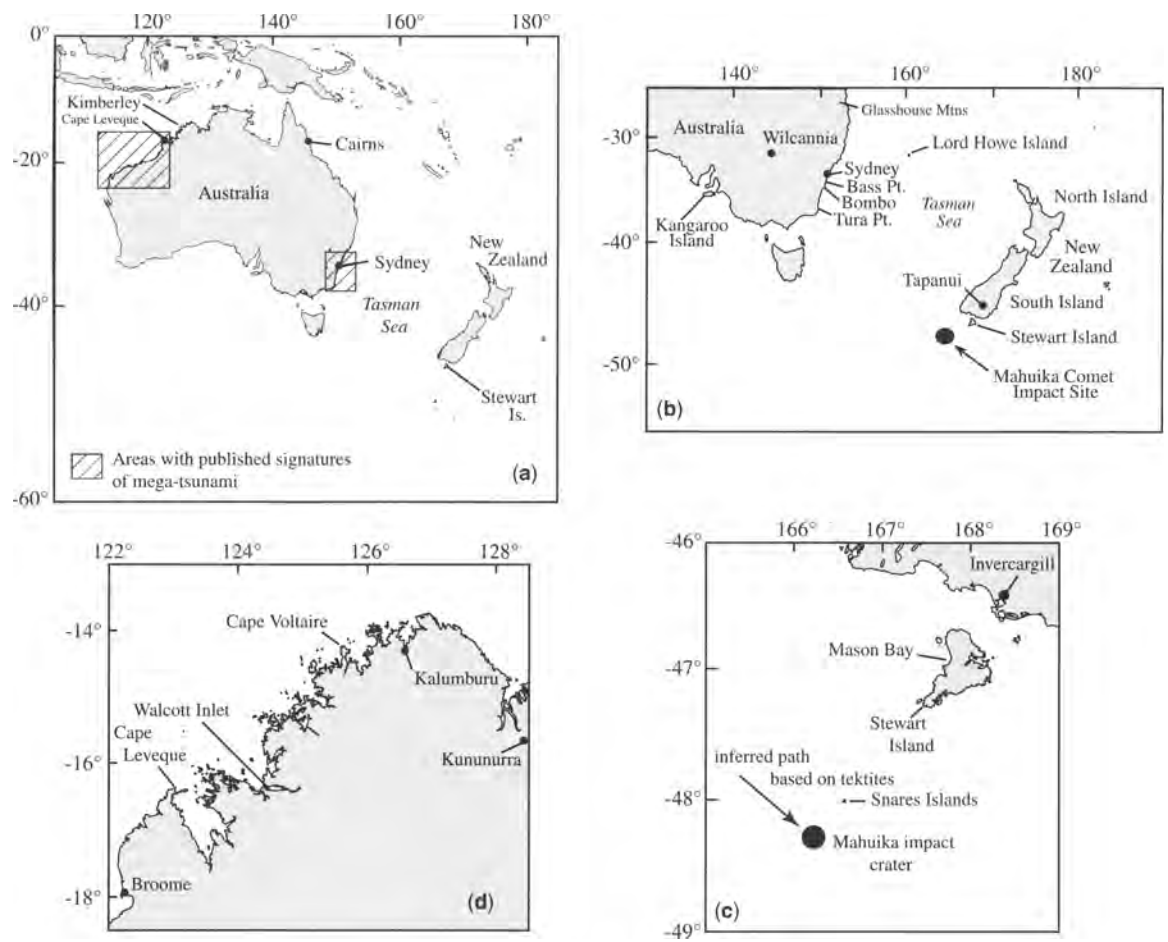

Fig. 1. Location maps (**a**) Australia and New Zealand; (**b**) Tasman Sea coastline; (**c**) Mahuika Impact area; and (**d**) the Kimberley.

this comet from the NW, across the east coast of Australia (Matzen *et al.* 2003). If the recent age of the event—which is yet to be confirmed by radiocarbon dating—were correct, Aborigines in Australia and Maori in New Zealand would have observed this comet's dying moments.

The purpose of this paper is twofold: to elaborate on the rich, indigenous oral history of the region to show that a recent cosmogenic mega-tsunami possibly occurred and to use similar types of oral history in the Kimberley region of NW Australia to identify other mega-tsunami in the Australian region.

Legends associated with comets and tsunami

Aboriginal legends

Aboriginal legends about comets and tsunami are ubiquitous throughout Australia (Peck 1938; Parker 1978; Johnson 1998). In the interior of New South Wales, the Paakantji tribe, near Wilcannia on the Darling River (Fig. 1b), tell a story about the sky falling (Jones & Donaldson 1989). A great thunderous ball of fire descended from the sky scattering molten rock of many colours. Unprecedented floods that forced people to flee to the tops of hills to escape drowning followed within a couple of days. Even though flooding fits within a scenario for a nearby comet impact into the ocean, such a story probably is modern and has incorporated elements of an older Aboriginal Dreamtime legend of the Flood. In South Australia, another legend tells of stars falling to Earth to make the circular lagoons fringing the coast.

Perhaps the most intriguing legend along the SE Coast of Australia is the story of the eastern sky falling quoted above (Peck 1938). It has several variants (Peck 1938; Massola 1968; Willey 1979; Johnson 1998). Aborigines in eastern Australia believed that the sky was held up on supports at the edges of the earth, and that the eastern prop either collapsed or was rotting. Tribes far into the interior of the continent were requested to send tribute to the east to be given to the spirit people in charge of holding up the sky so that it could be repaired. Possum rugs and stone axes were sent eastwards in response. Historians interpret the story as referring to the beginning of European colonization from the east; however, one version, quoted above (Peck 1938), is particular to the South Coast of New South Wales and may be describing the way tsunami affected the coast. The legend implies that the ocean fell from the sky. Substantial evidence exists for Aboriginal occupation of the open rocky headlands along this coast (Hughes & Sullivan 1974). At Bombo Headland, 70 km south of Sydney, tsunami overwashed a 40 m high headland. The wave separated from the headland and plunged back to the ocean surface 100–200 m into a bay on the lee side. Profuse amounts of coarse sediment dropped from the airborne flow into the bay under gravity (Fig. 2). Evidence of disturbed Aboriginal occupation 'silcrete hand axes and shaped blades' has been found on the lee side of headlands along this coast (Bryant 2001). Aborigines at these locations initially would have heard, but not seen, the tsunami approaching. Their first indication of disaster would have been when they looked up and saw the ocean dropping on them from the sky as the tsunami wave surged over headlands.

Additional physical and legendary evidence of major comet and tsunami impacts exists in SE Australia. In South Australia, the legend of Ngurunderi clearly alludes to tsunami (Flood 1995, p. 140–141). Ngurunderi was a great Ancestral figure of the southern tribes in South Australia, who established Tribal Laws.

> Long ago, Ngurunderi's two wives ran away from him, and he was forced to follow them. He pursued them... and went along the beach to Cape Jervis. When he arrived there, he saw his wives wading half-way across the shallow channel which divided Nar-oong-owie from the mainland. He was determined to punish his wives, and angrily ordered the water to rise up and drown them. With a terrific rush, the waters roared and the women were carried back towards the mainland. Although they tried frantically to swim against the tidal wave, they were powerless to do so and were drowned. Their bodies turned to stone and are seen as two rocks off the coast of Cape Jervis, called the Pages or the Two Sisters.

Nar-oong-owie refers to Kangaroo Island, South Australia (Fig. 1b). The history of Aboriginal occupation of Kangaroo Island remains enigmatic. The island shows extensive evidence of Aboriginal occupancy; but, when the first European, Matthew Flinders, landed on the island in 1802, it was unoccupied. Mainland Aborigines call Kangaroo Island, Kanga—the Island of the Dead. The coastline also evinces signatures of cosmogenic tsunami. Most significant are enormous whirlpools (features that have been linked to catastrophic flow under tsunami (Bryant 2001)) on the northern coast of the island, where the Aboriginal legend is set. In addition, there are vortex-carved caves and massive piles of imbricated boulders, some over four metres in diameter, near promontories.

Other tsunami and comet legends that could relate to the Mahuika Comet occur along the eastern coast of Australia. On the north coast of New South Wales, Aborigines speak of 'the moon setting in the east' and of flooding of rivers such as the Namoi from the ocean on a clear day. A spear from the sky fell into the sea followed by a great flood that changed the coastline (Cahir 2002).

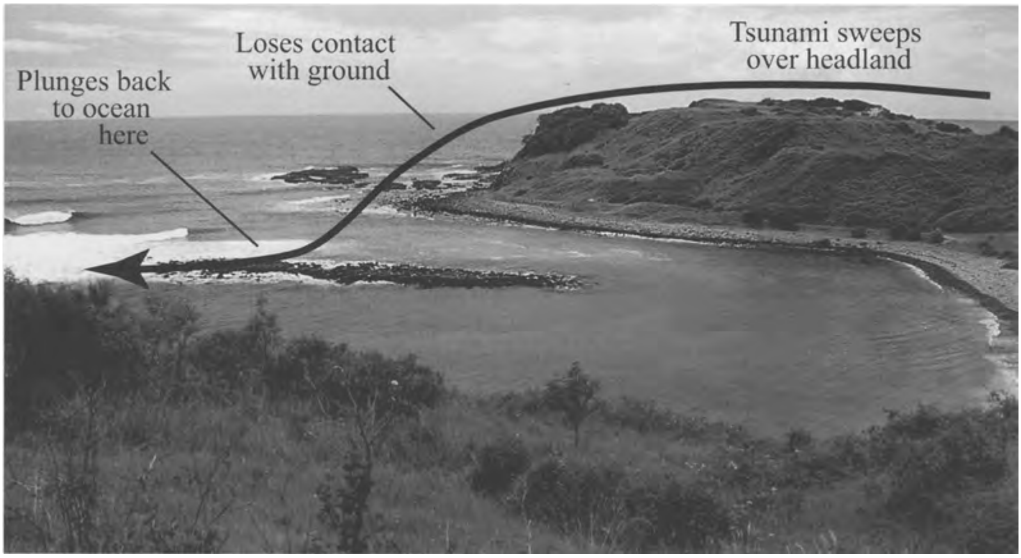

Fig. 2. Theorized flow of tsunami over Bombo Headland, NSW. The headland is 40 m above sea level on a tectonically stable coastline. The tsunami came in from the SE (the right), overrode and then detached from the headland. The boulder pile in the small bay is where the wave reattached to the ocean. Similar embayments in the region were occupied by Aborigines. The scenario shown here is responsible for Aboriginal legends about the ocean falling from the sky.

Individual large boulders on rock platforms are also identified as representing particular Aborigines struck down by a large wave. In SE Queensland, the Glasshouse Mountains, which lie at the western side of the coastal plain 20 km from the ocean, represent ancestral forms of Tibrogargan and his family. Tibrogargan one day was alarmed to see a great rising of the ocean and fled inland with this family. Individual peaks in the Glasshouse Mountains represent his family still gazing seaward at the threat. The family is estranged because Tibrogargan's son, Coonowrin, abandoned his mother, Beerwah, in the flight. Tibrogargan has turned his back on him and has vowed never to look on him again.

Maori legends

On the South Island of New Zealand, the Mahuika Comet impact would have been a dramatic event. Within 50 km of the southern coastline, it would have appeared as a fireball ten times larger than the sun, blown over 90% of the tree cover, and ignited grass and trees (Marcus *et al.* 2005). However, these effects would have ceased within 100 km of the coast. Steel & Snow (1992) believe that local Maori legends and place names refer to a comet event such as this one. They base their hypothesis on the legend of the *Fires of Tamaatea* (or *Tamatea*). Local ethnographic evidence is best chronicled in the Southland and Otago regions, centred on the town of Tapanui (Fig. 1b). Here there appears to be evidence for an airburst that flattened trees in a manner similar to the Tunguska event. The remains of fallen trees are aligned radially away from the point of explosion out to a distance of 40–80 km. Local Maori legends in the area tell about the falling of the skies, raging winds, and mysterious and massive firestorms from space. Tapanui, itself, translates as 'the big explosion,' while *Waipahi* means 'the place of the exploding fire'. Place names such as *Waitepeka*, *Kaka* Point, and *Oweka* contain the southern Maori word *ka*, which means fire. The local Maori also attribute the demise of the Moas, as well as their culture, to an extraterrestrial event. The extinction of the Moa is remembered as Manu Whakatau, 'the bird felled by strange fire'.

These interpretations have been criticized by Goff *et al.* (2003). Specifically, they state that the local place names referring to a cosmogenic fire event requires 'an in-depth knowledge of the culture and traditions of the Maori people' and interpretation requires the use of 'many references with cross-referencing between them ... as opposed to citing an individual reference' (Goff *et al.* 2003). We have since gone back to an original source, *The Maori-Polynesian Comparative*

Dictionary compiled by Tregear (1891). The dictionary is based on over 160 references and traces Maori terms back to their Polynesian sources. It supports some of the interpretations made by Steel and Snow (1992). The dictionary refers to *Tamatea* as a very ancient person. He was the fifth in descent from Rangi, the Sky. The *Fire of Tamatea* refers to an older legend related to some volcanic catastrophe or conflagration before the Maori came to New Zealand. Tapanui, which is at the centre of Steel and Snow's (1992) cosmic firestorm, lies at the edge of the destructive effects of the Mahuika impact. Masse & Masse (2006) describes legends in South America referring to wildfires caused by cosmic airburst events. He also notes that although the fires had a cosmogenic source, few legends mention this fact. Masse (1995) also points out that some Polynesian place names and the names for legendary heroes or supernatural beings can be broken down into their literal components. In this sense, the place name Tapanui (great or large tapa) may relate to the meaning of tapa, which in the 1891 *Maori-Polynesian Comparative Dictionary* translates as 'to split' or 'to pulverize soil' (Tregear 1891). Similarly, the word *ka* appears in this dictionary as meaning 'to burn, to be lighted, to take fire', while *kaka* means 'red-hot' (Tregear 1891). Nowhere in Maori or Polynesian sources does it mean 'fever' as stated by Goff *et al.* (2003).

Possible age of the recent cosmogenic tsunami event

It is possible to constrain the age of a regional cosmogenic mega-tsunami event and with it many associated Aboriginal and Maori legends using four separate lines of evidence. First, it is possible to surmise the most likely time of meteorite and comet impacts over the last two thousand years using a combination of Chinese, Japanese, and European records of meteor, comet, and fireball sightings. Figure 3 plots the accumulated record, up to the beginning of the nineteenth century, when scientific observations began in earnest. The meteorite records for China and Japan are based upon Hasegawa (1992), while meteorite records for Europe come from Rasmussen (1991). The Asian meteorite records are the most complete with European sightings accounting for less than ten percent of the record over the last one thousand years. The comet record from Asia is based upon Hasegawa (1992). A quasi-cyclic pattern is evident in the comet sighting records that can be linked to the dominance of the Taurid complex in the inner solar system. This complex formed from the breakdown of a giant comet that entered the inner solar system about 15 000 years ago (Asher & Clube 1993; Asher *et al.* 1994). Recent times when the Earth crossed the trail of this comet debris occurred during 401–500, 801–900, 1041–1100, 1401–1480, 1641–1680 and 1761–1800. These intervals are shaded in Figure 3. By far the most active period of the past two thousand years happened between AD 1401 and 1480.

Second, twenty-nine radiocarbon dates have been obtained from marine shell found in disturbed Aboriginal middens, deposited in tsunami dump deposits and sand layers, and attached to boulders transported by tsunami along the New South Wales coast (Bryant 2001). Some of these dates were obtained from the Tura Point area where mega-tsunami was first identified as an important coastal process in Australia (Young & Bryant 1992). The radiocarbon ages were converted to calendar ages using the INTCAL98 calibration table for marine samples (Stuiver *et al.* 1998). The dates centre on the year AD 1500 ± 85. These dates can only be stated as the most probable time for the deposition of marine shell by tsunami because the flux of atmospheric radiocarbon production around this time was highly variable leading to age reversals in the marine radiocarbon chronology. Based upon the Australian east coast deposits, it is 95% probable that a cosmogenically induced mega-tsunami event occurred between AD 1200 and 1730. This span also incorporates the age of major New Zealand tsunami deposits (Goff & McFadgen 2002; Nichol *et al.* 2003). Unfortunately, age reversals and the absence of any cross-correlation with a genealogical record make it impossible to identify up to five regional events in New Zealand in the fifteenth century as hypothesized by Goff & McFadgen (2002) and Goff *et al.* (2003). A cosmogenic source must be considered given the magnitude of the event on both the east coasts of Australia and New Zealand and the widespread distribution of that evidence throughout the region.

The preference for a major impact during this period is also supported by a radiocarbon date from Stewart Island, New Zealand—the closest large landmass to the Mahuika impact site (Fig. 1c). The southern coast of this island shows massive erosion characteristic of mega-tsunami in the form of ramps, knife-like sluices and flutes cut into granite and orientated towards the impact site (Fig. 4). All of these types of landforms have been linked to mega-tsunami (Bryant & Young 1996; Bryant 2001). An age obtained from pipi (*Paphies australis*) located about 500 m inland and 30 m above sea level at Mason Bay on the west coast of Stewart Island yielded a corrected age of AD 1301 ± 36.

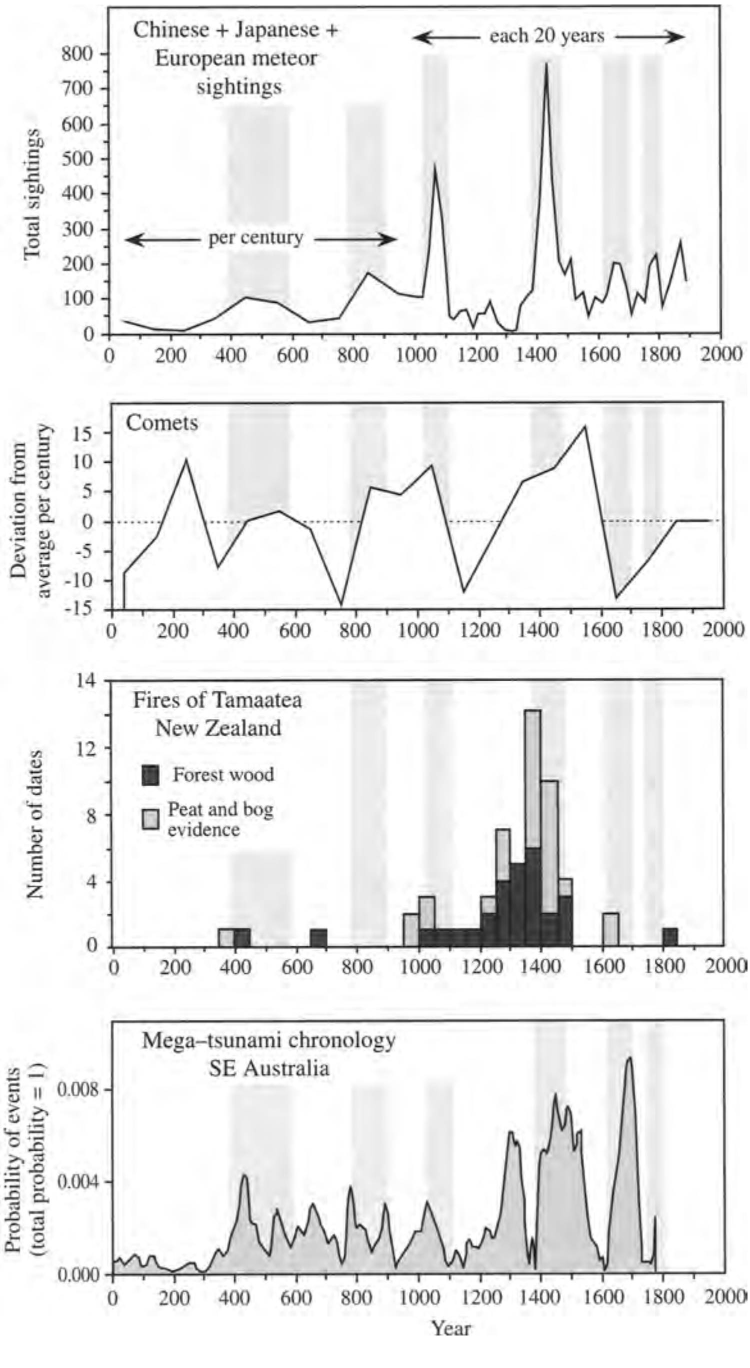

Fig. 3. Incidence of comets and meteorites, and related phenomena, between AD 0–1800. The meteorite records for China and Japan are based upon Hasegawa (1992), while meteorite records for Europe come from Rasmussen (1991). Peak occurrences are shaded. The Asian comet record is based upon Hasegawa (1992). The calibrated radiocarbon dates under the *Mystic Fires of Tamaatea* are from Molley *et al.* (1963) for forest wood and from McGlone & Wilmshurst (1999) for peats and bogs. The chronology of mega-tsunami is based upon twenty-nine radiocarbon dates of marine shell (Bryant 2001) with five additional acceleration mass spectrometry (AMS) dates from the Tura region of New South Wales. The panel was constructed by summing the calendar age distributions derived from the twenty-nine dates. The dips over the last millennium are an artefact of age reversals in radiocarbon chronology.

Fig. 4. Giant flutes cut into granite on the southern headland of Mason Bay, Stewart Island, New Zealand. The flutes point back to the Mahuika Comet Impact site. The flutes are over 40 m high and were cut by vortices in flow as the tsunami went over the headland from left to right.

Third, circumstantial evidence exists for a major environmental event that disturbed coastal Aboriginal culture within this period. For example, a disturbed midden has been found 30 m above sea level within Sydney Harbour (Attenbrow 1992). This is beyond the run-up of modern storm waves in the harbour. The date of this deposit is 1448 AD. There is also clear evidence that Aborigines switched from collecting large molluscs to fishing about 500–700 years ago (Sullivan 1987). We attribute this response to the fact that any large tsunami would have wiped out shellfish populations along the rocky coast. Aborigines thus switched to fishing to survive. At Bass Point, which is dominated by mega-tsunami erosion and which is a headland conducive to the legend of the ocean falling from the sky, the change occurred around AD 1380 (Bowdler 1976). Finally, middens at various sites along the South Coast of New South Wales indicate that edible mussels originating from more protected tidal inlets began to replace gastropods originating from rock platforms concomitantly with the switch to shell fishhooks (Sullivan 1987).

Fourth, it is possible to pin down the approximate age of the *Fires of Tamaatea.* The cosmic fires reported in Steel & Snow (1992) burnt vegetation across the South Island. There are two sources of organic material for radiocarbon dating this event: buried charcoal (Molley *et al.* 1963) and carbon derived from peats in swamps and bogs that have been burnt (McGlone & Wilmshurst 1999). This material traditionally has been interpreted as reflecting the time of deforestation due to Maori occupation in New Zealand. However, much of the burnt material comes from uninhabitable high country that was burnt on a vast scale. Figure 3 plots the distribution of dates, that span at least two centuries and terminate at the end of the fifteenth century. This wide range in dates is logical knowing that mature trees, already hundreds of years old, burnt. Goff *et al.* (2003) criticize this dating, pointing out that it is inaccurate, that there are ambiguous regions in the distribution of the dates, and that they peak before one in the observation of comets and meteorites. Even so, Bryant (2001) never tried to interpret the dates beyond the crucial point 'that few ages occur after the fifteenth century' concomitant with the peak in meteorite and comet observations. Even the replotting by Goff *et al.* (2003) of their corrected dates supports this assertion. The *Fires of Tamaatea* legend may well have a cosmogenic origin. More importantly, the timing of the fires is also coherent with the dating of mega-tsunami deposits along the adjacent coastline of Australia and New Zealand. These four lines of evidence all indicate that a regional mega-tsunami event that was probably due to a comet impact in the fifteenth century.

Cosmogenic tsunami in the Kimberley

Legends and geomorphic evidence

Some of the more intriguing legends about comets and tsunami come from the Kimberley (Fig. 1a, d). The NW coast of Australia shows some of the largest evidence collected to date of cosmogenic mega-tsunami (Bryant & Nott 2001; Nott & Bryant 2003). The direction of approach of this wave to the coast lies between 235° and 270°. However, evidence of this event has never been undertaken in the Kimberley, north of Cape Leveque, which is characterized by a rugged and indented coastline. There are five lines of evidence for cosmogenic tsunami in this region. First is the Aboriginal naming of landforms, the most significant of which is Comet Rock at Kalumburu (Fig. 5). Not only does the rock look like the head of a comet with an extending trail, but there is also an Aboriginal rock drawing on the lower face of the rock that mimics the form of the rock and that is orientated parallel to the rock feature. This rock is orientated 310° to the NW.

Second are specific legends about tsunami, the most notable of which occurs around Walcott Inlet (Fig. 1d). Here legends recount a very fast flooding from the ocean that filled this inland tidal body for up to 12 hours (Mowaljarlai & Malnic 1993). Other myths imply that water flooded to the top of 500 m high mesas surrounding this inlet. The flooding was extensive from Walcott Inlet in the south, to Kalumburu in the north, and to Kununurra in the east (Fig. 1d).

Third are the Wandjina rock art paintings and their associated interpretation. Wandjina paintings are very stylistic across the Kimberley. None is more than four centuries old. The paintings typically show a clown-like face painted white surrounding by an outer, barbed red halo that represents lightning (Fig. 6). They are without a mouth, their nose indicates where the power flows down (Mowaljarlai & Malnic 1993), and is a feature that looks remarkably like the comet symbol painted on the rock at Kalumburu. The Wandjina are the rain spirits of the Wunambul, Wororra, and Ngarinyin language people (Layton 1992). The Wandjina have great power and are associated mystically with creation and flooding rain. Their origin may be much older and traceable to the flood myths in the Dreamtime.

Fig. 5. Comet Rock, Kalumburu, Western Australia. The tail of the rock is orientated 310 to the NW. The painting of the comet is Wandjinan in age. This rock lies about 5 km from the ocean on a plain covered in a layer of beach sand.

Fig. 6. A typical Wandjina face painted on rock shelters throughout the Kimberley. The barbed hood represents lightning. Wandjina do not have a nose or mouth. The comet-like symbol in place of the nose represents power. Wandjina do not need a mouth because their knowledge is greater than what can be spoken.

Although linked to the annual monsoon, the Wandjina depict something much more intense. One legend tells about a flood that was brought on by the 'star with trails' (Mowaljarlai & Malnic 1993). The Wandjina caused a great flood that started in the north of Australia and flooded the whole country. Just as quickly as the land was flooded, it drained. The Wandjina spirits came out of the sky or the sea and fought a battle with the Aborigines that the Wandjina won (Crawford 1973). The fights were repetitive. As well, the Wandjina fought amongst themselves (Crawford 1968). They came after the flood recreating and restoring the old culture. Wandjina do not have a mouth because their knowledge is beyond speaking. Were they to have a mouth, floods would be generated that would drown the whole Earth. The Wandjina were also associated with life after the widespread Walcott Inlet flood event referred to above (Mowaljarlai & Malnic 1993). Today they control the monsoon with its heavy rain, thunder, lightning, and floods.

Fourth is the subtle disturbance of sandstone rocks sitting on flat landscape surfaces on interfluves. Except for one characteristic, these rocks could be interpreted as weathering features resulting from long-term erosion during the Holocene. This characteristic is the tendency for isolated boulders to form trains on flat surfaces that in some cases contain blocks leaning against each other like fallen dominoes. The Kimberley craton is remarkably stable and presently unaffected by large earthquakes. Something has not only shaken the landscape recently but also cast boulders against each other in an ordered fashion. The orientation of these 'castaway' boulders is 350° to the NW. We propose that the alignment of shaken boulders reflects the direction of the blast wave from a cosmic airburst.

Fifth is the evidence for catastrophic erosion of relatively small streams, similar to that observed elsewhere across the northern Australian monsoon region (Nott *et al.* 1996). In one of the steams feeding into the King Edward River, where the modern channel is less than 70 m wide and 2 m deep, the flood channel is more than 500 m wide. It has evidence of boulders being transported in suspension by flows more than 4 m deep with sufficient intensity to sculpt out erosional features characteristic of vortices eroded under catastrophic flow (Dahl 1965; Kor *et al.* 1991). These channels appear to be recent and beyond the capacity of maximum probable rainfalls, which are the upper design criteria for modern floods. Rainfall induced by a comet impact with the ocean is a possible phenomenon that could have carved these channels.

Field evidence

The challenge was to pursue the sources of this evidence to the ocean and detect the signatures of catastrophic tsunami in the coastal landscape. This

(a)
(b)

Fig. 7. The basalt headland at Cape Voltaire. (**a**) The northern side of the headland. Tsunami flow has cut a smooth, undular ramped surface into columnar basalt. Note the scarcity of debris evacuated from this quarry. (**b**) The debris eroded from the north side of the headland has been transported by the tsunami to the lee of the headland sheltered from cyclone waves. The columnar basalt blocks are aligned with the direction of flow 350° NW.

landscape is also one subject to some of the most intense tropical storms in the world (Nott 2004) associated with winds in excess of 300 km hr^{-1} and storm surges of 3.6 m (Bureau of Meteorology 2000). Two sites stand out as showing evidence of tsunami. The first is located at Cape Voltaire directly west of Kalumburu. Here, waves beyond the capacity of cyclones have truncated the ends of headlands. This erosion was not controlled by bedrock lithology or structure as exemplified by the erosion into columnar basalt on the headland. Tsunami erosion on the exposed side of the headland created a ramp that cuts across the dominant structural control that normally would have influenced coastal landforms (Fig. 7a). This ramp terminates about 20 m above sea level. It would be tempting to attribute the excavation of the ramp to storm waves but for one additional factor. Little debris evacuated from the ramp is present either on the ramp surface or offshore. Instead, the columnar basalt has been broken into 5 m lengths, tossed over the 40 m high headland and deposited on the sheltered lee slope above the influence of storm waves such that individual blocks reflect the direction of flow, 350° to the NW (Fig. 7b). The second site is further south at Walcott Inlet where the best Aboriginal legend for a tsunami exists. Here, at Collier Bay, a tsunami has infilled an embayment with a mixture of sand, gravel and shell that rises at least 6 m above the swash or storm surge limit of tropical cyclones. Everywhere in the Kimberley, the coastline evinces either the erosional effect of a catastrophic wave or its depositional residue in sheltered embayments.

Chronology

It is possible to date the timing of this mega-tsunami in the Kimberley using radiocarbon dating of shell. Again, the same methodology as was used in the Tasman Sea region was used to calibrate the ages. Thirteen dates have already been reported for the comet-induced mega-tsunami detected south of the Kimberley (Bryant & Nott 2001; Nott & Bryant 2003). These are presented in the top panel

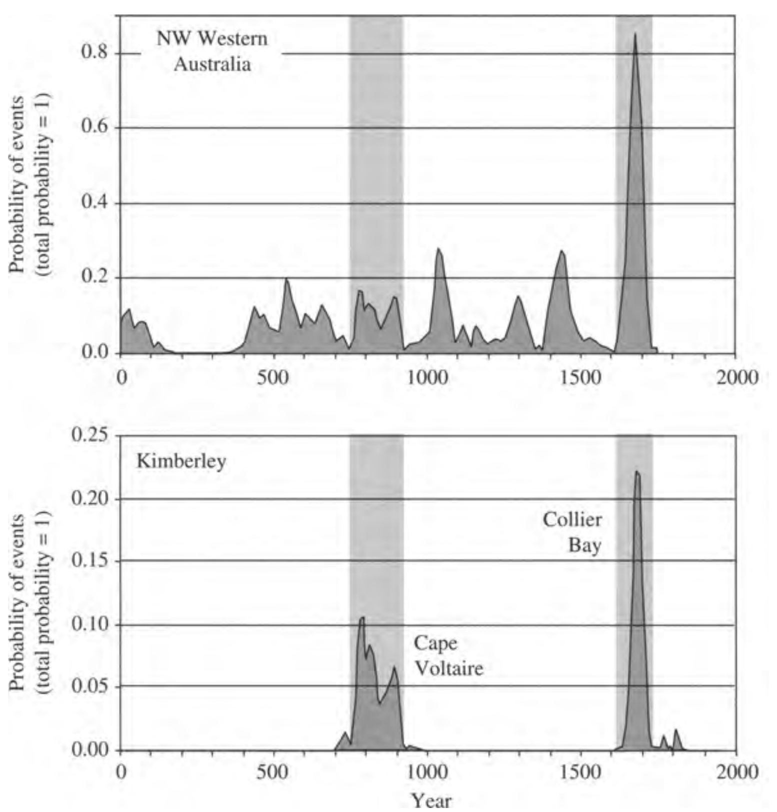

Fig. 8. The chronology for mega-tsunami in NW Australia. The upper panel has been constructed from thirteen radiocarbon dates using the same method as used in Figure 3 (Bryant & Nott 2001; Nott & Bryant 2003). The Kimberley dates are derived from a giant clam at Cape Voltaire (Wk14247) and molluscs at Collier Bay (Wk1448).

of Figure 8. The most recurrent age centres between AD 1620 and 1730 with a defined peak at AD 1690. The date from Cape Voltaire (bottom of Fig. 8) peaks earlier at 800 AD and may either be a separate tsunami event or the result of dating old shell. The date from Collier Bay corresponds with the prominent peak in NW Australia indicating that the effects of a mega-tsunami that occurred around the seventeenth century can now be traced along 1500 km of coastline. This age agrees with the age of the Wandjina paintings. Attempts are being made to retrieve more datable material from the Kimberley coastline to refine the chronology. Based on the evidence presented here, and because Aboriginal legends concentrate on the three main elements of a comet impact in the ocean: the comet itself, tsunami and flooding rains, this seventeenth century tsunami has been labelled the Wandjina event. No impact crater has yet been found, although attempts are being made to find it, if it exists. However, this is not a limitation to our research because both Aboriginal and Maori legends favour the explosion of meteoritic debris in the atmosphere, rather than an actual impact with the earth's surface. Bolides can also generate significant tsunami (Chyba *et al.* 1993; Verschuur 1996). The Wandjina event generated the biggest and most widespread mega-tsunami yet found in the Australian region. The wave reached a maximum of 35 km inland in the Great Sandy Desert, deposited sands up to 40 m deep on the lee side of headlands and laid down bedded gravels on the landward side of 40 m hills situated over 5 km inland (Bryant & Nott 2001; Nott & Bryant 2003). These aspects are an order of magnitude greater than that produced by any historic volcanic or earthquake generated tsunami originating from Indonesia (Nott & Bryant 2003). The spectacular nature of this cosmic phenomenon has dominated Aboriginal mythology for the past four centuries. Only by interpreting the proper significance of this rich oral history and artwork, especially in the Kimberley, can the true origin of this tsunami be recognized.

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Meteorite records in the ancient Greek and Latin literature: between history and myth

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Abstract: A catalogue of citations related to possible meteorites has been assembled by searching the ancient Greek and Latin literature up to the end of the West Roman Empire (AD 476). The catalogue illustrates the attitude of ancient populations towards the fall of meteorites and extends the record of meteorite falls back in time. The citations are arranged in the catalogue as: i) 'meteorite falls', when both the locality and the date of the fall are, at least approximately, indicated; ii) 'worshipped stones', when the written and archaeological sources suggest the actual existence of a stone as an object of worship, but the information about the locality and the date of the fall are missing or vague; iii) 'myths', when the connexion between an object said to have fallen from the heaven and the fall of a meteorite is weak or obscured by mythological traditions.

Over the last three centuries more than one thousand different meteorites from witnessed falls have been recovered worldwide. In many cases the dates and the circumstances of these fall events are well constrained and the related meteoritic material, still kept in public and private collections, has been subjected to scientific investigations. On the other hand, it is well known that documented falls predating the seventeenth century and for which meteoritic material still exists at our time are just two: the Nogata (Japan) fall occurred in AD 861 and the Ensisheim (Alsace, France) fall occurred in AD 1492 (Grady 2000). All the meteorites from witnessed falls recovered before these dates were lost or destroyed and we can obtain information about some of them only through written sources. Obviously, the information about meteorite falls becomes progressively less accurate as the date of the fall is further back in time, fading into mythical traditions.

In the Mediterranean area and Asia Minor, during the ancient age, many myths, superstitions and religious cults were associated with stones, metal objects or statues thought to have fallen from the heavens (Newton 1897; Burke 1986). Some of these stones were venerated as a representation of the deity by whom they were sent down to the Earth, others were considered supernatural gifts made by the gods to some predestined person. These stones were kept in famous shrines of ancient Greece, Italy and Asia Minor, and the images of the most celebrated among them were impressed on many ancient coins (Brezina 1899). The fall of meteorites was not always considered as superstitious but also strongly influenced the cosmological theories of the most ancient philosophers: the Greek pre-socratic philosophers Anaxagoras of Clazomenae and Diogenes of Apollonia (fifth century BC) were the first to propose the extraterrestrial nature of the meteorites and to give a scientific account for their origin. Other scientists/philosophers from ancient times accepted without prejudice that stones could fall from the heavens but either they did not accept their extra-terrestrial origin (e.g. Aristotle) or they did not attempt to propose any scientific interpretation of this phenomenon (e.g. Pliny the Elder).

The vast literature of ancient Mediterranean civilizations gives us the opportunity to extend our record of meteorite falls back to ancient times and to understand the attitude of ancient populations towards the fall of meteorites. To reach these aims, this paper presents a catalogue of citations, possibly related to meteorites, compiled by searching ancient Greek and Latin literature up to the end of the Western Roman Empire (AD 476). In consideration of the huge volume of ancient texts surviving to our times, this list is certainly not complete but it probably contains the most important meteorite records of the ancient Greek and Roman world. The records reported in this work refer to objects said to have fallen from the sky to the earth, or to objects that, by their nature, may have had a meteoritic origin. Mentions and reports of meteors, shooting stars, falling stars, bolides, fireballs, aerial explosions, etc., that are found in great number in the ancient Greek and Latin literature, are therefore excluded.

Ancient authors and their works are cited directly in the text and in Table 1. Within the text, the titles of the ancient works are reported only where necessary to avoid ambiguity. Figure 1 is a map of the central–eastern Mediterranean and Asia Minor showing the position of the localities

From: PICCARDI, L. & MASSE, W. B. (eds) *Myth and Geology*. Geological Society, London, Special Publications, **273**, 215–225.

Table 1. *Ancient Greek and Latin works cited in the text and their authors.*

Author	Work
Aeschylus, ~525 BC–~456, G	*Prometheus Unbound*
Herodotus, ~485 BC–~423, G	*The Histories*
Euripides, ~484 BC–406, G	*Iphigenia in Tauris*
Anaxagoras of Clazomenae, 5th century BC, G	*On Nature*
Diogenes of Apollonia, 5th century BC, G	*On Nature*
Aristotle, 384 BC–322, G	*Metereology*
Pytheas, ~380 BC–~310, G	*Description of the Ocean*
Daimachos of Plataea, 4th century BC, G	*On the Religion*
Apollonius of Rhodes, 3rd century BC, G	*Argonautica*
Anonymous, 3rd century BC, G	*The Parian Chronicle*
Cicero, 106 BC–43, L	*Against Verre*
Hyginus, ~64 BC–AD ~17, L	*De Astronomia*
Livy, 64 or 59 BC–AD 17, L	*History of Rome since its fundation*
Strabo, ~63 BC–AD ~23, G	*Geography*
Ovid, 43 BC–AD 17, L	*Metamorphoses*
Geminus, ~110 BC–~40, G	*Isagoge (or Introduction to Astronomy)*
Pliny the Elder, AD 23–79, L	*Natural History*
Plutarch, AD ~ 45–~120, G	*Lysander, Numa Pompilius, Lucullus*
Tacitus, AD ~55–~120, L	*The Histories*
Pseudo-Apollodorus, 2nd century AD (?), G	*Library*
Pausania, 2nd century AD, G	*Description of Greece*
Julius Obsequens, 2nd century AD, L	*Book of Prodigies*
Eusebius of Caesarea, AD ~260–341, L	*Preparation for the Gospel*
Philo of Byblos, 3rd century AD, G	*History of the Phoenicians*
Herodianus, 3rd century AD, G	*History of the Empire from the time of Marcus Aurelius*
Arnobius, 3rd–4th century AD, L	*Against the Haethens*
Servius Maurus Honoratus, 4th century AD, L	*Commentary on the Aeneid of Vergil*
Orpheus apocryphal, 4th century AD, G	*Lithica*
Marcellinus Comes, 6th century AD, L	*Chronicle*

G, wrote in Greek; L, wrote in Latin.

mentioned in the text. During the preparation of this work, the following internet resources for ancient Greek and Latin texts were used extensively in addition to book editions: IntraText (http://www.intratext.com/); The Perseus Digital Library (http://www.perseus.tufts.edu/); The Latin Library (http://www.thelatinlibrary.com/); The Internet Classic Archive (http://classics.mit.edu/).

Meteorite falls

This section contains ancient reports of stones fallen from the heavens with a reference, more or less approximate, to the locality and the time of the fall event.

The Aegospotami meteorite fall

This is, by far, the most famous, most cited and most reliable meteorite fall of antiquity. A large stone fell in the Thracian Chersonese (modern Gallipoli Peninsula) at *αἰγός ποταμός* (goat river) *c.* 469–467 BC. The fall of this stone profoundly influenced the cosmological theories of two pre-socratic Greek philosophers, Anaxagoras of Clazomenae and Diogenes of Apollonia (fifth century BC). Anaxagoras wrote that the Sun and the Moon and all the stars are fiery stones that are borne about by the revolution of the ether. He also thought that the Sun (that he conceived larger than the Peloponnesus) and the Moon and certain other bodies moving with them, but invisible to us, are below the stars. Diogenes (in honour of whom the Diogenite meteorite class was dedicated) also asserted that the heavenly bodies are fiery stones similar to volcanic ejecta, and that invisible stones were carried around along with the visible bodies.

The occurrence of the Aegospotami fall, along with its date, can be found in the Entry 57 of the Parian Chronicle, a list of significant events, occurred between *c.* 3800–264 BC, carved in a marble stele (successively broken into three pieces) by an anonymous writer, probably in 264 BC:

ΑΦ ΟΥ ΕΝ ΑΙΓΟΣ ΠΟΤΑΜΟΙΣ Ο ΛΙΘΟΣ ΕΠΕΣΕ ΚΑΙ ΣΙΜΩ ΝΙΔΗΣ Ο ΠΟΙΗΤΗΣ ΕΤΕΛΕΥΤΗΣΕΝ ΒΙΟΥΣ ΕΤΗ ΟΔΔΔΔ ΕΤΗ ΗΗΓ ΑΡΧΟΝΤΟΣ ΑΘΗΝΗΣΙ ΘΕΑΓΕΝΙΔΟΥ

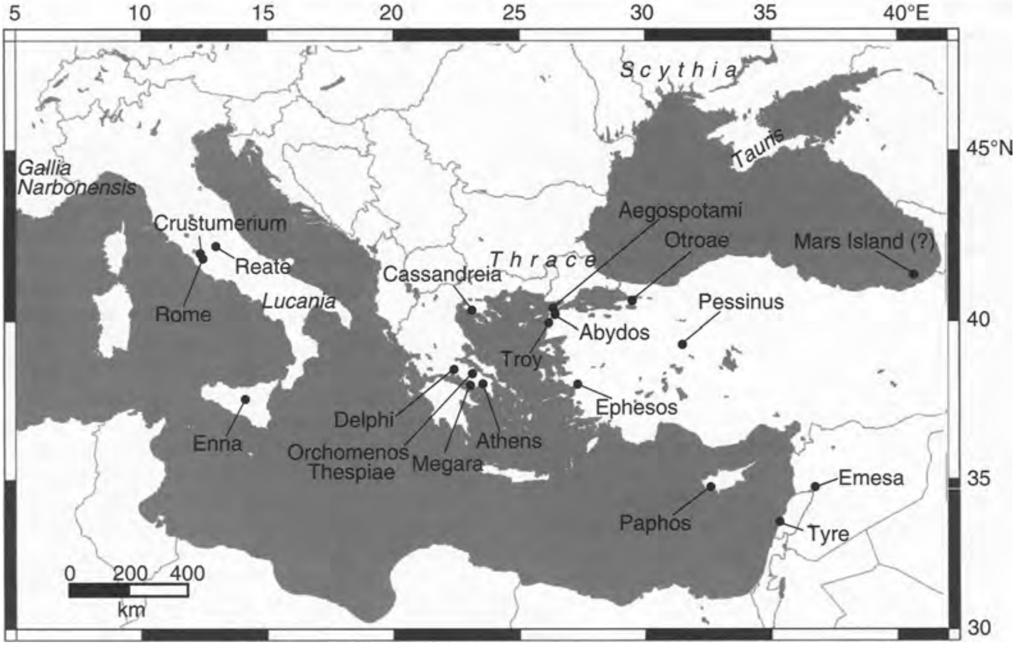

Fig. 1. Sketch map of the central-eastern Mediterranean area showing the localities mentioned in the text. Plain text, cities; italics, geographical regions.

(From when the stone fell in Aegospotami, and Simonides the poet died at the age of 90, 205 years, when Theagenides was archon in Athens).

The stone fallen at Aegospotami is also mentioned by Aristotle (I, 7, 32), who thought it was just a terrestrial rock lifted by strong winds and then fallen back to the earth. The cosmological theories of Aristotle, that would so deeply influence science in the centuries to come, denied that solid bodies besides the Sun, the Moon, the planets and the comets could exist in space. Pliny (II, 59) reports that the Aegospotami stone fell in daylight in the second year of the 78th Olympiad (467/466 BC), was as large as a wagon load, and could still be seen at his time, about 550 years after the fall. Plutarch (*Lysander*, 12, 1) writes about the stone fall of Aegospotami at the end of his account of the Aegospotami battle (405 BC) where the Spartan commander Lysander defeated the Athenians, putting a definitive end to the Peloponnesian War. Interestingly, Plutarch cites a previous writer, Damaichus of Plataea (fourth century BC), who in his work '*On the Religion*' reported that, a very large fiery body was observed in the heavens for 75 days continually before the stone fell. This body was not resting, but it moved in tortuous and broken trajectories, throwing flaming pieces in all directions, shining as falling stars do. Damaichus also wrote that when the local inhabitants, after the fear and astonishment of the exceptional event, came to the place where the stone had fallen, they did not see any fire or any sign of it but just a stone, that, however big, did not resemble the large fiery object observed in the sky.

Rain of stones in central Italy

Many 'rain of stones' events are reported by ancient Latin authors to have fallen in various places in central Italy. The most well known and ancient of these showers occurred on the Mount Albano (about 20 km SE of Rome) during the reign of the third King of Rome, Tullus Hostilium (about 650 BC; Livy, I, 5, 31). The Romans, struck by this portent, established a nine day festival (Sacrum Novendiale) that was celebrated whenever a similar phenomenon occurred. More than twenty stone showers are mentioned during the republican period, most of them in localities around Rome (e.g. Livy, VII, 4, 28; XXII, 5, 36; XXIII, 5, 31; XXV, 1, 7; XXXV, 1, 9; XXXVIII, 4, 36; XXXIX, 2, 22; XLII, 1, 2; Obsequens, 2; 18; 30). For the high frequency of occurrences and the long duration of the showers (some of them lasted several days), it is very unlikely that these showers were meteoritic in origin. Rather, they may have been related to the activity of the Quaternary volcanoes distributed along the Tyrrhenian coast of central–southern Italy. For example the numerous showers of stones that occurred in Latium between 217–202 BC, at the time of the Second Punic War (Livy XXII, 1, 1; XXII, 5, 36; XXIII, 5, 31; XXV, 1, 7; XXVI, 4, 23; XXVII, 7, 37; XXIX, 3, 14; XXX, 7, 38), have been related to a significant, but still poorly known, eruption of Vesuvius (Stothers & Rampino 1983). Other stone showers that occurred in cities around Mount Albano (Aricia, Preneste, Lanuvii) may be related to explosive phreatic activity probably associated with the waning stages of the Colli Albani volcanic complex Funiciello *et al.* 2003).

The Reate stone fall

The fall of a single large stone in Reate (modern Rieti, ~65 km NE of Rome) occurred in 212 BC (Livy, XXV, 1, 7).

The Crustumerium stone fall

In 177 BC a stone fell from heaven in the ancient city of Crustumerium (north edge of Rome) in the Holy Wood consecrated to Mars (Livy, XLI, 2, 9).

The Otroea meteorite fall

During the third Mithridatic War (74–70 BC) the army of Roman consul Caius Licinius Lucullus and those of Mithridate faced each other at Otroea, Phrygia, close to the Ascanian Lake (modern Lake Iznik, Turkey). Just before the battle began, a large body fell amidst the armies causing their temporary retreat. The body is reported to have been the shape of a barrel and the colour of melted silver (Plutarch, *Lucullus*, 8, 5). However, it is not clear, whether the body was seen to fall to Earth or was observed as a meteor.

Iron shower in Lucania

According to Pliny (II, 57) an iron shower fell in Lucania (= Basilicata, a region of southern Italy) in 54 BC. Pliny described the material that rained down as being similar to sponges. This might suggest either a shower of iron meteorites with regmaglypts (depressions resembling thumbprints produced on the surface of some meteorities) or the fall of volcanic scoriae from a nearby eruption.

Meteorite fall in Gallia Narbonensis

Pliny (II, 59) wrote that while he was serving as procurator in Gallia Narbonensis (SE France) in AD 70, he had personally seen a stone recently fallen from the sky on the territory of Vocontii Gauls (a people of Gallia Narbonensis occupying a portion of modern Dauphiné, SE France).

Meteorites fall in Thrace

A fall of three large stones from the sky, occurred in an unspecified locality of Thrace in AD 452 and was reported in a chronicle of the East Roman Empire (Marcellinus Comes, AD 452).

Worshipped stones

This section considers stones that were objects of ancient worship and that were associated with traditions attesting to their celestial origin. The references to the locality and date of the presumed fall, where present, are vague and often linked to legendary traditions. None the less, the existence of many of them, regardless of their meteoritic or terrestrial nature, is historically plausible. Ancient Greeks used for these sacred stones the word baitylos (βαίτυλος), probably from the Semitic Beth'El (home of God). The origin and the significance of this word are very complex and beyond the object of this work; however in Phoenician mythology, one of the sons of the gods Uranus and Ge is named Baetylus, and Uranus devised the Baetylia, having contrived to put life into stones (Eusebius of Caesarea, *Preparation for the Gospel*, X).

Baetyls were venerated in many temples of Greece and Asia Minor, almost invariably in the form of large, conical stones. Many of these baetyls were celebrated on ancient coins, mostly minted in the Asiatic provinces of the Roman Empire (Fig. 2). It is likely that baetyls kept in minor temples were just 'copies' of the 'true' sacred stone kept in the main temple. As an example, the baetyls in the temples of Artemis at Perga, Pogla and Andeda were considered by Wainwright (1931) as replicas of the sacred stone kept in the great temple of Artemis at Ephesus.

The Cybele stone

A black stone was worshipped in the ancient city of Pessinus (Phrygia/Galatia, Asia Minor). It was venerated as a simulacrum of the Mother of the Gods, Cybele (a divinity known under many different names by several civilizations of the Mediterranean area). According to Herodian (I, 11) the stone fell from the sky well before his time and was first found at Pessinus. The same writer affirms that Pessinus got its name from the fall itself (πεσεῖν is the aorist infinitive of the Greek πίπτω = to fall).

In 205 BC, during the fourteenth year of the second Punic War, the Romans, alarmed by certain omens occuring at that time, consulted the

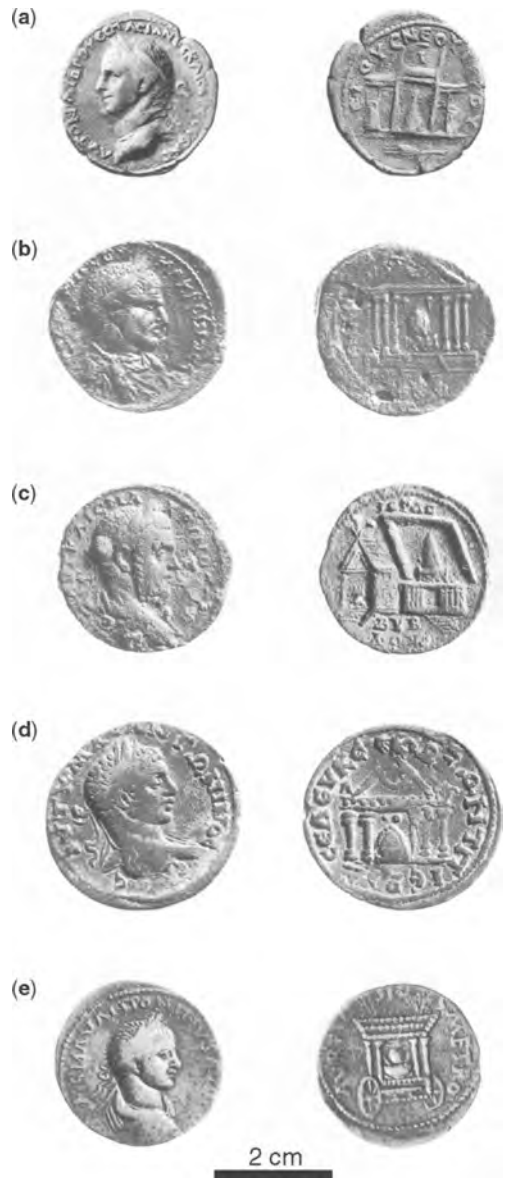

Fig. 2. Examples of ancient coins depicting baetyl stones. (**a**) Silver coin of Vespasian (Roman emperor AD 69–79) representing the stone simulacrum of Aphrodite within the temple of Paphos; (**b**) Bronze coin of Macrinus (Roman emperor AD 217–218) representing the sacred stone of Elagabalus within the temple of Emesa; (**c**) Bronze coin of Macrinus representing the sacred stone within the temple of Adonis at Byblos; (**d**) Bronze coin of Elagabalus (Roman emperor from AD 218–222) representing the sacred stone within the temple of Zeus Kasios at Seleucia Pieria; (**e**) Bronze coin of Elagabalus representing the chariot of Astarte carrying the stone simulacrum of the goddess.

Sibylline Books and found some verses foreshadowing that whenever a foreign foe (in this case Hannibal and his army) should carry war into Italy he could be driven out if the Idaean Mater (Cybele) were brought from Pessinus to Rome (Livy, XXIX, 3, 10; Strabo, XII, 5, 3; Herodian, I, 11). The Senate decided to send a commission to Attalus, king of Pergamus and friend of Rome, to ask for his help. Upon their arrival, Attalus conducted the Roman commissioners to Pessinus and handed over the sacred stone to them (Livy, XXIX, 3, 11). The commission brought the Pessinus stone to Rome, introducing the cult of Cybele to Italy. In 191 BC the stone was located in the Temple of the Great Mother of the Gods on the Palatine Hill. About five hundreds years after the arrival of the Cybele stone in Rome, Arnobius (VII, 49) made a description of the stone: '... a kind of stone, not a large one, one that can be carried in a man's hand without strain, in colour tawny and black, having prominent, irregular, angular points, a stone which we all see today, having a rough irregular place as the sign of a mouth, and having no prominence corresponding to the face of an image'. The stone, also called the Needle of Cybele (*acus Matris deum*), was one of the seven fatal objects upon which the prosperity and the safety of the Roman Empire depended (Servius, VII, 188). At the end of the nineteenth century, Rodolfo Lanciani, director of the archaeological excavations on the Palatine Hill area, did not succeed in recovering the Cybele stone. He consulted a book written in the first half of the eighteenth century by Monsignor Francesco Bianchini that reported the results of the former archaeological excavations made in the same area by Duke Francis of Parma in 1730. According to this book, the only object that was discovered in the private chapel of the emperors was a 'stone nearly three feet high, conical in shape, of a deep brown colour, looking very much like a piece of lava, and ending in a sharp point'. Unfortunately the stone was considered unimportant and it was lost again (Lanciani 1888). However, due to their different sizes, the stone found during the eighteenth century archaeological excavations may not be the same one described by ancient writers.

The stone of Kronos at Delphi

Pausania (X, 24, 6) reports that a small stone, held close to the tomb of Neoptolemus, the son of Achilles, was worshipped at Delphi (Phocys, Greece). Every day the stone, still extant at the time of Pausania (second century AD), was anointed with olive oil, and every festival it was covered with unworked wool. According to the tradition this was the stone that Rhea fed to her husband, Kronos, king of the Gods, in place of their infant son Zeus. Kronos swallowed the stone and vomited it out onto the earth. The Kronos stone should not be confused with the omphalos stone of Delphi.

The three stones of the Charites

The town of Orchomenus (Beotia, Greece) was the most ancient seat of the cult of the Charites (Graces). In the temple dedicated to them, they were worshipped under three stones thought to have fallen from the heaven at the time of the legendary king of Thebe, Eteocles (*c.* thirteenth century BC; Pausania, IX, 38, 1).

The stone of Apollo Karinos at Megara

A small pyramidal stone was worshipped under the name of Apollo Karinos in the old gymnasium of the town of Megara (Attica, Greece; Pausania, I, 44, 2). The obelisk represented on some Megarian coins of the third century BC may possibly be this stone.

The Eros stone at Thespiae

A very ancient statue of the god Eros, an unwrought stone, was venerated in the temple of Eros at Thespiae (Beotia, Greece; Pausania, IX, 27, 1).

The Abydos stone

Pliny (II, 59) cites a small stone, believed to have fallen from heaven, worshipped in the gymnasium of Abydos, an ancient city on the Asiatic side of Dardanelles close to the modern city of Çanakkale (Turkey).

The Cassandreia stone

An important meteorite fall is reported to have occurred in the city of Cassandreia, on the peninsula of Pallene (the westernmost of the three fingerlike extensions of the Chalcidice Peninsula, Greece). This city was founded by Cassander in 316 BC on the old site of the ancient city of Potidaea. Pliny (II, 59) mentions the worship of a sky-fallen stone in the city of Cassandreia, stressing that the town was colonized by the Romans on account of the meteorite fall itself. Some scholars however claimed that the etymology of the name Potidaea derives from the Greek ποθι and δαίω, to burn, suggesting that the fall of the meteorite occurred centuries before the Roman settlement. Wainwright (1930) wrote a paper concerning the identification of Ammon with Zeus and his connection with meteorites that contains an interesting reference to the Cassandreia meteorite fall. This paper reports that the city of Potidaea had been devoted to the worship of Poseidon, after whom it was named. The worship of Poseidon by the people of Potidaea is attested by a temple dedicated to this god, and by the use of the figure of Poseidon and his trident, on the coins minted at least since 500 BC. After the capture of Potidaea by Philip II of Macedon in 358 BC, the city entered a period of decline and the coinage ceased completely. Under Augustus, the city of Cassandreia became a Roman colony and it gradually became important enough to mint its own coins again. However, the horned and bearded head of Zeus-Ammon appeared on the new coinage rather than the symbols of Poseidon. Wainwright (1930) interpreted this significant change as an awareness by the Romans of the supernatural event (the meteorite fall) that had occurred, and their wish to honour the sky-god Zeus-Ammon to whom they ascribed that portent.

The Aphrodite stone of Paphos

A large cone-shaped black stone was worshipped in the ancient temple of Aphrodite at Paphos, Cyprus. This temple, and the stone it contained, was celebrated on many Roman coins. In most cases, the stone is represented within a double-columned temple with a peristyle and a semi-circular pool or fence in the forefront. Coins with such representation (Fig. 2a) were minted under Augustus, Drusus Jr, Galba, Vespasian, Titus, Domitian, Trajan, Didia Clara, Septimius Severus, Julia Domna, Caracalla and Geta. A mention of the Aphrodite stone can be found in the *Historiae* by Tacitus (II, 2). The Roman historian, reporting the visit of the young Emperor Titus to the Aphrodite temple at Paphos in AD 69, makes the following description of the Aphrodite simulacrum: 'the image of the goddess does not bear the human shape; it is a rounded mass broader at its base and smaller at the top'.

During the excavations of the Aphrodite temple carried out in 1888 in the Kouklia area by a German archaeological team, a large dark conical stone was found. However, the stone, currently exposed in the Archaeological Museum of Kouklia, was recognized as a local (terrestrial) gabbroic rock (Prof. F. G. Maier, pers. comm. 2004).

The Emesa stone

The ancient city of Emesa (modern Homs, Syria) was known in antiquity for the cult of the Sun god known under the Phoenician name of El Gabal (latinized as Elagabalus). Within the large temple devoted to Elagabalus there was a large conical black stone thought to have been sent from heaven (Fig. 2b). Herodianus (V, 3, 5) makes a detailed description of the external morphology of the stone: '... on it there are some small projecting pieces and markings that are pointed out, which the people would like to believe are a rough picture of the sun'. This description recalls the morphology of the Lafayette Martian meteorite, that represents one of the best known and most striking examples of an oriented meteorite (Fig. 3).

The Emesa stone is closely connected to the life of the Roman emperor Marcus Aurelius Antoninus (AD 204–222). From the age of fourteen Antoninus (whose true name was Bassianus or Varius Avitus) was a priest of Elagabalus in the temple of Emesa. Thanks to the intrigues of his grandmother Julia Maesa, sister of Julia Domna wife of the emperor Septimius Severus and mother of the emperors Caracalla and Geta, he was proclaimed emperor. In AD 219, he went to Rome carrying with him the Emesa stone. The short rule of Antoninus, also known as Elagabalus after his god, was an uninterrupted series of odd and dissolute actions. Elagabalus set up a bizarre ceremony concerning the Emesa stone: the stone was put in a driverless chariot and taken from the city to the suburb. The chariot was drawn by a team of large, pure white horses decorated with lots of gold and ornamented discs. Elagabalus walked in front of the chariot, but facing backwards looking at the god. A large number of different coins were minted to celebrate the Emesa stone. It was pictured in various forms: a stone with a star above; a stone carried by an eagle with a crown in its beak; a cone-shaped stone in a chariot drawn by horses. In AD 222 Elagabalus was killed along with his mother Soaemias by the praetorians and the Emesa stone was never seen again.

(a)

(b)

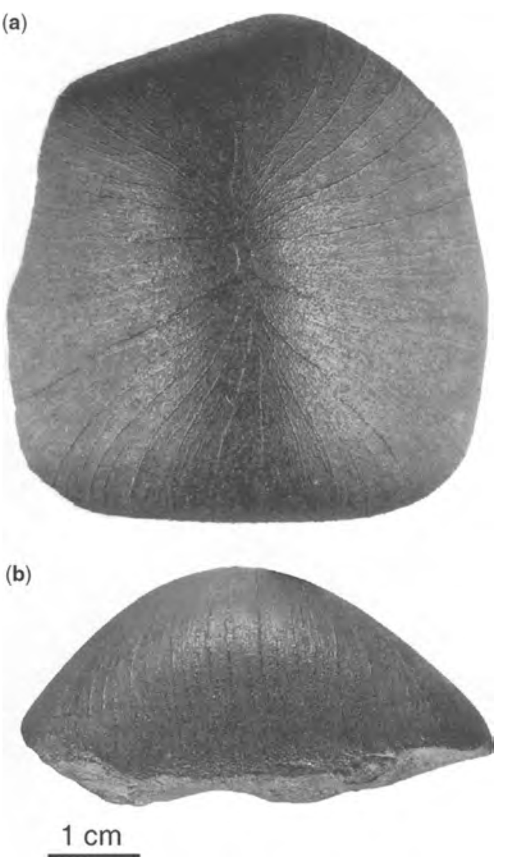

Fig. 3. Top (**a**) and side (**b**) view of the Lafayette oriented Martian meteorite held in the Smithsonian US National Museum of Natural History, Washington. Images taken from the 'Mars Meteorite Compendium' web-site (courtesy of C. Meyer, http://curator.jsc.nasa.gov/antmet/mmc/mmc.htm).

The stone of Astarte at Tyre

Some famous sacred stones were worshipped in the ancient Phoenician cities of Byblos (Fig. 2c), Aphaca, Sidon (Fig. 2e) and Tyre (modern Lebanon). One of them was venerated as the simulacrum of the goddess Astarte. Astarte, also spelled Ashtart, was one of the main deities of the Phoenicians and worshipped as both a heavenly and earth mother. The myth related to this stone was reported by Philon of Byblos (AD 64–141) who translated from the Phoenician to Greek the Phoenician history by the legendary Phoenician writer Sanchuniathon of Berytus. The work by Philon of Byblos was largely lost but a story about the stone of Astarte survived as a quotation in the *Praeparatio Evangelica* (Preparation for the Gospel) by Eusebius of Caesarea (Chapter X): 'And Astarte set the head of a bull upon her own head as a mark of royalty; and in travelling round the world she found a star that had fallen from the sky, which she took up and consecrated in the holy island Tyre. And the Phoenicians say that Astarte is Aphrodite'.

The Artemis stone at Ephesus

The Artemis stone at Ephesus (Aegean Sea coast of modern Turkey) is one of the most cited sacred stones of the antiquity as the tradition of its heavenly origin is found in the Bible (Acts of the Apostles 19:35). Notwithstanding its popularity in the ancient world, I was not able to find a mention of its heavenly origin or its description as an unwrought stone either in Greek or Latin literature.

Myths associated with sky-fallen objects

There are numerous myths and legends related to sky-fallen objects in the ancient Greek and Latin literature. In most cases there is no evidence of the actual existence of these objects. In other instances, they were real objects but they were not described as unwrought stones. Some of these mythical objects had supernatural attributes such as the faculty of speech and foresight (the Orites stone) or the power to protect the cities in which they were kept (the Palladium, the Ancile).

The Palladium

The Palladium was one of the most celebrated mythical objects of the antiquity said to have fallen from the heaven. A number of different versions concerning its nature, origin and fate have flourished, and just the most popular among them will be mentioned here.

The goddess Athena was reared by Triton together with his own daughter Pallas. While the two girls were playing, Athena hit Pallas, killing her. In order to calm her grief, Athena made a wooden statue in the likeness of Pallas, set it up beside Zeus, and honoured it in heaven. Later Zeus seduced Electra, one of the Pleiades, and since she, escaping from him, took refuge at the image, the god threw the Palladium into the Troad (NW of modern Anatolia) (Pseudo-Apollodorus, III, 12, 3).

Afterwards Ilus came to Phrygia where, after taking part in the games that were held by the king, he won a victory in wrestling. Following an oracle, the king gave him a cow, asking him to found a city wherever the cow should lie down. Ilus saw the cow resting at the hill of Ate, and prayed to Zeus to send him a sign. It was then that he saw the Palladium, fallen from heaven and lying before his tent, and was blinded by it, since the Palladium was not to be looked upon by any mortal. But later, after having made offerings, he recovered his sight, and built the city that he called Ilium (Troy) on that spot with a temple for the Palladium, for as long as it was preserved, the city was safe. The fate of the Palladium is very uncertain, and many versions of its removal from Troy were handed down: some authors (e.g. Pseudo-Apollodorus Epitome, 5, 10–13) report that it was taken away by the Achaeans during the Trojan War and brought to Greece, others that it was rescued by Aeneas and brought to Italy (e.g. Pausania, II, 23, 5). Indeed, according to the tradition, the Palladium, along with the stone of Pessinus, the Ancilia, the sceptre of Priamus, the ashes of Orestes, the terracotta quadriga from Veii and the veil of Iliona, was one of the seven fatal objects kept for many centuries in Rome by the Vestals, and upon which the safety of the Roman Empire depended (Servius, VII, 188).

The Ancile

Since the reign of the second King of Rome, Numa Pompilius (eighth–seventh century BC), a shield-shaped bronze object called Ancile was venerated as a sacred object connected to the cult of Mars Gradivus (Livy, I, 4, 20). The Ancile fell from the heaven into the hands of Numa (Plutarch, *Numa Pompilius*, 13, 1) during his eighth year of rule. To prevent the Ancile being stolen, on the initiative of Numa, eleven replicas of the shield were made. Every year during the month of March, the twelve shields were carried through Rome by the Salii priests. Plutarch also makes a description of the Ancilia: '... they are not made round, nor like proper targets, of a complete circumference, but are cut out into a wavy line, the ends of which are rounded off and turned in at the thickest part towards each other; so that their shape is curvilinear'.

The Orites stone

The apocryphal Orphic poem *Lithica* contains a legendary story possibly related to a meteorite. The god Apollo donated the stone called Orites to the Trojan Helenus, son of Priamus and Ecuba. Helenus and his twin sister Cassandra were both foretellers. In the *Lithica*, Helenus used the Orites stone (that had the faculty of speech) in his soothsaying. The anonymous Orphic writer describes the stone, also called siderite in the same poem, as rough, rounded, heavy, black and close-grained. In addition, it showed circular marks in relief above its whole surface.

Gold objects fallen from the sky in Scythia

The following myth, related to the very first origin of the Scythian people, is handed down by Herodotus (IV, 5): at the time of the early three rulers of Scythia, Lipoxais, Arpoxais and Colaxais, sons of Targitaus, four objects made of gold (a plough, a yoke, a battle axe and a cup) fell from the sky. The three brothers tried to recover the objects, but the eldest, Lipoxais, and the second, Arpoxais, were both driven back by the burning objects. A little time later, when the objects stopped burning, the youngest brother, Colaxais, took them and became the king of the whole Scythia.

The iron mass of Achilles

In the XXIII book of the *Iliad* by Homer are described the great funeral games organized by

Achilles to honour his dead friend Patroclus. The prize for putting the shot, won by Polypoetes, was the same object used for the game, that is a heavy, irregular, mass of iron (XXIII, 826–835). This mass was part of the spoils taken by Achilles when he had killed Eetion, king of the Hypoplacian Thebe (Cilicia) and father of Andromache, the wife of Hector. At the time of Homer, iron was considered as a quite precious metal in Greece, so this iron mass, owned by kings and heroes, might have had an extra value.

The black stone of the Amazons

In the poem *Argonautica* by Apollonius of Rhodes is mentioned (II, 1172) a black stone worshipped by the Amazons in the temple of Mars on the legendary Mars' Island (Black Sea).

The stone shower sent by Zeus for Heracles' aid

Strabo (IV, 1, 7) and Hyginus (II, 6, 3) quote some verses from the *Prometheus Unbound* by Aeschylus, now lost, connected to the myth of Heracles's Labours and possibly related to an ancient meteorite shower. During his return trip to Argolis, after the fetch of the Cattle of Geryon, Heracles journeyed the territory of the Ligurians, where he was attacked by this warlike people. During the fight Heracles expended all his arrows and he could not grab any stone off the ground as this was made of soft, stoneless sediments. Then Zeus came to his son's aid sending a shower of rounded stones that Heracles could use to defeat his enemy. Strabo (IV, 1, 7) identified the site of this legend with a plain lying halfway between Marseille and the mouth of the Rhone, about 20 km from the seaside (modern Plaine de la Crau).

The Artemis statue in Tauris

In the tragedy *Iphigenia in Tauris* by Euripides, Iphigenia, daughter of Agamemnon and Clytaemnestra and sister of Orestes, is a priestess in the Artemis temple in Tauris (modern Crimean Peninsula, Ukraine). In this temple, a statue of the goddess thought to have fallen from the heaven was worshipped. Orestes, landed in Tauris together with his friend stole, steals the celestial statue and carried it, along with his sister, to Halai Araphenides, a deme of Attica. Pausania (III, 16, 7) affirmed that the statue was brought to the temple of Artemis Orthia in Laconia (Peloponnesus).

The Athena Polias statue at Athens

Pausania (I, 26, 6) reports the tradition of a heavenly origin for the statue of the goddess Athena held in the polis of Athens.

The Ceres statue at Enna

Cicero, at the end of his famous oration against Verre, governor of Sicily from 73 to 71 BC, mentions a statue of Ceres worshipped since remote times in the city of Enna (central Sicily). He tells that the statue was held in high reputation by the inhabitants of Enna because it was believed to have fallen from the skies (II, 5, 187). However, in a previous point of the same oration (II, 4, 109), Cicero describes this statue as a small one, very ancient and of unusual style, but made of bronze.

Phaethon's chariot

The ancient Greek myth of Phaethon has been cited as the mythological transposition of a catastrophic collision between the Earth and an extraterrestrial body, possibly a comet. This large-scale event may have occurred in a distant past over an unidentified region of Europe. Following one of the most popular versions of the myth (e.g. Ovid II, 1–405), Phaethon was the son of Helios (or Phoebus, the Sun) and Clymene. When Epaphus, a boy of his same age, denied that his father was Helios, Phaethon went to his father's palace to ask for proof that he was his real son. Helios admitted that Phaethon was his own son, and, as a proof, told him to ask whatever he wished. Phaethon, who marvelled at the journey of the Sun disc across the firmament, immediately asked for his father's chariot and the right to drive his horses for a day. In spite of the attempts of Helios to dissuade his son, at dawn Phaethon started his dangerous trip through the sky, but very soon he lost the control of the chariot. The horses left the accustomed track, now climbing up to the top of the sky, now plunging right down to the earth. The peaks of the highest mountains caught fire, forests, pasture lands, crops and cities were burned. In the process, Lybia became a desert and the Ethiopians became black-skinned. In many countries springs and lakes dried out and rivers steamed. The earth's crust broke open and the sea receded. When the lamentations from Gaia (or Tellus, the Earth) reached Zeus's ears, he flung a mortal lighting bolt at Phaethon, who fell, leaving a long trail like a shooting star, onto the Earth into the river Eridanus (often identified with the river Po). Helios, beside himself with grief, hid his face, leaving the world without his light for a whole day.

Some attempts have been made to relate existing impact structures to the catastrophe imaged by the myth of Phaethon's chariot. The best candidates were found in the Kaali meteorite craters, formed 1690–510 BC (Veski *et al.* 2004) on the Island of

Saaremaa, Estonia. These craters have been studied extensively to understand the effects of this meteoritic impact on the environment and on the population already living in the area at that time (Veski *et al.* 2001, 2004). The total energy involved in the impact that formed the Kaali craters was estimated to be *c.* 4.7×10^{12} J (about the same as that released from the Hiroshima bomb); thus, it is very likely that this catastrophic event might have left a trace in the myths and legends of contemporary people. It has been proposed that the ancient Greek sailor and geographer Pytheas of Massalia could have visited the region of the Baltic Sea in the fourth century BC. Pythea wrote a book about his voyages called *Description of the Ocean*, now lost, that was quoted by many Greek and Latin writers of the antiquity. In particular, the Greek mathematician and astronomer Geminus reported the following citation attributed to Pythea: '... the barbarians showed us where the Sun goes to bed...'(Geminus VI, 8–9). This phrase could contain a reference to the fall of the Kaali meteorite but more likely to be related to the phenomenon of the very short length of the night observed at the northernmost latitudes and not known to the Greek explorers journeying these regions for the first time.

Concluding remarks

The catalogue reported in this paper shows that ancient populations were attracted by meteorite falls and recovered the fallen stones. The most common attitude of people living during the ancient Greek and Roman ages was to attribute a religious significance to these sky-fallen stones, though non-superstitious opinions about these phenomena were held by some philosophers and naturalists of the antiquity.

Unfortunately, with the notable exception of the Aphrodite stone at Paphos (which is of terrestrial origin), none of the ancient objects said to have fallen from the heavens has survived to our times. Hence, the actual existence of each one cannot be scientifically accepted without serious doubts. In some cases the fall of stones from the sky described by the ancient authors was just pyroclastic material erupted during a volcanic eruption. Indeed, during the time span investigated in this work, a high number of explosive volcanoes are reported to have been active in the Mediterranean area (e.g. Somma-Vesuvius, Etna, Aeolian Islands, Santorini; see Stothers & Rampino 1983). On the other hand, the fall of stones might have been mistaken for showers of large hailstones or for rain charged with sandy material from desert lands. Finally, it is possible that some of the stones worshipped had not actually been seen to fall from heaven but were just terrestrial stones morphologically similar to true meteorites that had fallen elsewhere (that is they could be false meteorites or, as they are called today, 'meteorwrongs'). Although at least six impact structures of Holocene age have been found in northern Europe (Czegka & Tiirma 1998), meteoritic impact craters of the same age have not been recognized unambiguously in the Mediterranean area; indeed, the meteoritic origin of the small subcircular depressions of Sirente plain (Abruzzo, central Italy), dated at fourth–fifth century AD (Ormö *et al.* 2002), have been seriously questioned recently (Speranza *et al.* 2004).

Considering the available estimates of the current flux of meteorites on the Earth's surface, it is not surprising that men living in the ancient Greek and Roman time witnessed the fall of meteorites and were able to recover some of the fallen material: as an example, taking one of the most conservative estimates of the current flux of meteorites weighing 1 kg or more, of 8.7 events per year in an area of a million square kilometres (Halliday *et al.* 1989), it can be calculated that over a surface of 1.2×10^6 km^2 (corresponding to the whole land surface of the modern Italy, Greece and Turkey) more than 12 500 meteorites ≥ 1 kg should have fallen in a period of about 1200 years time span (from the age of Homer to the end of the Western Roman Empire).

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Sooty sweat stains or tourmaline spots? The Argonauts on the Island of Elba (Tuscany) and the spread of Greek trading in the Mediterranean Sea

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Abstract: In various ancient authors (e.g. the 'Argonautika' of Apollonios Rhodios) curious news about the Island of Elba can be found, concerning the existence, somewhere on the shore near Portoferraio, of pebbles that are 'dirty' from the Argonauts' sweat. The Argonauts are said to have stopped on the island during their journey back from the looting of the 'Golden Fleece'. These pebbles are found to be typical of the gravelly beaches below the Capo Bianco cliffs. Such walls are made up of a bony-white aplitic rock dotted with blue-black tourmaline spots. Capo Bianco aplite is the uncommon result of the solidification of a boron-rich magma in a subvolcanic setting. Here, the separation of a boron-rich fluid phase gave way to the crystallization of peculiar spherical dark tourmaline clots in a very fine-grained white groundmass. This rock was noted by Argonauts (i.e. the ancient travellers they represent) and used as a lighthouse to the harbour of Argoos limen (now Portoferraio). Also in the myth, the unique mottled pebbles were recorded as stained by the Argonauts' sweat. The occurrence, within the same, complex myth, of 'data' concerning navigation (the white cliffs) and geology (description of the spotted aplite) identify the Argonauts as a blending of mineral prospectors, explorers and early eighteenth century-like naturalists, legitimatizing the commercial/political presence of Greeks in the region.

Fanciful tales or myths have arisen during the course of each culture's history, most often from either religious or social motivations. In some cases, a pre-scientific view of the natural world generated observations that became a relevant element of the structure of the myth. Only with progress in the scientific analysis of nature, perhaps first truly introduced by Herodotus, have we gradually developed a distinction between natural and mythical explanations. One aspect of myths is that they often recall specific places in which special or peculiar natural features are present, and for this reason, the Island of Elba could not be absent in the ancient mythology. In fact, this island has a privileged position for navigation in the central Mediterranean Sea, being located between Corsica and the Tuscan shoreline, and it was also famous in the classical world for its iron deposits, noted by Ps. Aristoteles (*De Mirabilibus Auscultationibus*, 93), Vergilius (*Aeneis*, X, 143–144) and Strabo (*Geography*, V); see also Corretti (2004*a*) and references therein. In particular, Elba occurs in the myth of Jason and the Argonauts that was codified by Apollonios Rhodios who describes the exceptional character of some unique rocks (perhaps the Capo Bianco aplite) as having both a special petrographical and mineralogical nature, as well as an extraordinarily bright, white colour of outcrop.

In this paper we describe the geology and petrology of the tourmaline-rich Capo Bianco aplite cropping out as a dismembered laccolith along the northern coast of central Elba, and we highlight the strict similarity between the petrographic features of the Capo Bianco rocks and the descriptions contained in the Argonauts' myth reported by Apollonios Rhodios. Finally, we discuss how accurate observations on this oddity of nature were 'metamorphosed' in the structure of a mythic narration.

The Tuscan Magmatic Province and the Island of Elba granitic rocks

Regional geology

The Island of Elba is located at the northern end of the Tyrrhenian Sea, a region affected by extensional

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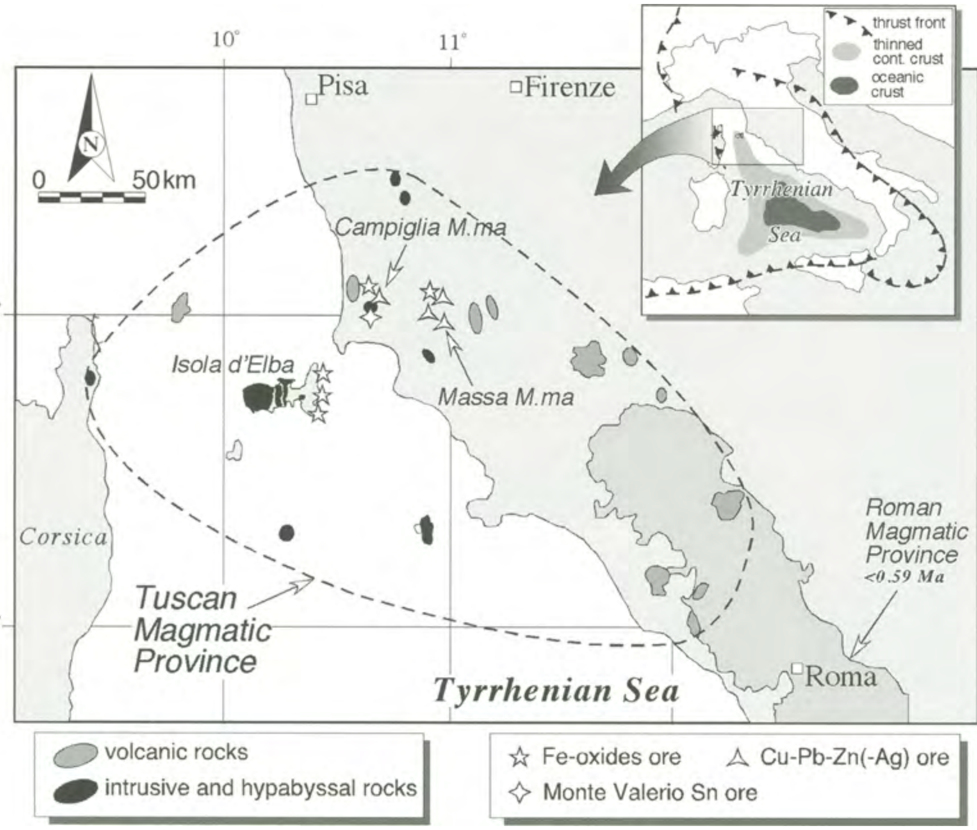

Fig. 1. Geological sketch map of the Tuscan Magmatic Province and location of the main ore deposits exploited in the Classical-Ancient world.

processes behind the eastward progressing front of the Apennine mobile belt (Fig. 1). The backbone structure of the Apennines was constructed during an early Miocene compressive phase in the collision zone between the Sardinia-Corsica block and the Adria plate (Scrocca *et al.* 2003). This orogenic system evolved diachronously as the regime of extension migrated from west to east, following the retreat of the compressive regime and the eastward rollback of the west-dipping Adriatic plate: these processes gave way to the opening of the ensialic northern Tyrrhenian back-arc basin. In this framework, magmas were generated in the mantle and interacted with crust-derived felsic magmas to generate the Tuscan Magmatic Province intrusive and extrusive products exposed over about 30 000 km^2 of southern Tuscany and the northern Tyrrhenian Sea (Innocenti *et al.* 1992; Dini *et al.* 2002; Fig. 1). This igneous activity migrated from west (14 Ma) to east (0.2 Ma) in an extensional ensialic back-arc setting as the west-dipping Adriatic plate delaminated and rolled back to the east (Serri *et al.* 1993). Thus the Tuscan Magmatic Province with its peraluminous boron-rich granites and rhyolites is one of the youngest anatectic plutonic-volcanic provinces in the world.

The Island of Elba intrusive sequence

Elba was constructed from five tectonic complexes that were thrust onto each other by about 20 Ma (Deino *et al.* 1992). The lower three complexes have continental features, while the upper two are oceanic in character (Trevisan 1950; Pertusati *et al.* 1993). Complex IV consists of Jurassic oceanic lithosphere of the western Tethys Ocean (peridotite, gabbro, pillow basalt and ophiolite sedimentary breccia) and its upper Jurassic–middle Cretaceous sedimentary cover (chert, limestone, and argillite interbedded with siliceous limestone). Complex V consists of argillite, calcarenite and sandy marl of Paleocene to middle Eocene age, overthrust by an upper Cretaceous flysch sequence.

Large-scale faults subdivided Elba into three geographical areas: western, central and eastern Elba (Fig. 2a). Western Elba consists of the Monte Capanne monzogranitic pluton, emplaced at 0.1–0.2 GPa, and its thermometamorphic carapace of Complex IV rocks that contain hypabyssal porphyry intrusions. Western Elba is separated from central Elba by the Eastern Border fault that roughly parallels the east side of the Monte Capanne pluton, truncating its contact aureole and dipping moderately to steeply eastward (Fig. 2a; Westerman *et al.* 2004).

Central Elba consists of Complex V flysch and enclosed porphyry intrusions, and is separated from eastern Elba by the low-angle Central Elba fault (Fig. 2) expressed as a tectonic mélange of rocks from Complexes IV and V. The rocks of central Elba were probably displaced about 10 km eastward from their original position by way of movement on the Central Elba fault (Westerman *et al.* 2004).

Eastern Elba consists of a stack of tectonic complexes. The upper portion of the stack, including part of the contact aureole of the upper Pliocene Porto Azzurro pluton, was displaced eastward by 5–6 km along the Zuccale fault (Pertusati *et al.* 1993) whose activity is geometrically and kinematically similar to that inferred for the Central Elba fault.

Restoration of the original tectonic setting of the three main sectors prior to extensional dismemberment of the island permits visualization of the pristine architecture of the intrusive complex of Elba Island. The intrusive complex was progressively emplaced within the tectonic stack of Elba with multiple injections of magma. These injections ultimately built up a multilayer laccolith complex, intruded at its base by a large pluton and finally cross-cut by a mafic dyke swarm (Westerman *et al.* 2004).

Ore minerals of Tuscany and Elba

The iron-ore deposits of Elba are part of the metallogenic province of Tuscany. Exploitation since Etruscan time (Corretti 2004*a*) has yielded significant quantities of iron, sulphuric acid from pyrite, lead–copper-zinc, silver, antimony, mercury, and gold, as well as industrial minerals and ornamental stone (Fig. 1). On Elba, about 60 millions tons of iron ore were extracted during almost three millennia of activity (Tanelli *et al.* 2001, and references therein). The iron deposits are restricted to a relatively narrow belt extending north–south along the eastern coast of the Island (Fig. 1). The ore bodies occur in variable settings, from stratiform to pod-like or vein-type bodies. In the northernmost area (Rio Albano–Rio Marina) they consist of hematite, pyrite and limonite. Southwards, the association of iron ores with skarn and/or aplitic dykes becomes more and more distinctive, with Capo Calamita ore deposits made up totally of a magnetite–ilvaite–hedenbergite–pargasite skarn.

Although the origin of the Elba iron ores is still debated, some of them are linked to Fe-remobilization/deposition during the activity of the Tuscan Magmatic Province: indeed, an adularia K–Ar age around 5.4 Ma (Lippolt *et al.* 1995) is very close to the emplacement age estimated for the Porto Azzurro pluton (5.9 Ma; Maineri *et al.* 2003).

There is some indirect archaeological evidence for the exploitation of minerals: iron ores from Elba; Cu–Pb–Ag ores from Temperino and Massa Marittima; and tin ores from Monte Valerio were possibly exploited from the eighth–seventh century BC until the Roman period. However, the archaeometallurgical products and rare furnaces found along the coasts of Elba and Tuscany (e.g. Populonia), indicate that extensive reduction of iron and copper minerals was accomplished in the Roman period (third to first century BC). The iron industry in particular grew to become the great economic resource of Populonia, drawing increasingly on the rich mineral deposits of the Island of Elba often mentioned in ancient texts (Ps. Aristoteles, Diodorus, Varro, Strabo, Plinius the Elder, etc.).

After the fall of the Roman Empire, the ore deposits of Elba and 'Colline Metallifere' fell into total oblivion for centuries. It was only during the Middle Ages (eleventh–fourteenth century) and Renaissance time (sixteenth–eighteenth century) that mining activity flourished again in Tuscany, particularly in the Ag–Cu (–Fe) district of 'Massa Metallorum' (now Massa Marittima in Southern Tuscany), but also in the Fe district of Elba. During the nineteenth century, exploration and exploitation of ore deposits in Tuscany took advantage of the first geological maps and studies of mineralogists and geologists from Italian and European Universities. After the Unification of Italy all mines became State properties and concessions were granted to different mining companies, a practice lasting into the 1990s when the last pyrite mine in southern Tuscany (Campiano) shut down. Today, the mining industry in Tuscany is facing the typical problems of most European regions, and extraction is currently limited to ornamental stone, building materials and a few industrial minerals such as raw ceramic material.

Overall, since classical times Elba has represented a place of great importance for its ore deposits and for its crucial position with respect to naval routes in the northern part of the central Mediterranean Sea. Certainly, ore deposits constituted an aspect of great interest that nurtured some

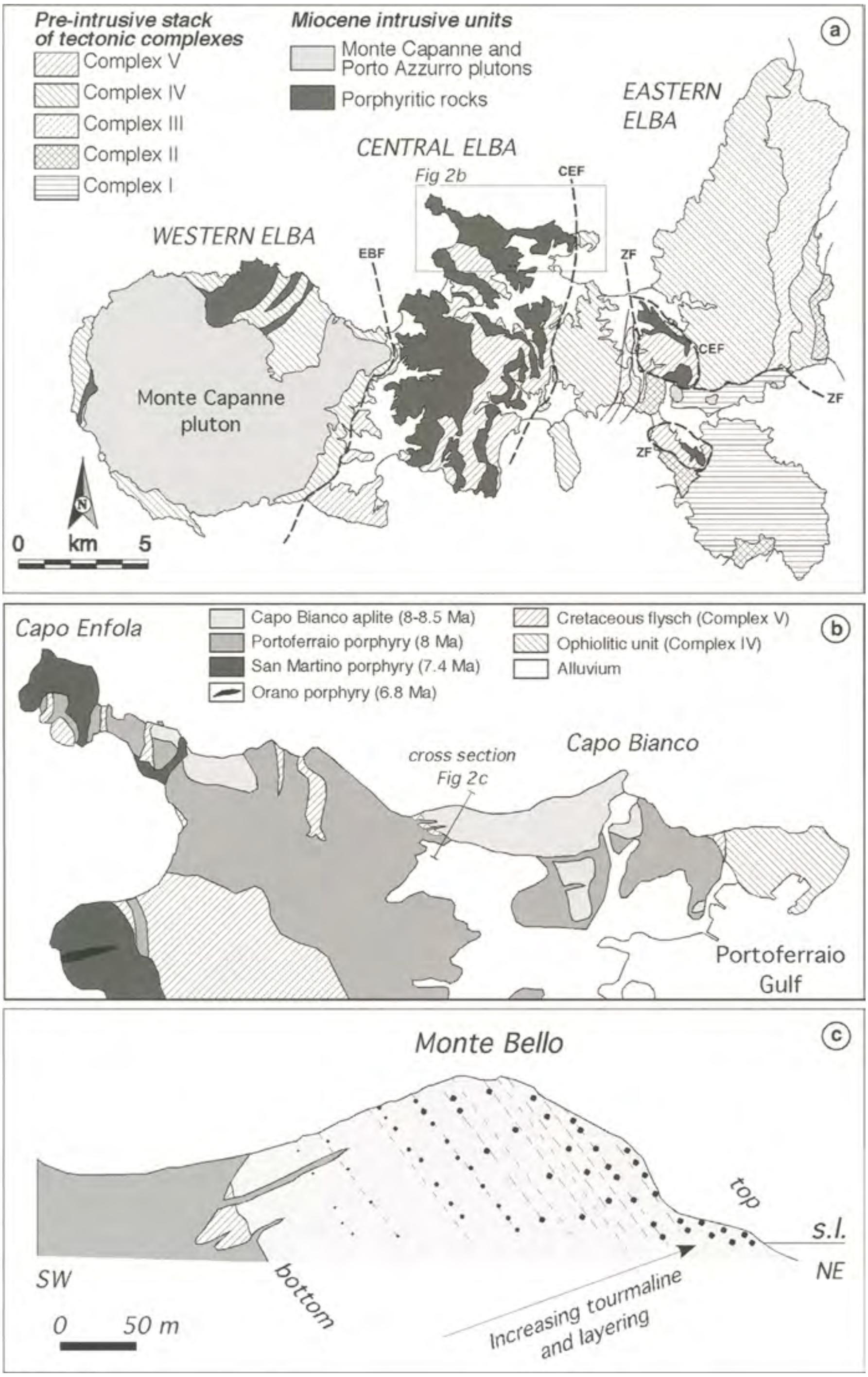

Fig. 2. (**a**) Simplified geological map of Elba Island (EBF, Eastern Border fault; CEF, Central Elba fault; ZF, Zuccale fault). (**b**) Detailed geological map of the Capo Bianco area. (**c**) Detailed cross section of the outcrop area of the Capo Bianco laccolith.

metallogenetic hypotheses, which today we consider imaginative but which dominated the naturalistic thought up to the second half of the nineteenth century (Savi 1836). These hypotheses were exposed for the first time by Varro in a Servian comment and then better described in a comprehensive and clear form by Strabo. This latter description, in his monumental work 'Geography', argues that the ore deposits of Elba are endless as the trenches from which the metal was extracted continuously filled again (*'fossae, unde metalla sunt eruta, rursum tractu temporis implentur'*; Strabo, 5, 2, 6). This idea should have hit the imagination of the classic world since Vergilius in the Aeneis also stressed it clearly (*'insula inexhaustis generosa metallis'* Vergilius, *Aeneis*, X, 143–144). It is not surprising that interest in Elba was not limited to the iron-deposits but extended to both morphological and lithological peculiarities. Among these the Capo Bianco aplite earned a special place for its bright white colour and for the presence of its gaudy black spots, unique in the central Mediterranean basin.

The Capo Bianco aplite

Geology and petrography

The Capo Bianco aplite is a white porphyritic rock (Fig. 3) with alkali feldspar granite composition. Its peculiarity induced nineteenth century geologists to use the now abandoned term 'Eurite' for its classification (Matteucci 1898). Detailed petrographic and geochemical data on Capo Bianco and other acidic intrusive rocks on Elba are reported in Dini *et al.* (2002) and Dini (1997) from which we draw the following main features.

The Capo Bianco aplite occurs in two tabular bodies, both partially intruded by younger granite porphyries: the deeper layer occurs in western Elba within metaophiolites and hornfels (Complex IV); the upper layer of the Capo Bianco aplite is exposed in central Elba, near Portoferraio, and is hosted by pelitic-siliciclastic sequences (Complex V). This upper layer originally had a length of about 3.5 km, thickness ≥ 120 m and was emplaced at a depth of 2.6 km (Rocchi *et al.* 2002).

The Capo Bianco aplite is made up of small phenocrysts (1–5 mm) of muscovite, K-feldspar, oligoclase and quartz set in a very fine-grained (5–250 μm) K-feldspar–albite–quartz groundmass. In some places, for example on the shore near Portoferraio, it is characterized by the widespread occurrence of black tourmaline orbicules and clots. These are made up of a tourmaline–quartz assemblage, with radiating, very fine-grained fibrous tourmaline needles and interstitial microgranular quartz (Fig. 3f). The orbicules often include phenocrysts of quartz and feldspars comparable in size and shape with those set in the main groundmass. The K-feldspar phenocrysts are frequently replaced by tourmaline. On the other hand, the orbicules rarely contain the lath-shaped albite microlites of the groundmass. Additionally, the albite laths, show flow-alignment parallel to the main rock layering, and wrap around the orbicules, thus defining a clear physical separation between the groundmass and the orbicule.

The isotopic age of Capo Bianco aplite is constrained by dates between 7.91–7.95 (muscovite–whole rock Rb–Sr; Dini 1997) and 8.5 Ma (muscovite $^{39}Ar/^{40}Ar$; Maineri *et al.* 2003).

Geochemical features

The Capo Bianco aplite is characterized by a very high silica content (72–75 wt%) and a strong peraluminous signature (Alumina Saturation Index in the range 1.3–1.5). These rocks exhibit very low contents of TiO_2, FeO_{tot}, MgO and CaO leading to the absence of mafic minerals and hence a leucocratic apperance. Trace element distribution is characterized by high Be, Cs, Rb, Nb and Ta, coupled with very low Sr, Ba, Zr and Th. Rare earth element chondrite-normalized patterns are flat ($La_N/Yb_N = 1.3$–2.2) and bear a very deep Eu negative anomaly.

The high $^{87}Sr/^{86}Sr$ (0.712–0.713), the low $^{143}Nd/^{144}Nd$ (0.51213–0.51214), and the $\delta^{11}B$ (-7.2 up to -7.6 ‰), coupled with geochemical data, point to an origin from a crustal, metapelitic source, possibly via a muscovite dehydration melting process (Dini 1997; Dini *et al.* 2002).

The boron content of this rock is low (5–30 ppm) in the tourmaline-free portions (near the base of the laccolith) and reaches very high values (2000–3000 ppm) in the tourmaline-rich zone at the top of the intrusive layer (Fig. 4). A diagram showing B v. B/Nb was utilized because the two elements have nearly identical solid/melt partition coefficients and are incompatible with the structures of most common granite-forming silicate minerals (quartz, K-feldspar, oligoclase–albite and muscovite in the Capo Bianco aplite case). Moreover, boron behaviour departs from Nb when its strong affinity with the aqueous phase is considered. In fact, there is some evidence that boron forms hydrated borate clusters in hydrous melts (see Dingwell *et al.* 1996). A first observation arising from Figure 4 is the overall high boron content of the Capo Bianco aplite and the strong geochemical similarity with peraluminous plutonic and effusive acidic rocks derived from upper crustal reservoirs. Such rocks share peraluminous chemistry, trace element patterns and isotopic signatures reflecting derivation from metasediments involved in late- to post-tectonic magmatic stages of continental

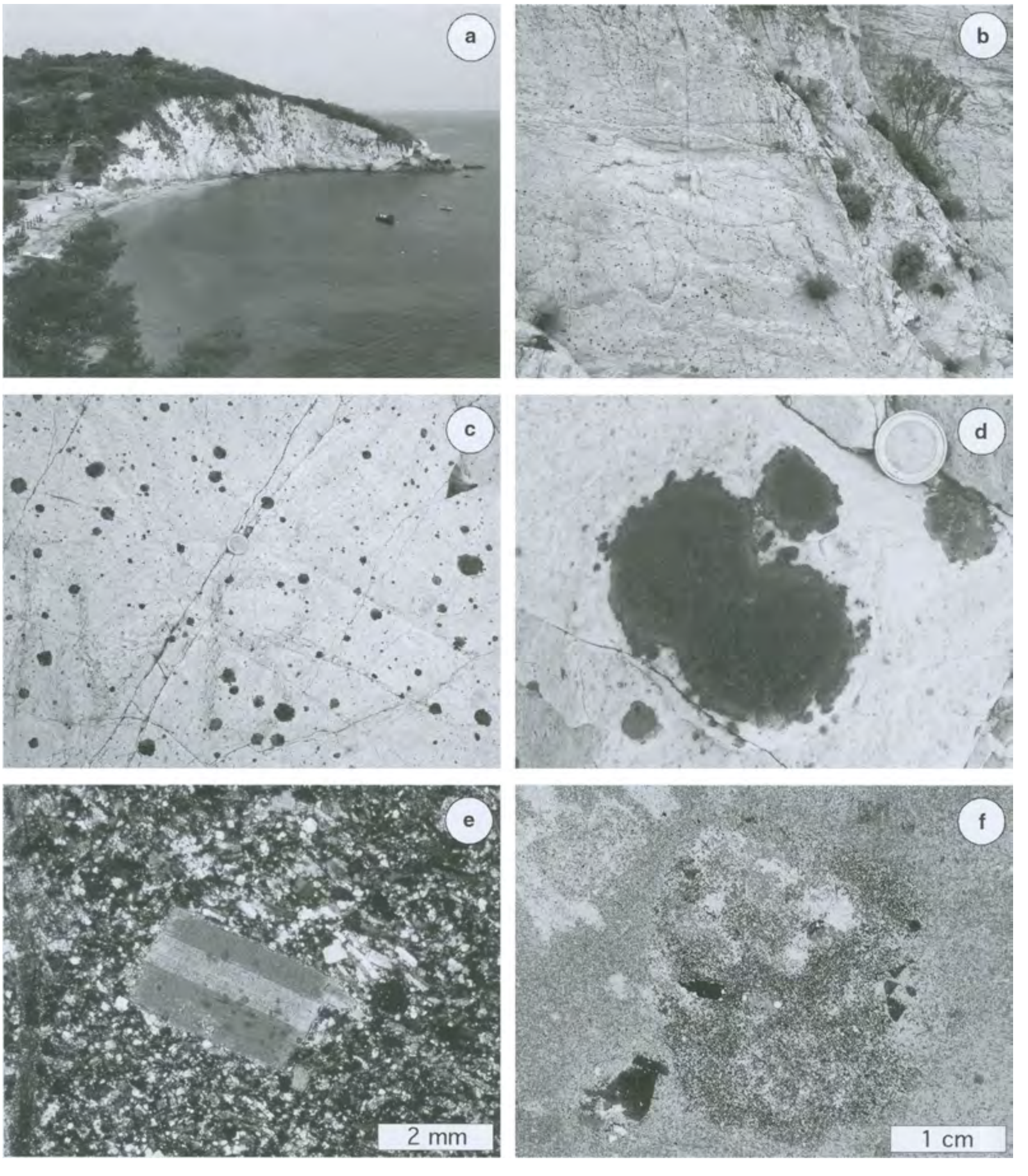

Fig. 3. (**a**) Capo Bianco promontory. (**b**) Outcrop view of the Capo Bianco aplite. (**c**) Enlarged view of the outcrop showing the distribution of tourmaline orbicules. (**d**) Close-up view of tourmaline orbicules. (**e**) Photomicrograph of the aplite texture, with a muscovite phenocryst. (**f**) Photomicrograph of a small tourmaline orbicule.

collisions (e.g. the Alleghenian–Hercynian fold belt, Himalayan belt) as well as in inner arc settings (Peru–Bolivia Cordillera Oriental).

The high boron content of Capo Bianco aplite can be explained by two concomitant processes: acquisition of high B content at depth during crustal melting, followed by a further enrichment due to local differentiation at the emplacement level. Extraction of low fractions of partial melts during the muscovite breakdown at the anatectic source can result in an initially high boron (and water) content. In any case, the melt was not realistically tourmaline-saturated as indicated by experimental data and theoretical modelling (see London *et al.* 1996 and references therein) and conditions for crystallization of tourmaline were reached only

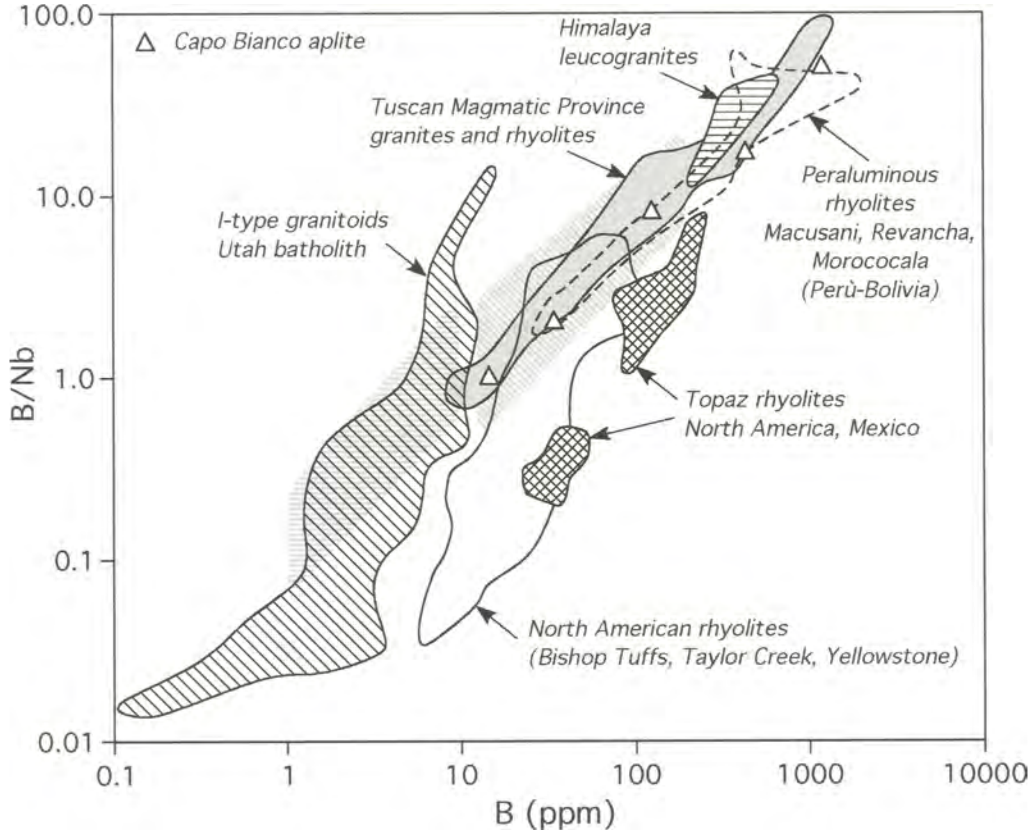

Fig. 4. B vs. B/Nb diagram showing the bottom-to-top boron variations for the Capo Bianco aplite laccolith cropping out in the Portoferraio area (Monte Bello section; see also Fig. 2c). Data are compared with the variation fields of selected acidic rocks from different localities in the world that are representative of B-rich and B-poor systems: South American peraluminous rhyolites (Pichavant *et al.* 1988; Morgan *et al.* 1998; Sandeman & Clark 2003), Himalaya leucogranites (Scaillet *et al.* 1990), granites and rhyolites from Tuscan Magmatic Province (Dini *et al.* 2004), topaz rhyolites from North America and Mexico (Congdon & Nash 1991; Webster *et al.* 1996), North America rhyolites-ignimbrites (Dunbar & Hervig 1992; Duffield and Ruiz 1992; Schmitt & Simon 2004), and I-type granitoids from the Utah batholith (W.P. Leeman, pers. comm.). The fields of upper (oblique shaded area) and lower continental crust (horizontal shaded area) are also reported (Shaw *et al.* 1986; Taylor & McLennan 1995; Wedepohl 1995; Leeman & Sisson 1996; McLennan 2001).

approaching the emplacement level when separation of a B-rich phase occurred. The low-density B-rich phase accumulated at the top of the tabular intrusion, producing the characteristic vertical zoning of the Capo Bianco aplite marked by the distribution of tourmaline orbicules.

Origin of tourmaline orbicules

Tourmaline orbicules of the Capo Bianco aplite were interpreted by Marinelli (1955) to result from a subsolidus autometasomatic process induced by circulation of hydrothermal fluid. However, the lack in the aplite of both pervasive tourmalinization and a quartz–tourmaline vein network connecting the orbicules, indicates that the orbicules, once formed, behaved as an almost closed system in the course of their crystallization. A closed system like this cannot have a hydrothermal nature, because it would result in miarolitic cavities as commonly observed in most intrusions. Instead, this requires crystallization from a volatile-rich silicate melt as supported by: (i) the complete filling of orbicules; (ii) the outward crystal growth of radiating tourmaline fibres; and (iii) the homogeneous, core to rim, composition of tourmalines (schorl–elbaite solid solution; Dini 1997), all in contrast with the extremely zoned (oscillatory, patchy) tourmalines that crystallize from aqueous fluids (London *et al.* 1996).

More recently, tourmaline orbicules have been frequently described in plutonic acidic rocks around the world and are commonly interpreted as results of exsolution of late-magmatic volatile-rich melts that did not escape the intrusive system (e.g. Sinclair & Richardson 1992). However, the Capo Bianco aplite did not crystallize in a deep plutonic environment that typically leads to concentration of volatiles in residual interstitial melt (second boiling process; Robb 2004, and references therein). Indeed, the low quantity of phenocrysts (1–10 % in volume) and textural evidence indicate rapid groundmass crystallization excluding the formation of tourmaline orbicules from volatiles concentrated in the residual interstitial melt.

On the other hand, textural features such as (i) the perfectly rounded shape of the orbicules; (ii) their physical separation from the groundmass highlighted by both wrapping by groundmass albite laths and the limited intergrowth with the groundmass; and (iii) the occurrence in the orbicules of phenocrysts from the surrounding magma are evidence for the separation of B-dominated silicate melt bubbles (by rapid decompression during the fast transfer of the melt to the emplacement level: first boiling process) from a crystal-poor magma.

In summary, the peculiar texture and distribution of tourmaline orbicules are best explained in the frame of the emplacement setting of this intrusion (Fig. 5). Indeed, when B-rich magmas are emplaced at plutonic depths, the relatively slow crystallization leads to the formation of aplitic and pegmatitic bodies hosting volatiles and boron. In those cases, tourmaline (the main boron mineral of the granitic systems) generally constitutes large crystals in association with feldspar, quartz and other rare minerals. In the rarer case of B-rich magmas reaching shallow levels (such as those of the Capo Bianco aplite), fast cooling leads to the separation of B-rich portions as distinct volatile-rich bubbles. If these bubbles are unable to coalesce and escape

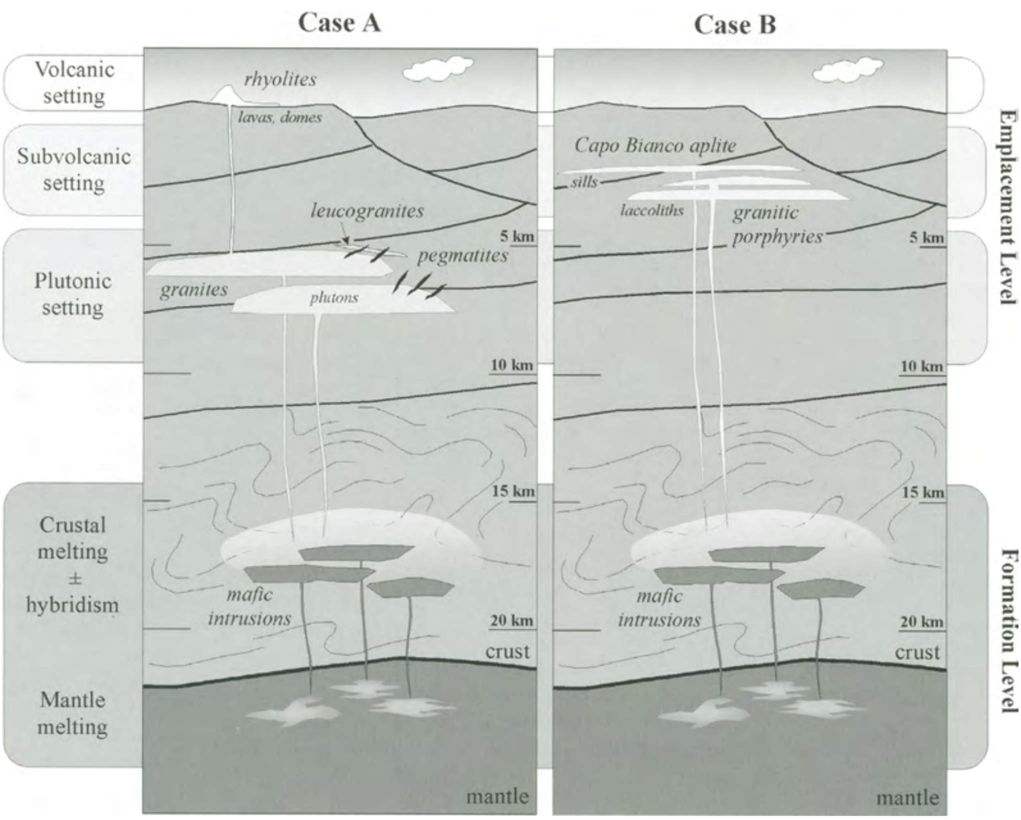

Fig. 5. Schematic cartoon for emplacement of crustal B-rich magmas in a late orogenic setting with thinned crust. (**a**) Emplacement of pluton at intermediate depth with segregation of B-rich leucogranite and pegmatite bodies. (**b**) Emplacement of sill-like bodies at shallow depth: here a B-rich fluid phase is exsolved from the silicate melt but it does not pool to form separate (pegmatitic) bodies.

the silicate melt owing to impermeable host rock, they cause the crystallization of tourmaline orbicules. Finally, in very peculiar cases (e.g. the Macusani obsidian, Peru; Pichavant *et al.* 1988) a boron-rich melt was erupted, but the rapid quenching and the P–T conditions in that case didn't allow the formation of tourmaline.

Capo Bianco aplite can thus be regarded as a serendipitous occurrence of a B-rich magma that escaped from the plutonic levels (or directly from the deep source) and stopped in a subvolcanic setting within impervious shales, just at the right depth for maintaining a snapshot of separation processes involving B-rich fluids and coexisting silicic magma.

The Capo Bianco aplite: an odd, attractive rock

The Capo Bianco aplite represents a chromatic and textural oddity able to catch the eye of even an absent-minded tourist. The first prominent chromatic character is the shining white appearance of the cliffs and the gravelly beaches at their base. The cliffs are clearly visible from many kilometres offshore and, due to the strong glare of the sunlight, their finer complex geometric and chromatic features (tourmaline orbicules, layering) are not revealed until the observer reaches land. Then, at the mesoscale the variegated aspect of the rock emerges from the shining background, and the close association of white quartz–feldspathic layers, pinkish muscovite-rich layers and blue-black tourmaline orbicules is unveiled to the observer's eye. Moreover, the mottled look of the rock is enhanced by the strong variation in orbicule size, ranging from a few millimetres up to 15 cm. The appealing chromatic contrast goes together with the regular geometry of tourmaline spherical orbicules, the rosette textures around them and the planar feature displayed by the regular interlayering of white, pinkish, and grey levels.

All these features make the Capo Bianco aplite an attractive rock for the casual passer-by, an intriguing and still enigmatic geological record for the petrologist, and a unique sight, to be shared among the ancient pathfinders of the Mediterranean Sea, and ultimately to be included in the myth of Jason and the Argonauts.

The myth of the Argonauts and historical sources

One myth, several routes

The legendary journey of the Argonauts is one of the most ancient and widespread Greek myths

Fig. 6. Argonauts at a water spring. Italic vase-painter, end of fifth century BC (*Lexicon Iconographicum Mythologiae Classicae*, vol. II 2, Zürich – München 1984, tab. 438 nr. 11). Note a 'strigil' in the right hand of the Argonaut in the foreground.

(Fig. 6). Though already mentioned in the Homeric poems and later authors (list of sources in Rizzo & Martelli 1989), it is best known through the four books on *Argonautika* by Apollonios Rhodios, Director of the enormous Royal Library at Alexandria in the third century BC, as well as from various collected tales about that mythical voyage.

Ancient writers made the Argonauts follow different sea and land routes to arrive to Colchis on the Black Sea and to return to Greece (Placido 1996). Although the route to Colchis remained the same (through the Bosphorus and the Black Sea), the return journey varied according to the increasing geographic knowledge of the Greeks. Early on, an itinerary was presumed to go up the ancient Phasis River to the ocean and then back into the Mediterranean by way of the Nile or even by an inland journey in North Africa (carrying the ship *Argo* on their shoulders). Once it was known (sixth century BC) that the Phasis was not connected to the Ocean, other itineraries were credited. In one of them the Argonauts sailed up the Istros (Danube) and then down through one of its arms to the Adriatic Sea and finally to Greece; another variant had the Argonauts descend to the Mediterranean through an arm of the Istros flowing into the Tyrrhenian Sea, then following the west Italian shore, crossing the Messina Straits and sailing to Greece. Another route involved choosing another river to get out of the Black Sea, sailing up the Tanais (Don), walking for a while, and going down another river, to arrive at the Baltic Sea, then tracing the NW European shores to the Straits of Gibraltar, whence they entered the Mediterranean and reached Greece through the Tyrrhenian Sea. Apollonios Rhodios' itinerary seems to be a mixture of different tales, since he makes the Argonauts sail up the Istros and then down one of its arms to the Adriatic Sea, then again upstream on the Eridanos (Po River) to the Central Europe lake system and downstream on the Rhotanos (Rhodane) to the Tyrrhenian Sea. This rather strange itinerary enabled Apollonios Rhodios to include in his poem a larger number of those tales related to the passing of the Argonauts that were widely spread along the Mediterranean shores; the exposition of such mythical deeds lying behind present names or traditions was a peculiar feature of Hellenistic poetry.

Origin and development of the 'Tyrrhenian' route

It is reasonable that the 'Tyrrhenian' section of the Argonaut myth dates back to the time of the Greek colonization in the West (eighth–sixth century BC). Etruscans had an early knowledge of this myth, which was represented on their pottery at least since the middle of the seventh century BC (Rizzo & Martelli 1989; Menichetti 1995). Though various place names connected to the Argonauts are present along the Tyrrhenian shore (Telamon, the island of Circe, etc.; Ciampoltrini 1995), Elba played a central role in this part of the heroic journey (Corretti & Benvenuti 2001; Corretti 2005).

The Argonauts stop on Elba is mentioned by various authors: by Apollonios Rhodios (4, 655–658), by the anonymous compiler of the nucleus of the *De Mirabilibus Auscultationibus* (chapter 105)—a list of 'marvellous things' (Gr. *paradoxa*, sing. *paradoxon*) typical of Hellenistic literature and falsely attributed to Aristoteles, by Diodorus of Tauromenion (4, 56: first century BC), by Strabo the Geographer (5, 2, 6: first century BC – first century AD), and, possibly, by Lykophron (*Alexandra*, 871–876), who wrote an obscure poem at the beginning of the third century BC. Possibly a trace of a tale about Argonauts at the Stoichades islands and on the shores of Elba is preserved in a few readable words on a papyrus' fragment (*POxy 2694*, 10–18), which mentions an Antigonos, probably Antigonos of Caristos, another writer of 'marvellous things' (*c.* 240 BC; Pearson 1975).

Since the tales show very similar features, it is reasonable to suppose that they derive from a single source, possibly from Timaeus of Tauromenium (end of fourth—first half of the third century BC) who collected the sparse historical and mythological evidence about the Western Mediterranean for his historical work; it is even possible that the historian Lykos of Rhegion—adoptive father of the poet Lykophron—is behind the notice in *Alexandra*, 871–876, concerning a sanctuary for Heracles founded by the Argonauts not found in the other texts (Amiotti 1982; Dognini 2003). Given that the pebble issue and the name of Argous Limen appear together for the first time in the lines of Apollonius Rhodius, he may be the one who unified the different tales about the Argonauts on Elba and in the West; in fact, as Director of the Alexandria library, he managed the largest collection of written texts in his times.

The detailed report of all these historical sources is beyond the scope of this paper (see Corretti 2005 for an exhaustive discussion of sources and different translations), but, hereafter, the well-known quotation by Apollonios Rhodios (Book IV, 654–658) is reported:

Στοιχάδας αὖτε λιπόντες ἐς Αἰθαλίην ἐπέρησαν
νῆσον, ἵνα ψηφῖσιν ἀπωμορξάντο καμόντες
ἱδρῶ ἅλις· χροιῇ δὲ κατ' αἰγιαλοῖο κέχυνται
εἴκελαι· ἐν δὲ σόλοι καὶ τρύχεα θέσκελα κείνων
ἔνθα λιμὴν 'Αργῷος ἐπωνυμίην πεφάτισται.

and translated according to Green (1997):

From the Echelons they set course for isle of Aithalia,
here they scraped off the abundant sweat of their toil with pebbles,
these still litter the beach, variegated in color,
with their quoits and heroic detritus,
in the harbour that is known today as the bay of Agro.

Discussion

As discussed in the following paragraphs, the evidence for the Argonauts' presence on Elba included: (i) the naming of the main harbour of the island, the Argoos limen (Harbour of Argo), from the name of the ship of the Argonauts (Apollonios Rhodios, Diodorus, Strabo); (ii) pebbles on the shore, used by the Argonauts to clean themselves (or soiled by their sweat and dirt, or made by their coagulated dirt) and therefore, becoming dirty or spotted (Ps. Aristoteles, *De Mirabilibus Auscultationibus*; Lykophron; Apollonios Rhodios; Strabo); (iii) some '*soloi*' or spherical stones or metal spheres, used in athletic games (referred to only by Apollonios Rhodios); (iv) some other objects not easily identifiable because this passage of the text of Apollonios Rhodios is corrupted; and (v) a sanctuary of Heracles (only according to Lykophron).

An analysis of the possible connection of these five items to the geology of Elba follows, such as it might have been perceived by ancient sailors and prospectors.

The Capo Bianco cliffs: a lighthouse for ancient sailors

The story of the Argonauts on Elba was primarily intended to explain the reasons for the name given to the harbour on the Island; however, the naming probably occurred before this harbour was linked to the Argonauts myth. '*Argoos limen*' means, in fact, 'shining, light harbour' (Chantraine 1990; for the meaning and the origin of the Greek adjective *argos*). The Argoos limen of Elba is not the only 'shining' place of the ancient Mediterranean. An *Argennon* Cape (*Cap Blanc* in modern age) protruded from the Ionian coast, in front of the Island of Chios, and could provide an anchorage (Hirschfeld 1895; with ancient sources). Another Argennon Cape was in the Island of Lesbos (Hirschfeld, 1895), another one lay on the East shore of Sicily, near Tauromenium (New Taormina; Hülsen 1895), and an *Argennus portus* is mentioned by Pliny the Elder (*Natural History*, **6**, 97). There was also a Mount *Argaion* (now Erdjiâs) in Cappadocia: it was covered with perpetual snow, and from its top it was possible to see both the Black Sea and Issos bay (Strabo, 11, 2, 7). Chromatic features were used by ancient mariners to mark relevant points along sea routes. The Greek name of Elba (*Aithale*, *Aithalia*, *Aithaleia*) was possibly connected to the chromatic feature of dark sands on its eastern shores (Corretti 2004*a*). As 'light' or 'white' promontories or shores could be more easily seen from a distance, a series of 'white capes' or 'white heads' followed the main sea routes. On Elba, another Capo Bianco rises north of Porto Azzurro in a strategic location controlling the Piombino Strait and access to the mining area from the south. The western edge of Elba, facing Corsica, is marked by Punta Nera and by Spiaggia delle Pietre Albe ('beach of white stones'). But the Capo Bianco near Portoferraio was much more important, flanking the entrance to one of the widest and most secure harbours in the Mediterranean, the Portoferraio Bay. The large and shining rock face was a signal to sailors approaching the island from the north, just as the Argonauts did in the myth (Apollonios Rhodios, 4, 655), and as people usually do today when coming to the island on ferries from Piombino and Livorno (Fig. 7).

Though 'shining' or 'white' places consist more often of promontories, there is evidence of harbours characterized and named after such distinctive features. We have already seen the *Argennus portus* mentioned by Pliny; referring only to Greek texts, Ptolemy (Ptol. 4, 5, 7; 4, 5, 15) records a *Leuke akte* ('white shore') and a *Leukos limen* in Egypt, while another *Leuke Akte* can be found in the *Periplus* attributed to Skylax of Carianda (sixth century BC), but in fact composed in the fourth century BC (Ps. Skylax, 67, 31); finally, the *Stadiasmus Maris Magni* (a portolan written in the third century AD), mentions another *Leukos limen* (*Stadiasmus Maris Magni*, 139, 2). These examples, though not exhaustive, show that the perception of bright colours may lie behind names given not to a single spot or a promontory, but to a wider area such as a harbour.

Identification of the Argoos limen with the Portoferraio harbour can be supposed on the basis of the *Tabula Peutingeriana*, a medieval but faithful copy of a fourth century AD map of the ancient world (Bosio 1983): the corrupted but clearly identifiable name *Ango portus* lies on one edge of the crescent-shaped island, therefore roughly reflecting the actual shape of the Portoferraio bay. If the Argoos limen is to be identified with Portoferraio, it should be possible to explain why the whole harbour was named after the shining aplite rocks: in fact aplite occurs on a wide shoreline, including a large sector of the northern coast and also a smaller outcrop inside the bay at Portoferraio, now lost to modern building activity. The only

Fig. 7. The shore between Portoferraio and Capo Enfola as observed from the ferry at about 7 kilometres from the coast. The shining cliff in the centre is Capo Bianco.

other reasonable locality for the Argoos Limen on Elba is in the Gulf of Porto Azzurro, south of another *Capo Bianco* and not far from the main mining areas of east Elba: however, it seems improbable that the bay at Porto Azzurro could be described as '... the best harbour in those places ...' (Diodorus, 4, 56).

Sooty sweat stains or tourmaline spots?

The tradition of 'dirty' or spotted pebbles on the shores of Elba is well established in the works of ancient authors, though its material basis still remains elusive, since texts have different ideas about the possible genesis of such stones. Even though the tradition grew among 'the Greeks living on the island' (Ps. Aristoteles, *De Mirabilibus Auscultationibus*, 105; possibly from Timaeus of Tauromenium), that is from reliable witnesses, the observation may have been reported more vaguely by later authors.

Ancient writers clearly considered that the Argonauts were sweating (after athletic games, or from having rowed from the Stoichades Islands), and that they did what every young Greek athlete would do: they scraped away the sweat and the dirt with '*strigils*' (metal blades specifically used by ancient athletes; Fig. 6) and flung it onto the shore soiling the pebbles. The smaller stones became *diapoikilous* (Strabo, 5, 2, 6) or *poikilous* (Ps. Aristoteles, *De Mirabilibus Auscultationibus*, 105); they were said to have become similar to the skin (Apollonios Rhodios, 4, 657–658), or to get their appearance (or skin: *chroian*) from the sweat and dirt flung by the Argonauts (Ps. Aristoteles, *De Mirabilibus Auscultationibus*, 105), or even to be made from consolidated sweat and dirt flicked to the ground (Strabo, 5, 2, 6). Lykophron simply says that they retained the greasy spurts of the Argonauts (Lykophron, *Alexandra*, 874: *eulipe stelgismata*).

The word *poikilos* (and *diapoikilos*) has to do with changing colours, or with different colours being present together (Chantraine 1990). The phrase *poikiloi psephoi*, for instance, is used in later Greek texts with reference to mosaics. On Elba this may have to do with a shore made by many pebbles of different colours, or with light-brownish small stones similar to skin, or with shining, changing pebbles— like *oligisto*, the hematite of Elba—or finally, with stones presenting a composite coloration, just like the aplite stones of *Le Ghiaie Beach* that show the famous tourmaline spots.

Some modern scholars tried to link the pebble tale to iron ore, which occurs in great abundance on the island. Both the dark and changing colour for the pebbles fit this hypothesis as would the idea, proposed in Strabo, *l. c.*, of the coagulation of Argonautic sweat and dirt. This would fit well with the interest in mineral resources, which brought ancient Greeks on the Western routes. Of course, since iron ore occurs only in eastern Elba, the shore where the Argonauts rested has to be looked for on the east coast of Elba. But in the mythical tradition that we are examining, the shore with the pebbles is strongly connected to the other major Argonautic trace, the Argoos limen, which is commonly identified with Portoferraio Bay and where it was impossible to find natural iron ore cobbles.

On the basis of this topographical datum (Argoos limen = Portoferraio), since the seventeenth century (Holstenius 1684) a location of the pebbles has been proposed on the Ghiaie shore, west of Portoferraio where the beach is covered with white, dark-spotted aplite stones. Only those with a direct experience of *Le Ghiaie Beach* ('The Gravels'; Fig. 8) could have proposed this identification; other scholars related this strange occurrence to the most strikingly obvious and well-known geological feature of the island, i.e. the iron mines. Moreover, gravelly beaches made up of hematite ores, iron hydroxide ores and oxidized volcanic rocks are widespread in the Mediterranean area, and their observation by ancient people probably did not represent a sufficiently unique experience to be included in a myth. The anonymous author (Timaeus?) lying behind the first compiler of the *De Mirabilibus Auscultationibus* wrote that such pebbles could not be found anymore and in any other place. They were a '*unicum*' (unique).

Recently, a different origin for the mythical pebbles has been proposed: they may have been derived from the observation of metallic, fayalite-rich slags on the shores of Elba (Boardman 2004). This hypothesis would fit with the interest by ancient navigators in prospecting shores in search for mineral resources, and even today ancient iron slags can be seen on the Elban coast; but it would conflict with the asserted uniqueness of the phenomenon (coastal iron slags deposits are widespread) and with the chronology of the Elban iron slags heaps, which until now have proved to be mainly Roman or medieval in age.

Tourmaline orbicules (soloi?) and athletic games at Capo Bianco

The noun *soloi* indicates a roughly spherical object, often made in hammered iron (Homer, *Iliad*, **23**, 826–835) and used by ancient athletes for an equivalent of shot put. The presence of *soloi* among the pebbles seems to indicate that athletic games had taken place, an expected activity for the Argonauts: the discus attributed for their use could be seen in a

Fig. 8. Typical spotted pebbles along the beach at Capo Bianco.

sanctuary in Colchis. It is possible that objects, looking like a *solos*, perhaps of a greater dimension (having been used by heroes), could be seen near the pebbles at the Argoos limen. Iron lumps are recorded to have come from Santa Lucia, in the interior of the island not far from Portoferraio, but the context of the nineteenth century find remains unclear (Zecchini 2001). On the eastern shores of Elba, below the mining areas, large lumps of iron ore (hematite) have botryoidal form. However, at Capo Bianco the erosion of the relatively softer aplite rock by differential weathering isolates the black and heavy tourmaline nodules that have a rather regular spherical shape (Fig. 9). It is difficult, now, to find large tourmaline nodules; but in ancient times some larger nodules may have been seen on the shore: the existence of a consolidated tradition about Argonauts would have done the rest. The discovery of isolated tourmaline spheres was common until a hundred years ago as reported by Matteucci (1898), and their relative scarcity today is indicative of their continued removal by tourists in recent decades (clear evidence that these blue-black spheres still have a strong appeal also for modern people).

The other unidentified vestiges

A few sentences must be dedicated to the presence of other objects on the Argonauts' beach, based primarily on the text of Apollonios Rhodios (**4**, 655–658) which was probably corrupted during the manuscript transmission (see a history of this part of the text in Livrea 1973). The word *teuchea* (equipment) may refer both to the armour of the Argonauts and to the equipment of the ship *Argo*, but the internal coherence of the poem seems to forbid both meanings. The sense 'weapon' has been connected with the common interpretation, among ancient people, of using prehistoric animal bones as heroes' weapons and related to commonly finding hippopotamus and rhinoceros skeletons on Elba (Livrea 1973). A meaning such as 'vase' or 'container' for *teuchea* is attested to by the tragedians. (On the Cista Ficoroni, for instance, the Argonauts are depicted filling amphoras with water and carrying them.) The original word might also be *truchea* (as suggested even by a *scholium ad locum*): in this case the meaning would be 'torn, worn out dresses' and generally, 'remains, ruins'. Finally, a reading *truphea* was supposed, with the meaning of 'worn out pieces of wood'.

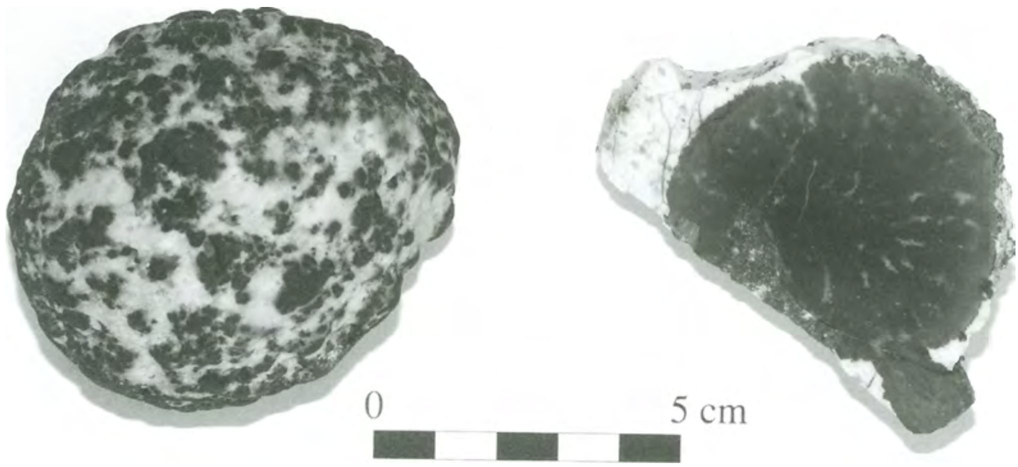

Fig. 9. Isolated spheres (*soloi*?) of tourmaline from Capo Bianco.

The Sanctuary of Heracles

The existence on the Island of Elba of a Sanctuary of Heracles has been reported only by Lykophron (*Alexandra* 871–876). In this passage, the description of the sanctuary built by the Argonauts is matched with the observation of the spotted pebbles on the beach. The cult of Heracles is linked to the Argonauts because he was their patron, as well as the protector of the Greeks along the 'Heraclean Way' across the Mediterranean Sea. However, the existence of such a place of worship on the Island of Elba is not supported by any archaeological find. The only known related record (Taddei 2001) is the finding of a Roman altar dedicated to 'Heracle Sancto' near the granite quarries of Seccheto (on the SW coast of the Island).

Conclusion

Were the Argonauts mineral prospectors, pathfinders or early eighteenth century-like naturalists? The passage of the Argonauts to the Island of Elba was supported, in the views of ancient authors, by several pieces of evidence. The first two (place-name derived from the colour of rock layers around the harbour; pebbles on the shore), probably the third (*soloi*) and, hypothetically, the fourth may have been derived from a careful observation of geological features, as we have shown. These observations were so precise that they led ancient authors to the precise statement that the presence of tourmaline in aplite (i.e. the spots on the pebbles) was unique (a *unicum*). Such an assertion implies a wide knowledge of Mediterranean geology. The same interest in natural resources of the island is at the origin of the various tales about the Elban copper and iron mines (Corretti 2004*b*), and must be explained.

With regard to landmarks and 'coloured capes', we must remember that ancient mariners paid great attention to colourful features on the land they passed as they created '*portolanos*' (harbour guides) along their routes. Of course Elba, lying at the crossroad of Tyrrhenian Sea routes connecting the coastal itineraries to the islands of Corsica and Sardinia and, thence, to Spain and Northern Africa, received particular attention.

Though a first observation could give a general idea of the geological characteristics of a country or an island, when it was possible, a more careful examination of the detritus on the seashore or along riverbeds was made: until modern times, this was the best way to determine the possible existence of mineral deposits in the interior. Ancient prospectors relied upon their attentive observation, the collation of data, and experience from other areas of the Mediterranean. Since Elba lies in an area rich in minerals and frequented by mariners interested in metal resources, and its location on sea routes makes it easily accessible from everywhere, it was an obvious location for exploration by sailors/prospectors in search of source of metals. Though fully unaware of modern geology, they were able to identify correctly the existence and the uniqueness of the aplite pebbles of Portoferraio.

The travels of the Argonauts had a complex significance in the ancient world. They symbolized the opening of new sea routes by Greek sailors, for trade, colonization, or in search of mineral resources (Camporeale 1992). Moreover, the heroes led by Jason clearly represented the Greek ideal of a brave and noble youth that did not disdain athletic games. So, Greek expansion, mainly in the West, created and used many local myths in order to legitimize the presence of Greeks in places of political, strategic and nautical relevance, sometimes making use of peculiar natural phenomena and connecting them to their favourite hero or god (Buonajuto 2000).

In the case of Elba, moreover, one source plainly says that the 'pebbles miracle' is told '... by the Greeks who live on the island' (*De Mirabilibus Auscultationibus*, 105; Colonna 1981). But who were these Greeks?

Corinthians are supposed to lie behind the diffusion of the Argonautic myth in Etruria (Rizzo & Martelli 1989), but mariners, prospectors and colonists from Euboea probably played an important role in exploring, discovering and naming this part of the Mediterranean in eighth–seventh century BC (Corretti & Benvenuti 2001; Zifferero 2002). The name of the island itself is thought to have been connected with Euboean activity in the Tyrrhenian (Corretti 2004*a*). Therefore, a Cumaean (Euboean colony) role in the diffusion of the Argonaut myth in Etruria has been proposed (Cerchiai 1995). Euboeans were followed in time (seventh–sixth century BC) by Ionians and Phocaeans (Breglia Pulci Doria 1997; Corretti & Benvenuti 2001; Corretti 2004*a*), who founded Marseille, the colony of Alalia in Corse, and Velia in Campania. They were present also in Pisa, where Elban iron ore has been found in archaeological levels. However, it is unknown whether they settled on the island or simply frequented its shores and harbours.

Syracuse was also interested in controlling the Tuscan archipelago. In 453–452 BC, 60 Syracusan warships attacked and subdued Elba, and the same was done in 384 BC under Dionysios, the tyrant of Syracuse. It is possible that a Siceliote garrison then settled on the island. The Syracusans may have been the direct source for Siceliote Timaeus, who wrote a few decades after Dionysius' last seizure of the island.

The identification of information that was transferred from myth to the history of the actual ancient world is a very hard task, probably doomed to remain as speculation. Such a process is particularly difficult when reconstructing features of the physical world (e.g. unusual rocks, maritime routes, etc.), and it is almost impossible when trying to define the actual behaviour and motivations of the actors involved in a classical legend. Nevertheless, the conclusion reached in this study is the great capability of ancient people to classify and memorize peculiar objects and features from the natural world (like colour and texture of rocks or promontories), highlighting the exceptional ones. The results of this ability were manifold: these data were useful for navigation and mineral exploration, as well as for legitimization of a commercial/political presence in a region. In such a scenario it is difficult to categorize the Argonauts only as mineral prospectors, pathfinders or early eighteenth century-like naturalists. Rather, we conclude that the people who successfully travelled across the ancient world must have acquired all these attributes.

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Place names describing fossils in oral traditions

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Abstract: Folk explanations of notable geological features, including fossils, are found around the world. Observations of fossil exposures (bones, footprints, etc.) led to place names for rivers, mountains, valleys, mounds, caves, springs, tracks, and other geological and palaeontological sites. Some names describe prehistoric remains and/or refer to traditional interpretations of fossils. This paper presents case studies of fossil-related place names in ancient and modern Europe and China, and Native American examples in Canada, the United States, and Mexico. Evidence for the earliest known fossil-related place names comes from ancient Greco-Roman and Chinese literature. The earliest documented fossil-related place name in the New World was preserved in a written text by the Spanish in the sixteenth century. In many instances, fossil geonames are purely descriptive; in others, however, the mythology about a specific fossil locality survives along with the name; in still other cases the geomythology is suggested by recorded traditions about similar palaeontological phenomena. The antiquity and continuity of some fossil-related place names shows that people had observed and speculated about mineralized traces of extinct life forms long before modern scientific investigations. Traditional place names can reveal heretofore unknown geomyths as well as new geologically-important sites.

Traditional folk names for geological features in the landscape commonly refer to mythological or legendary stories that accounted for them (Vitaliano 1973). Landmarks notable for conspicuous fossils have been named descriptively or mythologically around the world since antiquity, and some of the old names persist in modern usage and maps. Tracing the origins of such names reveals that oral mythologies of various pre-scientific cultures can contain knowledge of significant palaeontological evidence based on repeated observations over centuries, and this lore can lead to new geological discoveries. It can also demonstrate that rational efforts to understand the meaning of prehistoric bones and other petrified remains occurred before modern scientists began to investigate the fossil record.

How far back in time can oral folklore about natural phenomena be traced? Recent analyses of geomyths describing datable geological catastrophes, such as volcanic eruptions and earthquakes, and celestial events, indicate that some traditions have been passed down orally for thousands of years (Dixon 1984, pp. 153–155, 295; Barber & Barber 2005, pp. 6–9, 178–216 and references cited; Mayor 2005*b*, pp. 97, 98–99). Fossil-related geomyths are worthy of study because they show how, before the development of modern palaeontological science in the early nineteenth century, awareness of fossil evidence led to logical scenarios about the history of the earth and perceptive pre-Darwinian insights about extinct life forms.

Named fossil sites in classical antiquity and modern Greece

Evidence for the practice of naming specific fossil locales can be found in classical antiquity. Greek and Latin sources describe several place names associated with ancient discoveries of the immense skeletons of extinct animals and the aetiological geomyths that accounted for them. Dense concentrations of oversize petrified bones led to the notion that a great battle or slaughter had taken place there in the distant past. For example, ancient Greek writers reported that the smoking earth around the city of Megalopolis (ancient Greek for 'Giant City') in the Peloponnesus, where colossal bones of unfamiliar creatures emerged, was known as the 'Battleground of the Giants'. The god Zeus was said to have destroyed the giant Titans here with lightning in the mythic era before present-day humans. The bones of 'giants' had been unearthed and displayed in the Peloponnesus since at least the fifth century BC, according to the historian Herodotus (*c.* 430 BC) and other ancient authors.

In 1902, Greek palaeontologists discovered that the smouldering lignite soil around the ruins of ancient Megalopolis contains plentiful fossils of large Pleistocene mammals, including ancestral rhinoceros and elephant species that lived about 2 million to 10 000 years ago. The fossil bones are stained dark by the lignite, which can burn and smoke for long periods of time. The discovery of very large skeletons combined with this natural

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fact gave rise to the idea of a lightning-blasted battlefield where giants were once slain. According to the ancient writers Strabo (*c.* 30 BC) and Solinus (*c.* AD 200), the 'Headquarters of the Giants' was at Pallene, on the Kassandra Peninsula in NE Greece. The ancient place name and geomyth were confirmed in 1994, when Greek palaeontologists discovered rich Pleistocene fossil beds at Pallene. In the Roman era, the discovery of steppe mammoth fossils in a river bed in what is now Syria resulted in the naming of Orontes River, after the mythical giant whose bones were supposed to have been buried there (Mayor 2000, pp. 73, 98–99, 128–29).

According to the historian Plutarch (*c.* AD 100), a conspicuous bone bed on the Aegean island of Samos was called *Panaima* ('Bloodbath', or 'Bloody Battlefield'). The name designated a large flat surface of red soil where immense skeletons continually weather out. According to myth, a violent battle between the god Dionysus's war elephants and an army of Amazons took place here, and the bloodshed was so great that the earth was stained red. Notably, the ancient Greek name for the landmark, 'Bloody Battlefield', was still preserved on seventeenth century Italian maps of Samos, with the Latin name *Guerrarii*, 'Battlefield'.

The fossil beds of Panaima, some of the most prolific in Europe, were first excavated by scientists in about 1870. The most impressive bones are those of Miocene mastodons from about 8 million years ago. The myth about Dionysus's war elephants suggests that mastodon remains were apparently recognized as those of elephants as early as the first century AD. In the late nineteenth and twentieth centuries, Greeks of Samos began to refer to the site as *Elephanton Nekrotafeion*, 'Elephants' Graveyard' (Solounias & Mayor 2005, pp. 288–293). A few kilometres west, on a mountain known as Vigla, old nineteenth-century maps indicate the place name 'Christ's Footprints'. No fossil footprints on the island are yet known to palaeontologists, but the name may refer to fossil tracks or natural depressions in rock (N. Solounias, pers. comm. 2001).

Named fossil sites in ancient and modern Asia

Traditional place names have also been related to pre-scientific fossil discoveries in Asia. In northern India, for example, the mythic battle of the great Indian epic Mahabharata was said to have taken place in the rich Pliocene fossil bone beds of the Siwalik Hills. Asthipura, 'Town of Bones', was named because of the remains, thought to be those of giant heroes and war elephants, slaughtered during the legendary war.

In ancient China, the immense skeletons of dinosaurs and early mammals were identified as the remains of celestial dragons who brought rain and provided water. A Chinese chronicle of the second century BC reported that during the digging of a canal in northern China, 'dragon bones were found and therefore the canal was named Dragon-Head Waterway'. 'Dragon bones' were ground into powder for medicine, a practice that continues today among traditional Chinese (Oakley 1975, p. 40).

Other traditional Chinese place names allude to fossil bones. The name of a small village about 48 km SW of Beijing, *Zhoukoudian*, translates as 'Chicken Bone Hill'. It is located in a region of rich fossil remains, both large and small. In this case, prehistoric rodent bones were mistaken for chicken bones. Near Zhoukoudian, *LongGuShan* ('Dragon Bone Hill or Mountain') was a place where ancient miners quarrying limestone often unearthed large petrified bones of prehistoric animals. In 1929, LongGuShan was the site of the discovery of Peking Man, *Homo erectus pekinensis* (Boaz & Ciochon 2004, pp. 3–7).

In southern Guizhou Province, in south central China, a low hill was long known as 'Lurking Dragon Hill'. The hill contains the abundant remains of exquisitely preserved, 30–36 cm long Cretaceous marine reptiles with long necks, *Keichousaurus hui*. Generations of rice farmers used to search for small dragons here, which they considered good luck: they used the fossil-bearing stone to build their homes. In about 1850, local farmers collected enough silver to buy and preserve Lurking Dragon Hill. It was not until 100 years later that palaeontologists began to study the unique fossils (Morell 2005, pp. 82–83).

Another place name with possible palaeontological associations occurs in an ancient Chinese legend about White Bone Cave on Skeleton Mountain, where dangerous 'rock spirits' were encountered (Owen 1996, pp. 771–806). The notion that spirits were transformed into rock in places whose names included words for bone and skeleton suggests that the legend was a way of explaining mysterious fossils of unfamiliar animals (a similar concept appears in some American Indian geonames, discussed later).

Fossil-related place names in Europe

In Europe, various fossiliferous localities have long been known by folk names that refer to the invertebrate or vertebrate remains found there. An example from France recalls the ancient Greek names for fossil beds that were believed hold the bones of giants. The plain in the Lower Dauphine, France, a few kilometres from St Romans, contains rich deposits of Pleistocene mastodon fossils. Since at least the 1600s, it was called *Champs des Géants* ('Field of Giants'). *Montagne des Cornes* ('Mountain of Horns') near Rennes-les-Bains in the Corbières area of southern France is a folk name that derived from abundant rudists, Late Cretaceous bivalve fossils with a conical, goat-horn-like shape. An Eocene fossil site in southern France with rich reptile and large mammal fossils was traditionally known as 'Alaric's Grave'. The people of the nearby village, La Livinière, believed the bones were those of the Visigoth king Alaric and his warriors, killed in the fifth century AD (E. Buffetaut, pers. comm. 2005). In the Middle Ages, caves and other sites containing fossils of huge Ice Age cave bears were fabled to be the dens of dragons (Abel 1914). *Drachenhöhle* ('Dragon Cave') in Austria and *Drachenloch* ('Dragon Lake') in Switzerland are two place names preserving that medieval folklore (T. Tyrberg, pers. comm. 2005).

In England, a well in Wiltshire was named for marine fossils marked with a striking star pattern. A seventeenth-century antiquarian, John Aubrey, described the well, known as Holy Well or Star Well, as a spring where 'where five-pointed stones doe bubble up' (Aubrey 1969, p. 45). According to folklore, the stars were thought to be petrified elderflowers that had fallen into the spring. But the spring flows over a fault line between the cornbrash layer of the Great Oolite and overlying clay, and the tiny stone stars are fossils continually detached by the action of the water and carried to the surface. The fossils are individual segments of the stems of crinoids, plant-like sea-creatures commonly known as sea lilies (Fig. 1). Crinoids are related to starfish, hence the star-like shape (Jordan 1998).

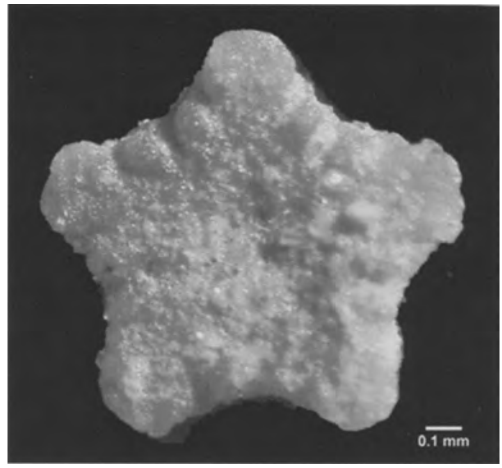


Fig. 1. Star-shaped fossil crinoid, like those at Star Well, in Wiltshire, England.

Modern American names for fossil sites

Numerous geographical names in the United States and Canada reflect fossil finds going back to colonial times. Some examples are Big Bone Lick (discussed below) and Big Bone Cave, Tennessee, where giant sloth remains (*Megalonyx jeffersoni*) were discovered in 1811. In Alaska, Big Bones Ridge and Elephant Point (named in 1826) are sites where woolly mammoth remains turned up; Dinosaur, Colorado, and Fossil, Oregon were named for nineteenth century palaeontological discoveries, as were Big and Little Lithodendron Washes in Arizona. Shark Tooth Hill in California and Shark River in New Jersey were named for abundant shark teeth, and fossil shells account for the name of Shell Canyon in Wyoming. Cliffwood Beach, New Jersey, was named for the Cretaceous petrified wood that erodes out of a seaside bluff; and Baculite Beach in Canada and Baculite Mesa and Oyster Ridge, Colorado, are so designated because of the abundance of Cretaceous marine fossils. Many other examples of colonial and modern geographical names based on fossil finds exist throughout the United States and Canada: some are translations of earlier Native American names.

Native American names for fossil sites

When searching for Native American topographical names that could be associated with prehistoric fossil remains, one must bear in mind that suggestive names in translation, such as 'skeleton', 'giant', 'skull', 'bone', and so on do not always indicate a fossil-based origin. For example, Skeleton Mountain in Calhoun County, Alabama, is a translation of a Creek Indian name for a winding stone wall atop a narrow ridge, erected by prehistoric Woodland Indian cultures, perhaps to create a snake effigy (Alabama Archaeology Society 2004). In contrast, a Yaqui Indian place name, Skeleton Mountain, described below, does refer to fossils.

Names for places in Native American cultures were often geological markers, but they also referred to conspicuous features of topography besides geology. For example, names described attributes of rivers, lakes, or mountains (such as 'stony', 'dry', or 'black'), or landform shapes that resembled animals (such as Bear Butte, South Dakota). Place names also commemorated historical and mythical events and people, indicated details of local economies such as a trading centre or hunting ground, described flora and fauna, or otherwise referred to notable things in the environment. Many place names provided a mental map of important resources or dangers (on Native American place naming, see Rydjord 1982; on traditional naming based on resemblances, see Barber & Barber 2005, pp. 97–102).

In the Western Hemisphere, conspicuous fossil remains of creatures of the Mesozoic (245 to 66 million years ago) and Cenozoic (66 million years ago until the last Ice Age, about 10 000 years ago) ages attracted attention, inspiring legends and place names. Some Native American fossil place names survive in translation only, such as 'Big Bone Creek' and 'Big Bone Lick' for the famous mastodon bone beds in the salt marshes and sulphur springs along the Ohio River. These exposures (now Big Bone Lick State Park, in Kentucky) first came to the attention of European naturalists in the mid-eighteenth century, after Shawnees, Delawares, and other tribes brought large molars and tusks to European forts. Several tribes' explanations for Big Bone Lick have survived, as discussed below.

Other place names, such as the Wyandot name for Big Bone Lick and the Hopi-named Moqui Cave in Utah (discussed below), retain the original language along with the tradition. Some Native American place names indirectly hint that a story about fossils once circulated, but is now lost. For example, the significant dinosaur tracksite in Cactus Park near Grand Junction, Colorado, lies beside a particularly large and ancient ponderosa pine tree, traditionally known to the Ute Indians as the 'Ute Council Tree'. Several sets of obvious Jurassic theropod dinosaur trackways (ranging from very large to turkey-sized) lie next to the venerable tree. They may have figured in a Ute legend that made the place an important meeting point (Lockley 1991, p. 185 and note 3).

Some Indian place names seem to indicate an awareness of fossil traces by referring to rock art that replicated genuine fossil footprints. Consider, for example, a place named by the Pit River or Achumawi people of Northern California. In 1908, the Achumawi elder Istet Woiche (born about 1840) told the traditional story of *Ja-mul dok-im-choi*, 'Coyote-man's Track', left in stone when the earth was young. On the south side of Big Bend on the Pit River, just east of Hot Springs, California, Woiche pointed out a large boulder in the gravel channel. The boulder has a noticeable depression, about 20 cm long, shaped like a man's footprint (Woiche 1992, pp. 85–160). This region of California is mostly volcanic, so fossil-bearing sediments are extremely rare, but it is possible for footprints to have been preserved in hardened lava flows. Authentic footprints of animals and people fleeing a volcanic eruption in 1790 are the subject of a legend in Hawaii (Mayor & Sarjeant 2001). Coyote-man's Track may be a natural foot-shaped depression, or the print could have been carved by an Achumawi shaman to replicate a genuine fossil footprint seen elsewhere (the Achumawi original homeland was the Southwest, where dinosaur tracks are common). It is interesting that two other California tribes, the Southern Nissenan people, and the Chumash, have myths that tell of Sky Coyote leaving pawprints and Sky Lizard leaving five-digit impressions in a large white rock in primeval times before humans (Chumash Creation Story 2003; P. Faris, pers. comm. 2005).The following sections present some traditional Native American names for scientifically recognized fossil sites, with a discussion of the associated myths from more than a dozen cultural groups, beginning with an Aztec geomyth and name that predates the Spanish Conquest in Mexico (1519), and concluding with a recent palaeontological discovery in Canada that confirms two traditional First Nations names for fossil locales.

Central and South America

In Tepexi de Rodriguez, Puebla, Mexico, *Pie de Vaca*, 'Cow's Footprint', was named for trackways of prehistoric camels that were mistakenly identified by local folk as hoof prints left by cattle (G. Callison, pers. comm. 2005). 'Enchanted Cave', near the village of Chimalacatlan in Morelos, Mexico, received its name because of the mysterious bones (of mastodons) that were excavated in the cavern by peasant farmers. In Colombia, an extensive deposit of mastodon bones near Santa Fe de Bogotá was dubbed 'Field of Giants', recalling the similarly named plain in France, above. When Charles Darwin explored deposits of enormous extinct animals of the Pampas in Argentina in the 1830s, his native guides showed him places they called 'Field of Giants', 'Mound of the Giant Creature', and 'Stream of the Unknown Animal'. In Central America, the practice of naming a place for its fossil traces can be traced back to the Aztecs.

Temacpalco. After the Spanish conquest of Mexico in 1519, some missionaries took an interest in local traditions. From about 1530 until 1580 in Yucatan, the Spanish Jesuit Bernardino de Sahagun met daily with a group of artist-scribes who were the keepers of Aztec oral history. Sahagun translated into Spanish a series of centuries-old narratives from the Aztec language, Nahuatl. His 'Historia general de las cosas de la Nueva Espana' is contained in a manuscript known as the Florentine Codex.

The Florentine Codex describes the Feathered Serpent God Quetzalcoatl's odysseys set in the twelfth century AD, around the time that the Aztecs first arrived in central Mexico. Various pre-Columbian Nahuatl place names commemorated places along the Feathered Serpent God's journeys. At one point in the myth, Quetzalcoatl stopped to rest. This spot was venerated because of 'the marks which Quetzalcoatl left upon the stone with his hands when he ... sat down'. The codex continues, 'His hands, they sank deeply; as if in mud did the palms of his hands sink down. Likewise his buttocks, as they touched the rock, sank deeply'. These marks of the god's hands and seat, the Aztecs told Sahagun, 'are clearly visible, so deeply are they' impressed in the bedrock. For centuries before the Spanish conquistadors arrived, the Aztecs had called the place *Temacpalco,* which means 'Impression of the Hands'. Temacpalco was about 19 km from Tenochtitlan, the Aztec capital (now Mexico City).

The prints were not illustrated in the Florentine Codex. The god's image combined serpent, bird, jaguar, crocodile, and human features. It seems likely that *Temacpalco* contained mysterious fossil impressions in bedrock which were explained by the myth of Quetzalcoatl resting (see Mayor 2005*a*, pp. 86–87, citing Sahagun 1970–82, book 3, part iv, p. 35, and Torquemada, *Segunda parte*, p. 50, cited by Sahagun's commentators). The sediments around Mexico City are of Pleistocene age, and may hold the tracks of large and unfamiliar Ice Age mammals, which sometimes resemble human prints. Tridactyl dinosaur footprints of various sizes have been studied by palaeontologists in the states south and west of Mexico City, in Michoacan, Coahuila, Puebla, and Oaxaca.

The Aztec myth about a god's prints in stone is not unique. For example, Aborigines point out a place on the coast near Broome, NW Australia, where the giant Emu-man walked and rested. Large feather-like fossil fern impressions in the Cretaceous-era sediments were the spots where Emu-man sat, and large three-toed dinosaur tracks on the beach show where he waded into the sea. The coastal rocks of Broome contain dinosaur prints that resemble gigantic emu tracks (J. Long, pers. comm. 2000). In North America, Delaware (Lenape) elders related their legend about Big Bone Lick to Thomas Jefferson. They maintained that one could view the impression of the Great Spirit's seat and footprints on a rock ledge. This was said to be the place where he descended and destroyed the 'Giant Buffalo' whose bones emerged along the Ohio River (Jefferson 1954, p. 43).

According to the Shawnees, impressions in rock 'like a man sitting in snow' were left by giant men who had once hunted the 'Grandfather of the Buffalo', whose great bones were found in the Ohio Valley. Besides Pleistocene fossils, this geographic region also boasts many noticeable trackways (Mayor & Sarjeant 2001; Mayor 2005*a*, p. 54 and n. 18). Similar Assiniboine and Sioux legends about seat prints in stone were collected in Montana by ethnologist Robert Lowie (Lowie 1909, p. 105). Some of these folk motifs may have been inspired by observations of fossil footprints of mammals or dinosaurs, or even impressions of dinosaur hindquarters, which have been scientifically recorded (Mayor & Sarjeant 2001, p. 157). Another possibility is the fossil of a giant turtle, whose carapace creates a large human 'sitzmark'-like impression.

The Aztec myth about Temacpalco, Impression of the Hands, is the earliest fossil-related place name recorded by Europeans in the New World. It was written down by the Spanish in about 1530, but it had been preserved in oral folklore from pre-Columbian times, originating some time after AD 1200, when the Aztecs first settled in the region of Mexico City. The following geomyth from northern Mexico was also set in the pre-Contact era.

Skeleton Mountain. The Yaqui legend about Skeleton Mountain, a sacred site in Sonora, NW Mexico, begins by explaining how a certain *kawi*, 'mountain', came to be named *Otom* or *Otam Kawi*, 'Skeleton Mountain'. Heaps of fossil bones weathered out of this and other foothills of the Sierra Madre Occidental above the Rio Yaqui (Fig. 2). The legend of Skeleton Mountain tells of an enormous raptor bird that preyed on the Yaquis' ancestors. Oral versions of the tradition were recounted by two Yaqui elders from Sonora, Mariano Tapia, born about 1887, and Refugio Savala, born in 1904.

In the legend, long ago before pueblos, the Yaqui people still lived in crude shelters made of mud and branches, cowering in constant fear of monstrous bird of prey that lived on the slopes of *Otam Kawi*. The multitude of bones and skulls spilling out of the slopes of Skeleton Mountain were said to be the victims of the raptor. A brave youth set off to destroy the bird. He dug a hole in the bone field and hid there in ambush. After he killed the huge bird, the boy led a party of elders from the Yaqui villages to see the proof of the pit he had dug and the giant creature's remains (Savala 1945).

Fig. 2. Skeleton Mountain (*Otam Kawi*), a fossil site that figured in Yaqui legend. Sonora, Mexico. Photo: D. Burckhalter.

The Yaqui legend of Skeleton Mountain accounted for the variety of fossil bones weathering out of the mountainside, and it described the discovery, by digging, of the remains of a gigantic bird. Could the tale have been influenced by ancestral memories about Ice Age teratorns, enormous Pleistocene raptors with 3.7–5.2 m wingspans which coexisted with early humans in the Americas? Teratorns and prehistoric giant condors (with a 3 m wingspan) may have been capable of grabbing children and small adults. But it is more likely that observations of petrified or mummified carcasses of immense prehistoric raptors and their bone-filled nests contributed to the tale of Skeleton Mountain.

In the 1970s in the gravel beds along Rio Yaqui below Skeleton Mountain, Mexican and American palaeontologists began to study the remains of Pliocene and Pleistocene elephants, bison, horses, and other prehistoric creatures that lived about 5 million to 10 000 years ago. The fossils wash down from the western slopes of the Sierra Madre and are frequently found by Yaqui people today on Otam Kawi and other hills. Higher up, more complete skeletons erode out of the mountainsides, and patches of earlier Jurassic–Cretaceous remains may also exist in the Sierra Madre, which could include the fossils of pterosaurs or flying reptiles (R. White, pers. comm. 2002).

Versions of the legend of Skeleton Mountain probably originated before European Contact, since it is set in the period of primitive mud and wattle shelters, before the development of sophisticated pueblo settlements. By the time the Spanish encountered the Yaqui in about 1730, the Yaqui had been living in pueblos for many centuries. The traditional account shows no European influence, and the place name *Otam Kawi* is still used today.

North America

Great Horn River. The Iroquois Confederacy, based in what is now New York State and Pennsylvania, included the Onondaga, Seneca, Cayuga, Oneida, Mohawk, and later the Tuscarora nations. The territory of the Delaware (Lenape) group, whose language was Algonquian, ranged from New York to Virginia and Ohio. Iroquois and Delaware people had long observed the fossil remains of mastodons, especially huge ivory tusks, in their territories. In Algonquian and Iroquoian languages, the word *chemung* and its variations, *shemung*, *skeemon*, *shimango*, etc. mean 'great horn'. Chemung River and Chemung County in central New York derive from the Cayuga and Seneca word *chemung*, place of the great horn. Recently, local historians reported that nine tusks have been found in the Chemung River, confirming the Indian names. The Delaware version, *shemung*, was given to the Shemung River in eastern Pennsylvania, another region where mastodon fossils occur.

The name *chemung* was undoubtedly in use before the arrival of Europeans, but the earliest documentation of the name and variations appeared in the mid-1700s. A French translation, *Chaamonaque*, occurs on a map of 1757; there is a reference to the Shemung River in Pennsylvania from 1767, and to a place called Shemung near Jamestown, Virginia in 1777 (Hilbert 1975). In about 1795 in Paris, Georges Cuvier (the father of modern palaeontology) received a letter from the American naturalist Benjamin Smith Barton stating that Delaware Indians had found mastodon molars and a 3 m-long ivory tusk in a tributary of the Tioga River, near the head of the North Branch of the Susquehanna River, in New York State. Barton wrote that '*les sauvages delawares*' called the stream *Chemung*, which he translated as 'Rivière de la Corne' or 'River of the Horn'. In 1808, Thomas Jefferson learned of a Delaware discovery of a very large spiral tusk in the same river (Mayor 2005*a*, p. 62 and n. 25).

At the time of Cuvier and Jefferson, Euro-Americans were struggling to explain the masses of mastodon fossils in America. They actively sought out Delaware and Iroquois knowledge about the bone beds, recording their traditional explanations for how these remains came to be buried in the earth. The Iroquois imagined that the tusks were the horns of huge water monsters that had lived in ages past and might still lurk in deep water. Perhaps because the Pleistocene-era mastodon bones, teeth, and tusks frequently emerge from riverbanks and marshes of the mid-Atlantic states, the Iroquois and other groups assumed that they belonged to water creatures. In contrast, the Delaware and Shawnee identified the huge remains along the Ohio River as the Grandfather of the Buffalo', viewing them as gigantic ancestors of the largest horned animal they knew, the American bison. As noted earlier, they imagined that the Great Spirit had destroyed these giant beasts with lightning before the time of present-day humans. These Native traditions provided alternatives to the biblical myth of Noah's Flood that prevailed in Europe and America until Cuvier's declaration that mastodons were the extinct ancestors of living elephants (on mastodon discoveries in colonial America, see Semonin 2000).

Witch Buffalo at Bitter Spring. The Wyandots (Hurons) of the Great Lakes area also had an oral tradition about the mastodon and other large mammal bones that lay in the salt bogs of Big Bone Lick on the Ohio River. The Wyandot legend, first written down by an ethnologist in 1850–90, identified the remains as those of 'Witch [or Spirit] Buffalo', immense bison that stood as high as trees with horns extending from their foreheads as long as a man is tall (Fig. 3). Long ago, these Witch Buffalo had dominated the 'great and ancient spring' of pure water at Big Bone Lick, forcing out smaller game animals and keeping the Wyandots from hunting or gathering salt there. At last, the Witch Buffalo were wiped out, leaving the heaps of big bones at the spring. After the destruction of the giant bison, the pure spring became undrinkable. The place where the Witch Buffalo had once reigned and then died came to be called *Oh-tseh-yooh-mah*, 'Spring of Bitter Water' (Barbeau 1994, pp. 276–278).

The Wyandot geomyth accounts for the sulphur springs, briny marshes, and masses of fossils at Big Bone Lick. Notably, among the Pleistocene animal remains along the Ohio River are the skulls of extinct giant bison with straight horns spanning 1.8 m. Apparently these remains were recognized by Wyandots, Iroquois, and other early Indian observers as much larger relatives of living bison, leading to the names 'Witch Buffalo' and 'Grandfather of the Buffalo' to refer to all of the enormous creatures that had perished there in the past.

Place Where the Great Mosquito Monster Lies. Other types of fossil remains captured the attention of Iroquoian groups. The Tuscaroras pointed out a rock near Brighton, south of Syracuse, New York, that held the tracks of the Great Spirit and of the Giant Mosquito Monster. According to David Cusick, a Tuscarora Indian who published traditional Iroquois oral chronicles in 1825, this large flying creature lived at the same time as giant bears, huge lions, and mastodons, thousands of years before the arrival of Columbus.

The Great Mosquito Monster was said to have been killed at a salt lake bed located at Onondaga, New York, known to the Iroquois as *Kah-yah-tak-ne-t'ke-tah keh*, 'Place where the Great Mosquito Monster lies'. According to another version of this legend told by the Seneca chief Cornplanter (1736–1836), long ago the Cayugas and Onondagas came to view the huge carcass. The body was bigger than a bear's and its wingspan was as long as three men. Its claws were as long as arrows and the beak was filled with sharp teeth. The Great Mosquito Monster's footprints were also pointed out: they were three-toed, like a bird's, but about 51 cm long and the trail could be followed for about 91.5 m (Cusick 1825, p. 18; Canfield 1902, pp. 59–61).

The site of the legendary monster's death, in a salt lake bed, and its physical description suggest a conflated and garbled account of various fossil types found in New York State. Raptor birds of the Pleistocene epoch had very large talons and wingspans. But the toothy beak suggests the skull of a crocodile-like reptile, perhaps a Triassic phytosaur of 200 million years ago. Another fossil possibility is the large, 'false-toothed' bird (*Pseudodontornis*) of the Pleistocene. Long-standing traditions about real raptors of the Pleistocene and Holocene, such as teratorns and giant condors—or

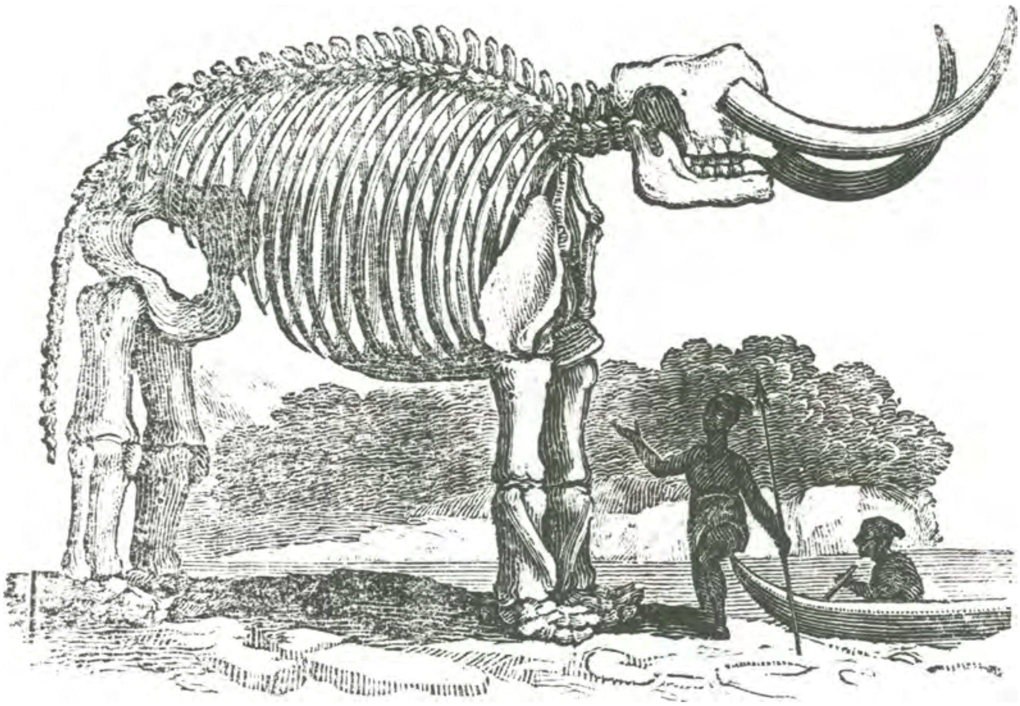


Fig. 3. Native Indians discovering a fossil mastodon skeleton along a river in the NE United States. Wood engraving by A. Anderson, for T. Bewick's *A General History of Quadrupeds*, 1804. Courtesy of Graphic Arts Collection, Department of Rare Books and Special Collections, Princeton University Library.

discoveries of their fossil remains—may have contributed to this and other widespread Native American tales of flying monsters. New evidence shows that the range of large condors extended over the North American continent until fairly recent times. For example, in 1984 palaeontologists at the Hiscock archaeological-palaeontological site in New York State discovered skeletons of very large condors along with the human artifacts (Chandler 2001).

What about the footprints of the Great Spirit and the Mosquito Monster? As noted earlier, fossil tracks of extinct mammals, such as giant sloths or bears, can resemble large human prints, and dinosaur tracks have been taken for human hand or foot prints or bird or lizard tracks (for a survey of worldwide fossil footprint lore, see Mayor & Sarjeant 2001). The large bird-like footprints near Syracuse suggest a trackway of a three-toed dinosaur, but that region is not known for Mesozoic sediments. However, tens of thousands of very conspicuous tridactyl dinosaur prints exist not far away, in the Connecticut River Valley of Connecticut and Massachusetts, and in Rockland County, southern New York. The Connecticut Valley dinosaur footprints were first noticed by white settlers in 1802, who attributed them to 'Noah's Raven' from biblical myth. Some of these large tracks were identified as *Eubrontes* dinosaur prints in 1845, and others were made by *Grallators*, theropods that lived about 200 million years ago (Fig. 4). The largest prints measure about 43 cm long, and the trackways crisscross and extend for some distance in the rock (Weishampel & Young 1996, ch. 4 and pp. 106–105; Mayor & Sarjeant 2001, p. 151).

Fossil footprints called 'Devil's Tracks' (probably a mistranslation of Indian words for 'sacred' or 'mystery' tracks) have been associated with American Indian lore since colonial times. Sites with this name occur in Long Island, New York; Montville, Connecticut; and Rhode Island. Indians of the Northeast collected rock slabs containing footprints (called *uki* stones by the Iroquois) and transported them to villages for religious purposes (B. Mann, pers. comm. 2002). The Great Spirit and the Mosquito Monster tracks may have been brought to Syracuse as *uki* stones, or they may have been man-made replicas of real dinosaur tracks, a common type of rock art across the American continent. In the eastern

Fig. 4. *Grallator* dinosaur track, like those found in the Connecticut River Valley.

United States in the 1840s, the geologist Charles Lyell investigated some bird and mammal tracks in rock in Pennsylvania and found them to be Indian carvings. Recently, archaeologists discovered a dozen isolated pseudo-fossil footprints, about 30 cm long and 13 cm deep, carved into granite outcrops (real fossil footprints are impossible in granite) across southern New England (D. Schwartz, New England Archaeological Research Association, pers. comm. 2000).

Lake of the Water Spirit's Bones. In northern Indiana, Lake Manitou, also known as Devil's or Spirit Lake, was originally called 'Lake of the Water Spirit's Bones' by Potawatomi Indians. *Manitou* means powerful nature spirit, but was translated as 'demon' or 'devil' in English, hence the numerous Spirit and Devil's lakes on US maps. Since the late 1700s, white settlers heard stories from Indians about the lake. Gigantic water monsters were said to lurk at the bottom, and huge bones appeared on the shore from time to time. The Indians avoided fishing or camping at the lake. Influenced by these eerie legends, homesteaders began to report live water monster sightings as early as 1828. Massive mastodon fossils often emerge from lakeshores and streams in Indiana, and their unfamiliar forms and dimensions apparently inspired the lake's Potawatomi name and folklore (Mackal 1980, pp. 210–211).

Wonderful Bone Creek and spirit animal mounds. The Pawnees were intensely interested in remarkable objects that stood out on the surface of the windswept prairies of Kansas and Nebraska, such as meteorites, large fossil bones, and marine fossils of striking appearance. Records going back to about 1750 show that the Pawnee name for Spring Creek, a tributary between the North Loup and Cedar River north of Grand Island, Nebraska, was *Paruksti Kisu Kitsu*, 'Wonderful Bone Creek', because of enormous, unfamiliar animal bones discovered along the creek bed (R. Echo-Hawk, pers. comm. 2002).

The rolling terrain of Kansas and Nebraska was covered by the great inland sea during the Cretaceous period (144–65 million years ago), and the distinctive chalk bluffs of the Niobrara Formation contain the petrified remains of many kinds of marine creatures, enormous mosasaurs, long-necked plesiosaurs, huge sea turtles, and large pteranodons (flying reptiles), as well as palm-sized shark teeth and countless seashells. Overlying alluvial Miocene to Pleistocene mammal deposits also dot Kansas and Nebraska. Bones of mammoths, mastodons such as *Stegomastodon* and *Amebelodon*, rhinoceros and camel species, and giant sloths continually erode out of mounds along river drainages.

Wonderful Bone Creek demonstrates that such remains commanded the attention of the Pawnees at an early date. Pawnee medicine men undertook vision quests at *nahurac* ('spirit animal') mounds along riverbanks in Nebraska and Kansas, where they encountered mysterious creatures and received special healing powers. The names of seven spirit animal mounds have been preserved. One, *Pahua* ('Hill Swimming on Water'), was on the Republican River in western Nebraska, described by Pawnee elders as a high timbered bank or island where immense petrified bones spilled out. Medicine men tunnelled into Pahua to commune with the spirit animals and giants. In about 1700, a Pawnee hunting party excavated a very large fossilized femur poking out of Pahua. This 'giant's' bone was transported back to the village and enshrined until the late nineteenth century in the Stone Medicine Bone Lodge, a society of traditional healers. Powder from the mineralized thigh bone, probably that of a mastodon or mammoth, was used to make a medicinal infusion, recalling ancient Chinese 'dragon bone' medicine (Dorsey 1906, pp. 294–295). The notion of 'spirit animals' at fossil exposures also recalls the Chinese legend of White Bone Cave and the Potawatomi legend of the Water Spirit's bones.

The traditional names for two other *nahurac* mounds also indicate early Pawnee fossil discoveries. *Nakiskat* ('White Bone Mound') was named for fossil that protruded from a high bank near the confluence of the Platte and Missouri rivers in Nebraska. White Eagle, a Pawnee elder interviewed by ethnologists in 1914, told of a great medicine man who had received his healing powers from strange creatures at *Nakiskat*. Another famed medicine man, described by the early ethnologist George Bird Grinnell, had learned his healing powers inside 'The Mound where Spirit Animals Sleep', the name for a bluff about 61 m high on the Platte River in Nebraska. Both mounds are in areas with fossil exposures (Grinnell 1928, pp. 246–247; Parks & Wedel 1985, p. 162 and n. 4).

According to Pawnee myth, before present-day people existed, the Creator became angry with the giant beings and sent flood waters to destroy them. These huge beings 'sank down in the mud and were drowned. The great bones found on the prairie are [their] bones .... We have seen big bones underground', the elders told Grinnell, and 'they convince us that giant beings did sink into the soft ground in the past'. After the destruction of the giants, said the elders, the Creator 'created a new race of men, small, like those of today' and he promised that the bones of those former powerful creatures would provide strong medicine for the Pawnees (Grinnell 1961, pp. 354–356; Dorsey 1906, p. 296).

The Pawnee names for mounds that contain 'spirit animals' and bones of 'giants' reflected their geomyth about extraordinary creatures of great magnitude that drowned and were buried in mud long ago. Petrified clams, fish, turtles, and other out-of-place sea creatures scattered across the arid prairie were evidence that the prairie was once flooded. The myth accurately envisions the vast, shallow sea that covered the Great Plains in the Cretaceous era, and accounts for the skeletons of huge marine reptiles and other large creatures that had been trapped in soft mud.

Big Bone River. According to a traditional Osage Indian oral tale first published by Albert Koch of the St Louis Museum in 1840, long before white settlers arrived in Missouri from the eastern United States, monstrous animals had invaded from the east. The animals already occupying the land of Missouri were infuriated by these intrusions, and in the valley of 'Big Bone River', in south-central Missouri, the invading monsters and the native animals assembled for a battle, in which many on both sides were killed. After the battle, according to the myth, the monsters' carcasses were buried by the Great Spirit in the Big Bone River. The myth also said that the Osage ancestors had gathered some of the bones and made burnt offerings. Every year the Osages gave offerings at a rock ledge overlooking Big Bone River and the battlefield of the monsters.

The legend was confirmed by historical palaeontological discoveries. In 1806, in Paris, Georges Cuvier acquired a mastodon molar from Big Bone River, sent to him by Benjamin Smith Barton, who earlier had reported the place name *Chemung* in New York, above. There were thousands of mastodon bones along the 'rivière des *Indiens Osages*' (the Osage River) and Big Bone River, Barton wrote. Many of the skeletons were buried in a standing position and were well preserved in peat bogs.

These rivers proved to be a rich source of fossils for early American palaeontology. In 1838, Albert Koch, inspired by the Osage oral narrative of the Battle of the Monsters, unearthed the remains of a giant ground sloth *Mylodon* on the Osage River. In 1839, with further digging along Big Bone River, Koch amassed hundreds of molars and tusks and several enormous skeletons, including a well-preserved *Mastodon americanus.* Koch dubbed one of the skeletons the 'Missourium' and exhibited it (misassembled), along with the first printed version of the Osage fossil tradition about Big Bone River, in Philadelphia, Dublin, and London (Fig. 5).

The Osage oral tradition, published by Koch in 1840, is striking on many levels. The abundance of so many large, unfamiliar bones of mastodons, giant beavers, oxen, horses, and giant sloths in the river valleys was explained by a great war between competing animals. The most productive river was known as 'Big Bone River' (it has since been renamed the Pomme de Terre River). The scenario shows that the Osage distinguished several different species of animals of a past era, a notable palaeontological perception in a pre-scientific culture. The Osage also noticed that some of the fossils seemed burnt, whereas others had sunk deep in the riverbed; thus the detail in the legend that their ancestors had burned some carcasses and the Great Spirit buried others in Big Bone River. Indeed, some *Mastodon giganteus* bones discovered in Koch's excavations were charred by fire and mixed with ashes (Mayor 2005*a*, pp. 200–207). Moreover, many of the fossils are blackened by the lignite in the peat, which makes them look burnt. This detail brings to mind the lightning-blasted 'giant' bones in the ancient Greek Battlefields of the Giants, discussed at the beginning of the paper.

Bird and lizard tracks. The Navajos and Pueblo Indians were aware of the impressive dinosaur tracks in the deserts of the Southwestern United States (Fig. 6). As noted earlier, three-toed theropod dinosaur footprints resemble avian tracks and palaeo-Indian petroglyphs and pictographs often include drawings of birds along with artistic

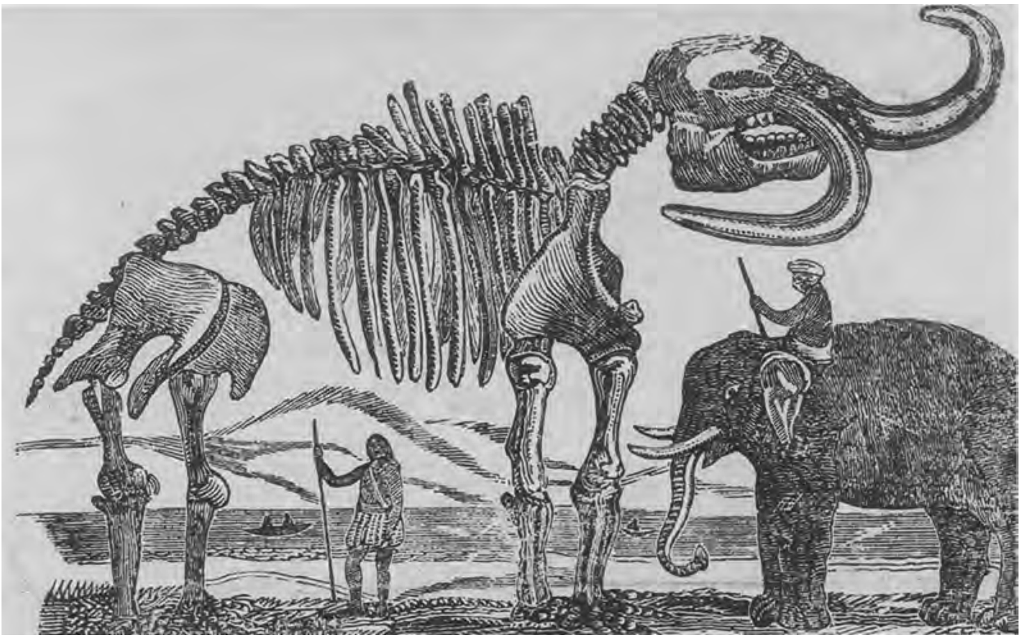


Fig. 5. Osage Indian standing under a mastodon skeleton, at Big Bone River, Missouri. From Albert Koch's exhibit in Dublin, about 1843. A version of the Osage tradition of the Battle of the Monsters at big bone River accompanied Koch's fossil displays. Courtesy of American Philosophical Society, Philadelphia.

representations of dinosaur tracks (Fig. 7). The resemblance to bird tracks is evident in the old Navajo place name for an extensive *Dilophosaurus* dinosaur trackway near Cameron, Arizona: 'Place with Bird Tracks' (Lockley 1991, p. 185).

In New Mexico, the traditional Indian name for a site near Jemez Pueblo (occupied in AD 1450–1700)

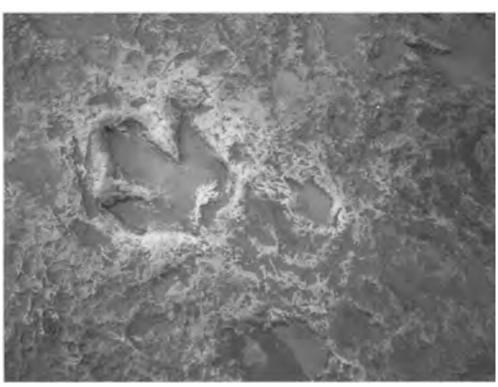
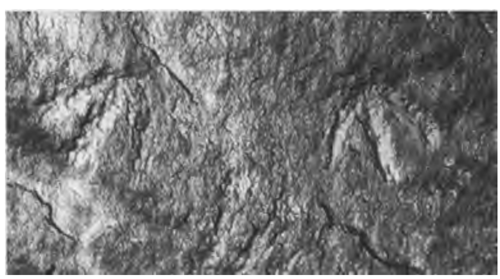
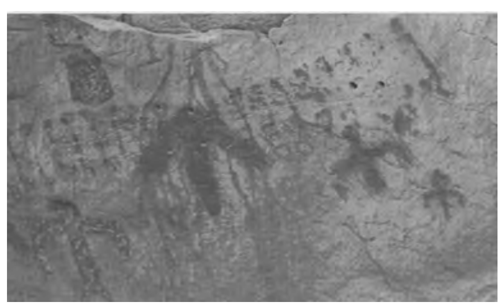


Fig. 6. 'Place of the Bird Track' was the Navajo name for a *Dilophosaurus* dinosaur tracksite, like this one near Moenave, Navajo Reservation, Arizona. Photo: A. Mayor.



ACTUAL DINOSAUR TRACK



PICTOGRAPH OF DINOSAUR TRACK

Fig. 7. Top, dinosaur footprints, Zion National Park, Utah. Bottom, Indian pictograph near the fossil tracks. Photo: G. McDonald, US National Park Service.

Fig. 8. Bechan Cave, Utah. The Navajo name *Bechan* describes the vast heaps of mammoth dung in the cave. Photo: S. Anderson, Northern Arizona University.

is *Gee-tow-ta-own-lay-new*. According to William Whatley, the tribal archaeologist at Jemez Pueblo, the name translates as 'Place where the giant stepped' (Mayor 2005*a*, p. 139 and n. 37). The San Isidro fossil beds adjacent to the pueblo contain theropod *Camarasaurus* and sauropod *Seismosaurus* dinosaur remains. The name perhaps referred to fossil footprints. The myth that once accompanied the place name is unknown.

West and north of Tuba City, beyond the Navajo village of Moenave, on the Navaho Reservation in Arizona, Ancestral Pueblo petroglyphs were carved (AD 1000–1200) on cliffs containing dinosaur remains. Later, Navajos observed the giant reptile fossils around Tuba City and Moenave, along with fossilized nests containing dinosaur eggs and hundreds of criss-crossing dinosaur tracks impressed in hardened mud. The traditional Navajo name for this place is *Naasho'illbahitsho Biikee'* or 'Big Lizard Tracks' (Tuba City 2004). In Navajo mythology, many different kinds of fearsome water monsters and other terrifying creatures had populated the previous ages before the present age. All of the monsters were destroyed by the mythical Twin Heroes and buried in the ground or else transformed into distinctive landforms.

Bechan Cave. A different sort of fossil deposit inspired the descriptive Navajo name for Bechan Cave, in southern Utah. *Bechan* translates as 'Big Faeces'. Bechan Cave, a large rock shelter in Navajo Sandstone, is renowned among palaeontologists as one of the world's most remarkable deposits of mammoth dung (Fig. 8). The cave contains more than 300 square metres of woolly mammoth coprolites (fossilized excrement) and a great amount of hair, left by the Ice Age pachyderms 12 000 years ago (Mead *et al.* 1986).

Moqui marbles. Moqui is a Hopi word that appears in several place names in Utah, such as Moqui Cave near Kanab; Moqui (or Moki) Canyon near Lake Powell; and Double Moqui, a rounded Ancestral Pueblo structure in Grand Staircase-Escalante National Monument. These places were named for unique spherical concretions called 'moqui marbles', formed of pink sand encased in a layer of dark grey-red hematite. Ranging from very small up to 20 cm in diameter, moqui marbles weather out in large numbers at the bases of Jurassic Navajo Sandstone Formation cliffs in Utah and Arizona (Fig. 9).

In the Hopi language, *moqui* means 'dear departed ones'. According to Hopi tradition, the spirits of dead relatives descend to earth at night and play games with the marbles. When they depart at dawn they leave the marbles as a reassuring sign to the living relatives that they are

Fig. 9. Moqui marbles eroding out of Navajo Sandstone Formations, Grand Staircase-Escalante National Monument, Utah. Photo: B. Beitler, University of Utah.

happy in the afterlife. The Hopi collect the marbles to honour and welcome the spirits of their ancestors. *Moqui* names designate places with great concentrations of the stony spheres.

One scientific theory hypothesized that moqui marbles were Cretaceous molluscs trapped in sand about 130 million years ago. As the molluscs decomposed, the internal liquid was drawn out, leaving hollow centres. As water filtered through the outer shell over the ages, fine pink sand filled the centres and iron deposits formed in layers around the outer shell, along with phosphorus and lime from the molluscs' shells. In 2004, some scientists proposed an alternative theory, that moqui marbles were formed about 25 million years ago from chemical reactions between bacteria in briny fluid and precipitating minerals that resulted in the layered spherical concretions. They suggested that the 'blueberry' concretions found recently on Mars were similarly formed and indicated the presence of water and bacteria. In a striking parallel to the Hopi idea that moqui marbles in the desert represented life after death, the Martian marbles are taken by scientists as a positive sign of past life on the barren planet (University of Utah 2004).

The Hopi and their Ancestral Pueblo ancestors collected other kinds of fossils, including ammonites and petrified wood, for sacred purposes. Numerous Navajo names for geological features of the Painted Desert and Colorado Plateau refer to terrible monsters killed in deep time (Mayor 2005*a*, ch. 3). This evidence of early interest in explaining geological and palaeontological features makes it likely that many other traditional Native American place names in the Southwest were inspired by observations of the large dinosaur exposures and curiously shaped invertebrate fossils that are so conspicuous in the desert.

Animal Bones Brutally Scattered About. In 1892, a University of Nebraska geologist examined the great quantities of fossils that continually eroded out of a high butte above the Niobrara River at Agate Springs, western Nebraska. The skeletons were identified as a variety of large Tertiary mammals, including rhinoceros-like brontotheres, entelodonts (giant carnivorous pigs), and chalicotheres (huge grazing beasts with claws). Beginning in 1904, palaeontologists from the Carnegie Museum (Pittsburgh, Pennsylvania), Yale University (New Haven, Connecticut) Princeton University (New Jersey), the American Museum of Natural History (AMNH, New York City), and other US institutions undertook extensive excavations at the prolific fossil site, now Agate Springs Fossil Beds National Monument. The butte, which was dubbed Carnegie Hill, produced tons of significant fossils. Huge blocks of the massed bones are currently displayed in the AMNH and other natural history museums. The animal remains on Carnegie Hill were so densely packed that single block measuring 1.5 by 2.4 m contains nearly 5000 fossil bones.

For the Lakota Sioux, Agate Springs on the Niobrara River was a traditional place for gathering food, finding special stones and bits of fossil bone for medicine bundles, and making offerings to the spirits. Long before the palaeontologists flocked to Carnegie Hill, which entombs thousands of ancient mammal fossils, the Lakota had given the butte a vividly descriptive name: *A'bekiya Wama'-kaskan s'e*, 'Animal bones brutally scattered about' (Fig. 10). It was a sacred place because of the immense bones of mysterious creatures, believed to have been fearsome monsters destroyed by lightning bolts hurled by Thunder Birds. When the earth was young, Sioux mythology visualized a cosmic battle between Thunder Birds (*Wakinyan*) and their eternal enemies, the Water Monsters (*Unktehi*). The bones of these primeval creatures had turned to stone and still littered the badlands of the western Dakotas and Nebraska. At Agate Springs, the layers of animal bones were so thick and jumbled that destruction on a very large scale

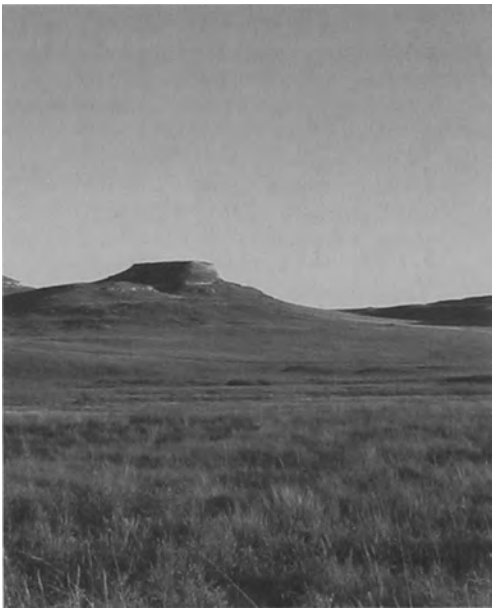


Fig. 10. 'Animal Bones Brutally Scattered About' was the Lakota Sioux name for Carnegie Hill, Agate Fossil Beds National Monument, Nebraska. The masses of Miocene animal fossils in the butte were identified as the remains of *Unktehi*, monsters destroyed by Thunder Beings, according to Lakota tradition. Photo: A. Mayor.

was imagined by both scientific and pre-scientific observers (Mayor 2005*a*, pp. 245–249).

The Racetrack. Another striking Sioux geomyth accounted for the geology and palaeontology of the Black Hills of South Dakota. The Black Hills area is surrounded by masses of vanished creatures from many eras, from dinosaurs and pterosaurs to mammoths and 'Thunder Beasts' (the Sioux name is preserved in the scientific name *Brontotherium*, a rhino-like behemoth). A curious geological depression also encircles the Black Hills. This broad valley of red siltstone erodes from the greenish Morrison Formation sediments just inside a steep ring of Cretaceous hogback ridges. The racecourse-like depression rimmed with prolific fossil beds is called the Red Valley by geologists. The feature was also noticed by the Lakota, who called it the 'Big Racetrack' (Zimmerman 2003, p. 103).

The tradition of the Big Racetrack was recounted by the Lakota storyteller James LaPointe. In the 'first sunrise of time', before the existence of the Black Hills, all the immense and strange creatures, including the *Unkche Ghila*, or dinosaurs, were summoned for a great race. A seething mass of animals covered the land, the earth shook under the pounding feet of the beasts, and the sky turned dark with circling birds. Around and around the animals raced, and as the weaker creatures were trampled the earth beneath began to 'sink crazily under their weight'. A huge mound began to bulge in the centre of the Racetrack. The rising mountain burst, spewing fire and rocks, mixing with the clouds of dust thrown up by the feet of the running beasts. The animals were felled by rocks and smothered in ashes and debris. The remains of the great Racetrack are still visible in the Red Valley around the Black Hills and the bones of all the beasts in the race for survival lie buried where they fell (LaPointe 1976, pp. 16–19, 51).

In fact, the Black Hills were formed during the Cretaceous and into the Miocene, when intense volcanic activity and tectonic forces violently uplifted a 346 m dome of granite rock, and then rapid erosion ate away the ash and soil atop and all around the dome. In the Lakota legend of the Racetrack, careful observation of geological landforms and fossils and mythical explanations can yield surprisingly accurate perceptions, in anticipation of modern geological and palaeontological knowledge.

Grandfather of the Buffalo. The concept of naming vertebrate fossils of extraordinary size the 'Giant' version of a known animal or the 'Grandfather' of a species was apparent in names for mastodon fossils, discussed earlier. The concept also appeared among the Blackfeet bands of Alberta, Canada, the Piegans. For generations, the Piegans revered an exposure of enormous skeletons in a 91 m deep ravine near the Red Deer River. In about 1860, the French explorer Jean l'Heureux accompanied the Piegans on their traditional journey to make offerings at the burial place of the 'Grandfather of the Buffalo'. Among the rocks tumbling down the ravine they pointed out the bones of a powerful animal whose vertebrae measured 51 cm in diameter. The fossil site was marked with numerous dedications of cloth and tobacco.

The bones venerated over centuries by the Piegan belonged to stupendous dinosaurs, the horned ceratopsians, duck-billed hadrosaurs, armoured ankylosaurs, and towering theropods of the Red Deer Valley. These fossils were first scientifically collected by William Dawson in 1874, Joseph Tyrrell in 1884, and Charles Sternberg and many others in what is one of the most productive dinosaur localities ever studied. The Red Deer River Canyon is now Dinosaur Provincial Park. Archaeologists have found a Piegan vision quest site overlooking the fossil-laden valley once known as the burial grounds of the buffalo's ancestors (Spalding 1999, pp. 22–23; Mayor 2005*a*, pp. 291–292).

Like the Delaware and Shawnee who believed that mastodon bones belonged to the 'Grandfather of the Buffalo', the Piegans associated the big bones of dinosaurs with the largest animal they knew. The Canadian palaeontologist David Spalding has commented that, although their interest was spiritual, their interpretation can be considered 'scientific' in that the Native observers recognized the fossil animal's great antiquity, its disappearance, and its 'possible relationship to a living descendant', impressive insights for a pre-scientific culture (Spalding 1999, pp. 22–23).

Giant Marmot tracks and monster's hip bone. In the summer of 2004, geologists surveying an isolated area in British Columbia discovered the first scientifically studied dinosaur tracks in Canada west of the Rocky Mountains. The Early Cretaceous dinosaur footprints were found in Bowser Basin north of Terrace on the Skeena River. The discovery was announced by the Royal British Columbia Museum in Victoria in September 2004, as the first evidence that dinosaurs once roamed western British Columbia. But, as reported in the *Vancouver Sun*, the tracks and bones of giant creatures no longer seen alive had long been known to the First Nations people of the region, the Gitxsan (or Gitksan). As the report relates, the traditional Native knowledge and 'wonderfully evocative names' preceded the scientific discovery of the dinosaur traces (Boswell 2004).

Those names were first recorded in writing in the 1970s, when about 100 Gitxsan elders, including Walter Blackwater, David Green, James Morrison, and David Gunanoot, identified the eminent geographical features—rivers, ridges, mountains, and valleys—of their ancestral territory. Neil Sterritt, a former Gitxsan leader and geologist who was the manager of Ksan Historical Village near Hazelton, BC, recorded and mapped the names.

Two of the Gitxsan topographical names referred to the presence of dinosaur fossils and tracks in the area. South of Panorama Lake, a mountain was named *Wii gwiikw* 'Giant Marmot', sometimes mistranslated as 'Giant Groundhog'. A ridge extending from the mountain to Muckaboo Creek NE of Meziadin was called *Wil maxhla dox hla genx wii gwiikw*, 'Where You Find the Tracks of the Giant Marmot'. The 2004 discovery of dinosaur tracks is in similar terrain just north of Panorama Lake.

The elders who told Sterritt about the tracks identified them as the prints of a giant 'Whistler', the tribe's nickname for the hoary marmot (*Marmota caligata*), a large (up to 14 kg) rodent with long curved claws and a bushy tail that thrives in the Yukon, Alaska, and the northern

Fig. 11. Hoary marmot, a large rodent that inhabits the northern Rockies, Alaska, and the Yukon. The Gitxsan place name for a set of dinosaur tracks in British Columbia, 'Where You Find Tracks of the Giant Marmot', suggests that they associated the tracks with a gigantic relative of the living species.

Rocky Mountains (Fig. 11). Unfortunately, we do not have the full myth about the *Wii gwiikw*, but the place names designating the mountain and ridge with Giant Marmot tracks show that the Gitxsan imagined that colossal relatives or 'grandfathers' of the hoary marmot had once lived. They may have perceived some similarity between tracks left by living marmots and some Cretaceous creature's footprints in stone.

Many other First Nations geomyths refer to finding the remains of very large, extinct versions of smaller living species. For example, several Canadian First Nations traditions describe the 'Giant Beaver' as the extinct ancestor of the familiar living beaver, and tell of discoveries of its bones or teeth. This accurate perception was based on observations of fossilized giant beaver species of the Pleistocene, *Castoroides* and *Palaeocastor*, which reached the size of a bear.

Another Gitxsan place name, *Gi'gai'a*, means 'Hip Bone'. A landmark in a canyon near the headwaters of the Skeena River, *Gi'gai'a* was described by the elders Gunanoot, Green, and Morrison as the pelvic bone of a 'big monster', so large that a man 'could walk right through it'. Skerritt, who mapped the traditional geography in the 1970s, believed at the time that *Gi'gai'a* was an exposure of a dinosaur skeleton. He now remarks that 'science has verified his people's oral history' (Boswell 2004; Gitxsan elders 2004). The Native observers recognized the pelvis of a dinosaur as an animal hipbone of extraordinary dimensions, but its unusual morphology led them to assign it to the anatomy of a monster unlike any known creature.

Carol Evenchick, leader of the geological crew that made the 2004 find, noted that 'the elders' accounts provide a rare and spine-tingling correlation between traditional aboriginal knowledge and scientific research'. The place name *Gi'gai'a* generated excitement among palaeontologists over the possibility that other sensational fossil discoveries will be made in the region (Boswell 2004; Gitxsan elders 2004).

Conclusions

As this brief survey of traditional folk place names describing prehistoric remains demonstrates, many pre-scientific cultures around the world observed significant fossil remains of extinct creatures over time and attempted to describe and explain them. In some cases they attempted to imagine the appearance, behaviour, and disappearance of the creatures. Some compared the anatomy to known species and thought of the vanished creatures as ancestors or giant versions of living creatures. The study of place names in fossiliferous localities helps to illuminate early evidence for human curiosity about palaeontological remains. It also helps scholars discover previously unknown geomythology and may indicate locations of important geological sites to scientists.

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Giants and elephants of Sicily

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Abstract: In Sicily, the great abundance of fascinating and impressive natural phenomena, have fed the imagination of men, who have interpreted them as the manifestation of the existence of supernatural and fantastic beings giving rise to myth and legend. Amongst these many myths, that of the cyclops Polyphemus, is closely linked to the geopalaeontological history of Sicily. The discovery, often inside caves, of the fossil skulls of elephants, in which there is a great nasal hollow (in the frontal part) where there was a trunk in life, gave rise to the belief that one-eyed giants had existed, in the past. The nasal hollow was wrongly interpreted as the orbit of a single frontal eye that characterized these monstrous beings, and the gigantic size was inferred by the notable dimensions of the skulls and the bones that are frequently found. In 1830 Giorgio Cuvier, attested to the fossil nature of the bones and put an end to the different inferences formulated about their origin.

Situated in the centre of the Mediterranean sea, a land of meeting and clash of civilizations of different peoples and cultures, Sicily has been seen as a fantastic country, characterized by a great wealth of environments and landscapes, due to the complexity of its geological structure and to the extremely varied geomorphological assessment of the island. The great abundance of fascinating and impressive natural phenomena, such as the active volcanoes, the thermal springs, and earthquakes, have fed the imagination of men, who have interpreted them as the manifestation of the existence of supernatural and fantastic beings giving rise to myth and legend.

Amongst these myths, that of the cyclops Polyphemus is closely linked to the geopalaeontological history of the island. Sicily, in the last few million years, has witnessed a succession of different animal populations. They reached the island when it was connected with continental Italy because of the eustatic oscillations of the sea level. Among the fossil remains that characterize the Quaternary faunas, it is possible to distinguish those of the elephants that, coming from Asia, populated continental Europe during the Quaternary period, even travelling to Sicily and the surrounding islands. Here, the biogeographic isolation caused the development of a dwarf size that represents a palaeontological peculiarity of Sicily, Malta, and some other islands of Mediterranean Sea.

The discovery of the skulls of such elephants, that have a large nasal hollow where the trunk was during life gave rise to the belief that one-eyed giants had existed. However, the nasal hollow was wrongly interpreted as the orbit of a single frontal eye that characterized these monstrous beings, and the gigantic size was inferred by the notable dimensions of the skulls and the bones that are frequently found.

Within the calcareous rocks in Sicily are numerous caves. These caves became preferencial places of 'preservation' of the fossil remains of the vertebrates that during the Middle and Upper Pleistocene populated the Sicilian-Maltese archipelago. The different migrations are reflected by a sequence of different faunal complexes, characterized by the presence of different kinds of elephants that were localized around 500 000 years BP (complex to *Elephas falconeri*) and around 200 000 years BP (complex to *Elephas mnaidriensis*), before man's presence in Sicily.

The last migratory wave continued up to the Upper Palaeolithic (11 000 years BP) when, depending of the lowering of the sea level, due to the Wurmian's glaciations, *Homo sapiens* reached Sicily following the great herbivores. The human presence of the Upper Palaeolithic and of the subsequent periods (Mesolithic and Neolithic) is well documented in the deposits recovered in many Sicilian caves. In addition to the burials and the skeletal rests, the remains of meals, represented by animal bones, hulls of terrestrial and sea molluscs occur in abundance as do the remains of ancient hearths with coal fragments as well as flint, in quarzite and obsidian tools. Therefore the caves had been inhabited since the Upper Palaeolithic and the Pleistocene deposits, in which the fauna was limited to great mammals. The caves were thus known to the first inhabitants of the island, who,

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coming into contact with the fossilized skulls of these elephants, began to elaborate the myth of gigantic beings endowed with single eye, precisely the Cyclops (Fig. 1).

The Odyssey: Ulysses and Polyphemus

Giants are present in the myths of almost all ancient civilizations. Nevertheless, it is certainly due to Homer that the figures of Polyphemus, have entered collective imagination. One of the principal episodes of the *Odyssey* is based on the meeting of Ulysses with one of these monstrous beings, described in the Book IX. The Greek victors, who had conquered Troy after a long siege, prepared the fleets with the sole desire to return to their country. On the way home, Ulysses' ship, surrounded by fog and darkness, ran on to some cliffs, the Cyclops' island. These giants were beings characterized by a physical particularity that, besides their strength and the superior stature, differentiated them from other human beings: they possessed only one eye in the centre of their forehead; a characteristic that, even if not clearly said by Homer, could easily be deduced from the description of the subsequent events. The event of Ulysses' dramatic meeting with Polyphemus, of his friends' tragic death, devoured by the monster, his blinding and the final escape is too well-known to recount here (Fig. 2). It is sufficient to note that the place of this fantastic meeting was situated on the eastern coast of Sicily, on the slopes of Etna so that one had identified in the stacks of Acitrezza the enormous blocks cast into the sea by Polyphemus, made insane by his blindness and by anger in the vain attempt to sink Ulysses' ship.

The charm of the whole story is such that it is easy to understand that Virgilio, several centuries later, could not resist the temptation to speak about it in his work *Aeneid*, inventing an improbable travelling companion of Ulysses (Achemenide), forgotten by the Homeric hero in the agitated escape from Polyphemus. Achemenide lives afraid of being found out and eaten by Polyphemus; he was reassured by the pious Aeneas who rescued him, and he narrates those terrible events in a story of strong pathos, where the central scene is the blinding of the monster (Fig. 3). Apart from Homer and Virgil, many other authors of antiquity treated the myth of the Cyclops.

Hesiod (seventh century BC) speaks of it in the *Teogonia*, Empedocles from Agrigento (492–433 BC) affirms that an extinct race of gigantic men existed

Fig. 1. Comparison between *Elephas mnaidriensis* skull (by Pohlig 1893) and Polyphemus' head (Second century BC, Boston, Museum of Fine Arts).

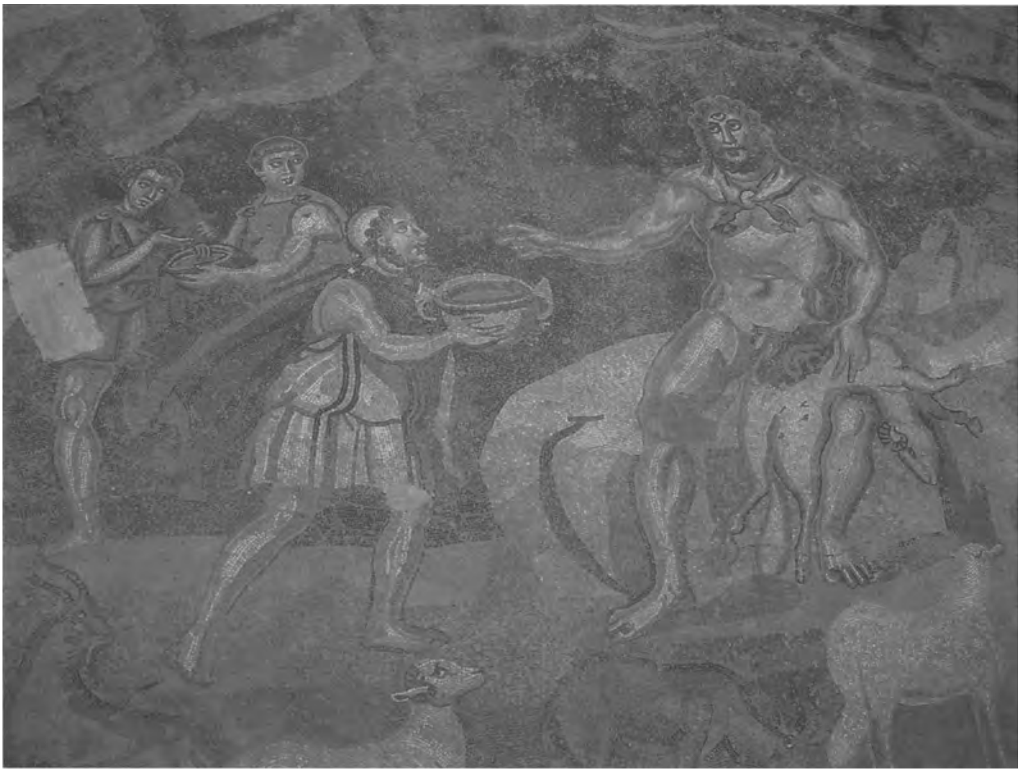

Fig. 2. Ulysses offers the wine to Polyphemus Mosaic of the Villa del Casale (Piazza Armerina, Enna).

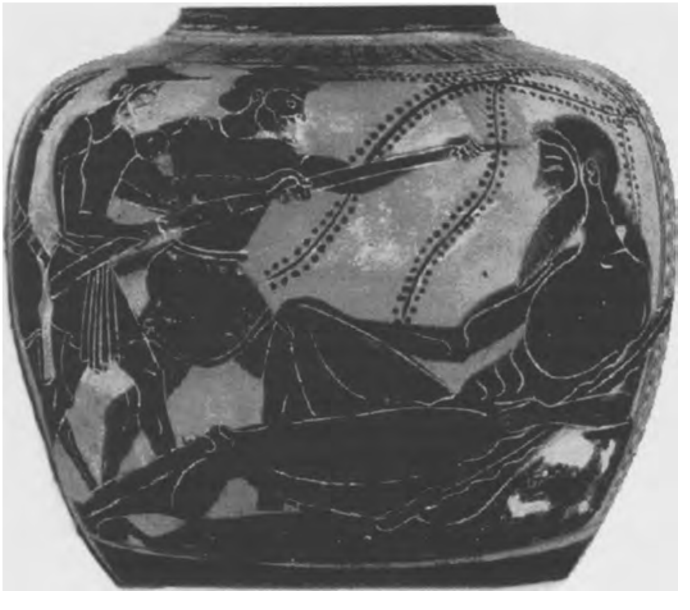

Fig. 3. Blinding of Polyphemus, vessel with black figures, 500 BC.

in the caves near the coasts of Sicily; Euripides (485/484–405/403 BC) devotes a satiric drama *The Cyclops to the Myth*, Thucydides (460–400 BC) in his *Histories*, and Ovid (43 BC – 18 AD), in his *Metamorphoses*, offer us the image of a Polyphemus refined in manners because he was in love with the nymph Galatea.

Giants of Sicily

During the Middle Ages the myth of the Cyclops was mixed with that of the existence of giants that had populated the island in ancient times. This gave birth to the myth of a stock of giants, ancestors of the present inhabitants, who lived before the Flood, whose bones can be found frequently in Sicilian caves. Giovanni Boccaccio (1313–1375), in the *Genealogia degli Dei* (1365) tells us about some remains, dating back to 1342, of a giant found in a cave situated at the foot of Mount Erice, overlooking Trapani. Some citizens were astonished by these remains and took up arms at the sight of that huge man; everything turned into dust and everyone believed they were the remains of Polyphemus or the legendary King Erice (Fig. 4).

In 1558 Tommaso Fazello (1498–1570) published a monumental history of Sicily in Palermo, in which he asserted, without hesitation, that the first inhabitants of the island after the Flood were giants that might be identified with the Cyclops who, in memory of that great flood, started living in the mountain caves, in particular on Etna. Fazello lists numerous other Sicilian places where bones of giants had been discovered: Maredolce (near Palermo), where the remains of a giant measuring 18 cubits were discovered; Gerate (Syracuse) '*un cadavere di un uomo alto 20 cubiti* (a dead body of 20 cubits)'; Petralia Sottana (Palermo) where '*dove si trovarono resti di giganti alti 8 cubiti* (the rests of giants tall 8 cubits were found)'. Other discoveries were made in the cave of Piraino (today Cave of Puntali or Armetta) near Carini (Palermo), at Calatrasi, a fortress not far from Entella (Palermo), at Mazzarino (Caltanissetta) and at Melilli (Syracuse). The authority of Fazello adds credibility to the existence of an affirmed progeny of giants that are said to have lived in Sicily before the Flood; no Sicilian researcher has doubted this belief, and the news about new recoveries of 'giants' bones' have multiplied.

The mythical culture spread, characterized by the belief that the Sicilians descend from a remote stock of giants, and that such heroic and extraordinary progeny constituted a *gloria gentium* for the whole Sicilian people. In 1614 Mariano Valguarnera (1564–1634) claimed as 'evident proof' of the antiquity of Palermo the recovery of bones of giants of immoderate greatness and Di Giovanni (1615) individualized the place '*Maredolce … essere stata abitazione de' primi giganti, che in questa nostra piana abitarono* (Maredolce has been the residence of the first giants, that lived in our plain)'.

Vincenzo Auria (1625–1710) reported in 1663 that many bones were extracted from the earth and prepared on the ground from the Cave of St Ciro '*formò l'intero corpo umano e gigantesco* (they formed the whole gigantic human body)'. In 1742, Antonio Mongitore (1663–1743) spoke of histories and of giants in Sicily. He went back to earlier stories about the recoveries of Mount Erice and narrated how the inhabitants of Erice preserved three enormous and heavy maxillary teeth of that body that were set at the foot of the Crucifix of the church of the Virgin Mary. He also told that in the village of Giuliana, the head of giant had been found inside the Convent of the Olivetani but that the boys of the place had totally destroyed it. For the author this was enough to show the existence of the giants as the first inhabitants of Sicily. Also the Villabianca (1720–1802), wrote: '*Contrada di Maredolce … celebre perchè stimata sepoltura de' giganti* (the country of Maredolce is famous because it is the esteemed burial place of giants)'; and he added '*riguardo poi alle anticaglie che assai nobilitano questo bel fonte (Maredolce), sono le grotte della sua sorgiva per esservisi ritrovato sotto l'anno 1547, … fortunatamente un cadavere di quei giganti che un dì abitarono la nostra Isola, di statura dell'altezza forse di due uomini* (as far as old curiosities are concerned these give dignity and beauty to that beautiful source [Maredolce]. Among these curiosities there are the caves of its spring where a dead body was found in 1547 … fortunately the dead body of a giant that once lived on our Island, he had the stature and the height perhaps of two men).'

Nevertheless, with the advent of Illuminism, these certainties started to change and Carlo Castone di Rezzonico (1742–1796), who visited Sicily in 1793 and 1794 represents this change. In the account of his trip he wrote how, near the village of Capaci, there were some caves where numerous bones of giants were recovered but he avoided going in because he was convinced that they were the remains of a whale or of some other sea monster.

From myth to science

On 1 April 1830 in the Giornale Officiale di Palermo '*La Cerere*' an article appeared marking the birth of vertebrate palaeontology in Sicily and it marked the passage from mythology to science. The article was by Baron Antonino Bivona Bernardi (1830). He reported the fraud that happened in

Fig. 4. The giant of Erice by Atanasio Kircher, *Mundus Subterraneus*, Amsterdam, 1678.

those months in some Sicilian fossiliferous places. For several months great quantities of fossilized bones were extracted from a deposit of bones discovered in Palermo, at Maredolce (cave of St Ciro). They were resold with a discreet profit. Although creationist, Bivona Bernardi realized that such bones belonged to animals that had become extinct at '*che al tempo del gran cataclismo, il quale estinse tutti questi animali per dar luogo a quei della creazione attuale* (the time of the big cataclysm, leaving way to those of the actual creation)'. In his subsequent articles he gave a list of recovered animals (remains of a hippo, of an elephant, of a gigantic buck, of an animal similar to the tapir, of an *elasmothrium*, a kind of horse, and of an ox similar to those of today) delineating a first scientific study. But the determinations show the effects of the lack of knowledge of the time: in fact, the only scientific works which Bivona Bernardi could find to compare the discoveries, were the works of George Cuvier and the study of Blumenbach on the primitive elephant.

Few believed the theory of Bivona Bernardi, because the legend that remains were those of hippos brought to the lake of Maredolce by the Arabs for their *naumachies* seemed more reasonable, whereas the remains of elephants were attributed to the animals used by Hasdrubal in the battle against Metello fought near Palermo in 251 BC during the first Punic War.

The bones found together with those from other caves were sent through the consul of France in Palermo to Giorgio Cuvier, who attested the fossil nature of the bones and put an end to the different inferences formulated on their origin. Cuvier, in fact, was considered a second new Aristotle whose decisions to put an end to the dispute of 1830 without the possibility of discussion. The Bourbon Government, when it knew the facts, tried to put an end to the dispersion of the fossil remains and it entrusted the Committee of Public Education to effect an excavation in the Cave of St Ciro '... *potendo quelle ossa ad oggetto servire di studio, e formare l'ornamento del museo di storia naturale nella Regia Università di Palermo* (because those bones could be used for a study, and they could form the ornament for the museum of natural history in the Royal University of Palermo)'.

The direction of the excavation was entrusted to the abbot Domenico Scinà (1764–1837) who in 1831 published '*Rapporto sulle ossa fossili di Maredolce e degli altri contorni di Palermo*', the first true scientific study on the fossil bones of St Ciro. Scinà attributed the remains of the elephant to the *Elephas primigenius*, the mammoth, the only elephant recognized by Cuvier, even if, in fact, Nesti had discovered the species *Elephas meridionalis* in 1825.

Although the mystery had been solved, the bones of the giants still stimulated the imagination of writers and poets. In fact, the news of the discovery of the bones of giants had gone beyond the island borders and in 1864 Jules Verne (1828–1905), in his *Voyage au centre de la terre* tells of a fossilized human skeleton '*of the quaternary era*' whose bones have deceived scientists for centuries: '*Io ho letto la relazione sullo scheletro scoperto a Trapani nell' XI secolo in cui ognuno ha riconosciuto in esso Polifemo, e la storia dei giganti rinvenuti nel XVI secolo nei dintorni di Palermo* ... —*Osteologia dei giganti!* ... *e io so che Cuvier e Blumenbach hanno riconosciuto in questi resti semplicemente ossa di mammuthus e di altri animali dell'era quaternaria* (I have read the relationships on the skeleton in Trapani, discovered in the XI century when everyone recognized in it Polyphemus, and the giant's history exhumed in the XVI century in the outskirts of Palermo ... —*Osteology of the giant!* ... *And I also know that Cuvier and Blumenbach have recognized in those remains simply bones of mammoths and other animals of the quaternary era*)'.

The fascinating history of the elephants

In 1867 Baron Francesco Anca, an eclectic and erudite amateur naturalist, and Gaetano Giorgio Gemmellaro, Professor of Geology at the University of Palermo, faced a problem related to the Sicilian fossil elephants. They believed that among the remains preserved in the collection of the Geological Museum at the University of Palermo, they could identify four kinds of elephantine. Among them was the living African elephant (*Loxodonta africana*), a species recognized in various parts of Italy and of Europe and that, together with the hippo (*Hippopotamus pentlandi*), would have represented the proof of a connection between Sicily and Africa (this theory was developed by many researchers of the time) which would have allowed the transit of these mammals.

Hans Pohlig (1893) and Raimond Vaufrey (1929) attributed the Sicilian elephants to the Asian kind *Elephas maximus*. They hypothesized, that such faunas had originated on the Italian continent, through connections that occurred during the lowering eustasic phases of the Pleistocene sea level, between Italy and Sicily, in the Straits of Messina. The attribution to the group *Elephas*, of the Sicilian fossil remains had already been completed by H. Falconer (1868), who had been in Sicily in 1859. He effected an excavation in the cave Maccagnone near Carini (Palermo) and found both the kind *Elephas antiquus* and the Maltese dwarf kinds, the *Elephas melitensis*. As far as the finished excavations were concerned, in 1929, in the cave of Luparello (Baida, Palermo), Vaufrey formulated a theory according to which the Sicilian fossil elephants, belonged to four different kinds, *Elephas antiquus, Elephas mnadriensis, Elephas melitensis and Elephas falconeri:* they descend, in a decreasing order, from the European elephant: *Elephas antiquus*. He was convinced that he had found the stratigraphical proof of this progressive reduction; in fact, according to the French researcher, the *Elephas mnadriensis* lay from a stratigraphical point of view below the *Elephas falconeri*, and thus was more ancient than the latter. Such a theory of the progressive reduction of size, connected with the insularity, well explained the existence of the different sizes of fossil elephants, and besides, it was framed in the gradualist Darwinian vision of the linked evolution to a narrow insular environment, characterized by the absence of predators, from the redoubled alimentary resources and from the limited genetic exchange. This theory has conditioned most of the following studies, conducted by numerous authors who have analysed the Sicilian fossil mammal faunas and particularly the elephants, often only on bibliographical bases. Osborn (1942) and Aguirre (1968–1969), proposed an African descent for the Sicilian elephants. In 1959 in the cave of Spinagallo (Syracuse), a rich layer of dwarf elephant bones was discovered; the great quantity of material allowed a detailed study of the smallest elephantine kind so that in 1968 Ambrosetti reached the conclusion that the two smallest kinds actually belonged to a single kind denominated for priority by the name of *Elephas falconeri*. This kind was characterized by an ample dimensional variability, probably due to a marked sexual dimorphism. According to these last studies the phylogenetic succession of the Sicilian elephants was fixed, from the most ancient to the most recent, in the following kinds: *Elephas antiquus, Elephas mnadriensis, Elephas falconeri*, characterized by a progressive reduction in size. In 1985 Bada and Belluomini effected an absolute dating, based on the racemization dating method of the amino acid on some elephants' molars coming from different Sicilian places. The results were confusing and they led to the overturn of the theories that had existed until then: according to the dating obtained the *Elephas falconeri* (the smallest) lived around 500 000 years ago, a long time before the *Elephas mnadriensis* (Fig. 5), which resulted of an age of about 230 000 years. The definitive confirmation of the exact succession of the elephants came in 1988, thanks to the discovery made by Burgio and Cani (1988) who studied the fossils and the stratigraphic succession in the travertine quarry of Alcamo. The travertine of Alcamo has been known from 1928, for the great abundance of the fossils of 'dwarf' elephants, but beginning from the 1970s, periodic investigation has led to new discoveries that have enriched the list of Sicilian fossils with a terrestrial giant turtle. In 1988, the demolition of a thin strip that divided two adjacent quarries brought to light a big fracture filled with red earth that formed after the deposition of travertine. The red earth contained remains of

Fig. 5. Skeleton of *Elephas mnaidriensis*. Geological Museum 'G. G. Gemmellaro', University of Palermo.

Elephas mnadriensis, the travertine that contained the remains of *Elephas falconeri*. It was therefore an incontestable stratigraphical proof that confirmed the dating of (Belluomini & Bada 1985), sweeping away any hypotheses of progressive reduction of size. This discovery put the different Sicilian elephantine faunas in the correct chronological succession and proposed a different reading of the presence of mammals in Sicily during the middle and upper Pleistocene. It delineated, in a more articulate way, a new evolutionary scenery of the Sicilian environment and of the different phases of population that have existed. In fact, in the last 800 000 years, in relation to the sequence of the geological phenomena, like tectonic rise and eustatic oscillations of the level of the sea, there has been a radical change in the animal population in Sicily. From insular faunas characterized by endemic kinds, with evident phenomena of dwarfism and gigantism and with the almost total absence of predators it passed to a very balanced fauna, in which there were predators of continental and endemic kinds. The long trip for the dwarf elephants of Sicily, from the Homeric myth to the most modern views of the palaeontological sciences seems, therefore, to have come to the end but the study of such faunas certainly does not end here; it will keep on developing new and stimulating themes of research to answer the questions that the most recent scientific discoveries have set.

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On the discovery of the ice age: science and myth

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Abstract: The discovery of the ice ages began with the invention of the Great Ice Age by Louis Agassiz, in the first half of the nineteenth century. His ideas were shaped by the interpretation of skeletons and frozen remains of large mammals found in Siberia, at the beginning of the nineteenth century. The concept of the Great Ice Age stands in contrast to earlier notions emphasizing widespread flooding, notions that owed much to the Great Flood described in the Bible, and which gave rise to geological terms such as 'diluvial deposits' and 'glacial drift'. Nordic myth as recorded in Iceland during the Middle Ages likewise contains observations and interpretations concerning the remains of giant animals emerging from frozen ground and makes reference to large-scale flooding. The ancient cosmogony related by Icelandic poets postulates the former existence of a kingdom of ice, represented by a primeval Ice Giant, whose rule is ended by the newly emerged gods. According to the myth, the melting of ice (the blood of the dying Giant) caused widespread flooding that killed the large creatures abundant during ice time.

There was a time, not so long ago (in the 19th century), when the geologically young deposits left behind by vast ice sheets originating in Scandinavia were ascribed to the Great Flood described in the Bible and earlier in the Gilgamesh Epic. These sediments, once labelled 'diluvial' have since been recognized as of glacial origin. The Great Flood, on the other hand, remains an enigmatic phenomenon. Recent explanations range from invoking a regional inundation to calling on cosmic impact. The regional scenario focuses on the drowning of settled lands on the shelf of the Black Sea as a result of the sea-level rise at the end of the last ice age (Ryan & Pitman 1998). The global scenario, put forward a decade ago, envisages worldwide flooding events resulting from huge waves generated by a series of celestial objects hitting the ocean in various places (Tollmann & Tollmann 1995). The Tollmann impact scenario may seem outlandish and entirely beyond belief. However, an analogous celestial bombing run was observed in July 1994, when the numerous fragments of a comet, on colliding with Jupiter, produced a neat row of powerful explosions within that planet's atmosphere (Burnham 1994).

The somewhat trivial lesson from the preoccupation of geologists with the Great Flood for more than two centuries is that we tend to assign meanings to ancient legends and traditions in terms of actual events. If a tradition reports that something bright fell from the sky and caused great damage (including, for example, the killing of whales), we might rightfully suspect that a comet or asteroid hit the ocean (Sagan & Druyan 1985; Baillie 1999). Similarly, if a myth reports on rivers marked by unusual stench (as does the cosmogony of the Edda), we ought to give thought to what that might mean and where we might find such rivers. This open-minded attitude allows us to take on the role of the audience at the fireplace where stories are being told by the bard. The reason why geologists are privileged, among scientists, to slip into such naïvety has to do with their training as creators of stories based on rather slim evidence (a fact remarked on by Mark Twain). For example, we can look at some piece of rock in Kansas or northern Germany, and tell a wonderful story about enormous glaciers carrying that rock over hundreds of miles, thousands of years ago.

My point is that those who reconstruct geological history are engaged in a type of myth making, an activity carrying the risk of being assigned to the lunatic fringe by the less adventurous, and yet an activity that is potentially fruitful. In recent times, the most striking example of the process whereby strange and wonderful stories about the past become textbook science is the discovery of impact as the cause of dinosaur extinction (Raup 1986; Alvarez 1997). I hasten to add that geologists are not the only scientists engaged in the sport of creating amazing stories; astrophysicists and climate historians, are also prone to contribute fantastic tales to modern scientific discussion, sometimes enthusiastically (Gribbin & Plagemann 1976; Hoyle & Wrickamasinghe 1979; Baillie 1999). Such narratives illustrate how, in our own time, scientifically trained minds attempt to make sense of complex and surprising phenomena, dimly perceived and poorly understood. One striking example of a poorly understood natural phenomenon is the disappearance of large mammals from Eurasia and North America, after the last ice age. On this issue, Darwin in his book

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Voyage of HMS Beagle remarked. 'It is impossible to reflect on the state of the American continent without astonishment. Formerly it must have swarmed with great monsters; now we find mere pigmies compared with the antecedent allied races'. (Darwin 1836, p. 170.) The former presence and subsequent disappearance of 'great monsters' has exercised storytellers for uncounted millennia well before scientists started to examine the issue.

Thus, myths of ancient giants who once roamed the earth and have long since disappeared have an element of geological truth. A search of the truth content of myths is not necessarily crowned with success. In fact, failure can be spectacular and obvious. Illustrations are not difficult to find in connection with Plato's Atlantic legend. For example, one Atlantis enthusiast took the discovery of freshwater diatoms in the tropical Atlantic off Africa (Kolbe 1955) as evidence that portions of the sea floor were once above sea level in the region. The truth is that the diatoms lived in lakes of the Sahara and were blown to sea after the lakes dried (along with silicified cells of Cyperaceae and Gramineae; Kolbe p. 160). The appearance and disappearance of lakes in the desert, of course, is a story tied to long-term climate fluctuations related to ice age dynamics. The evidence for long-term wet–dry cycles includes lake deposits, as well as pictures on rock walls of wild cattle and other animals hunted in regions now too dry to support such life (Strieder 1984).

There is no doubt that communications of our distant forebears, through myths and pictures, are more than faint echoes of archaic superstitions (Barber & Barber 2004). This is readily appreciated, for example, when contemplating the cave drawings of Altamira and Lascaux, images that show animals no longer extant. They tell us things that we cannot possibly know except from the interpretation of fossil bones. These drawings demonstrate great talent for communicating observations in a setting presumably dedicated to shamanist activities (that is, hunting magic; Kühn 1956, 1971). Beliefs about beings and events in an imaginary world, however abstruse, do not diminish the fact that the mammoths and rhinoceroses sketched on the cave walls represent animals that did once roam the region, before they became extinct (Fig. 1).

We must assume that ancient humans were keen observers of their environment, and gave meaning to their observations by linking them to their needs within the framework of their culture and traditions. How could deep insights into the workings of the world be communicated to following generations? By both creating myths and elaborating on existing myths, re-shaping them to carry the new information gleaned by the most brilliant among the storytellers. We cannot readily re-trace the emergence of myths generated in ancient cultures long extinct. But we can observe similar processes at work when Charles Lyell (1797–1875), founder of classical geology, called on ice-rafting to bring Scandinavian debris to flooded regions in northern continents, thus giving rise to the notion of 'glacial drift'. In this particular case, the story is fundamentally flawed: the sea level is low during ice ages, because some of the ocean's water is tied up in ice sheets; thus, ice-rafting and flooding of shelves are unlikely companions except during the very time of glacier decay. However, Lyell's basic premise is correct: the material was indeed transported over long distances. A subtle tie-in to the tradition of the Great Flood, modified to carry the new insight, provides the background to Lyell's interpretation (judged 'excellent' by Darwin).

Discovery of the Great Ice Age

The person commonly credited with discovering the ice age is the Swiss naturalist Louis Agassiz (1807–1873), well known as the founder of the Museum of Comparative Zoology at Harvard University (where he resided from 1848). Agassiz envisaged enormous ice sheets expanding from arctic regions deep into Europe and North America. The record of their former presence is seen in the polished rocks of deeply eroded landscapes and in the moraines rimming the formerly glaciated regions. Significantly, many of the large rocks associated with such moraines carry grooves from where they were dragged by the ice across hard ground. The rocks, which are common in northern Germany and Denmark, have long been labelled 'erratic', as they have no obvious source in the vicinity where they occur. They were used in building giant grave structures, between five thousand and four thousand years ago, and as building material all through the last millennium. Ancient legend has it that they were the playthings of giants, a notion that is reflected in common language to the present day. (In southern Sweden, the erratic rocks are 'things thrown by giants'.)

Agassiz's insights owed much to the search for causes of the extinction of large mammals, whose bones and teeth were studied by Georges Cuvier (1769–1832), the leading vertebrate zoologist of his time. Cuvier was a mentor to the young Agassiz. Cuvier discovered that the mammoth is not a representative of living elephants. He concluded that the animal must be extinct, therefore. The discovery that extinction is real was a major event in the history of geology with monumental implications for the understanding of the evolution

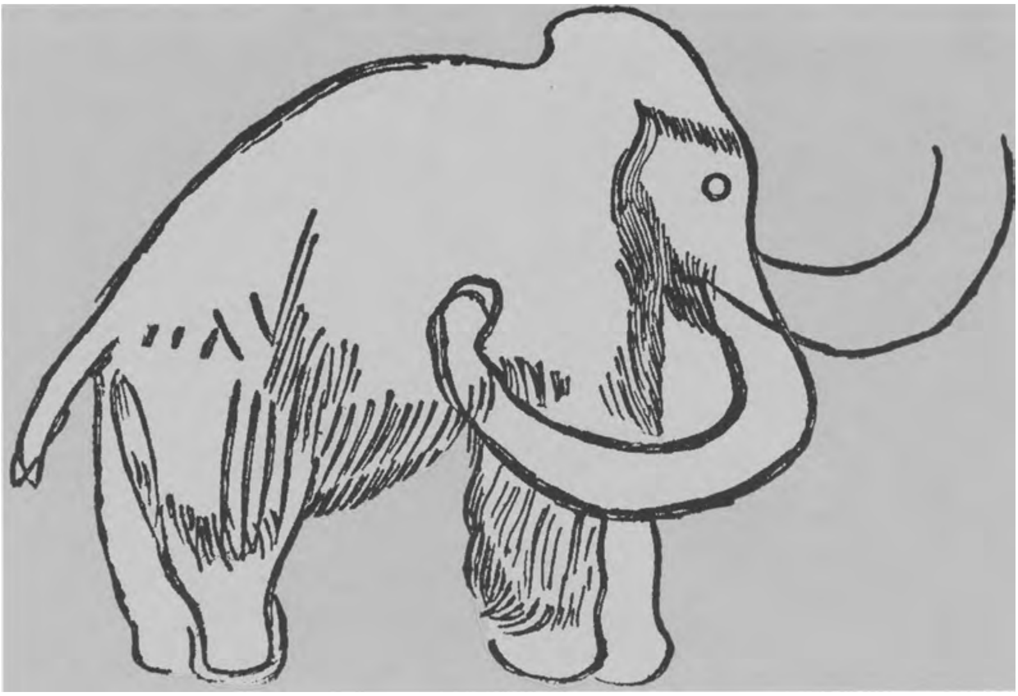

Fig. 1. Cave painting of a mammoth (Les Combarelles, near Les Eyzies, Dordogne). Image adapted from a drawing by Herbert Kühn.

of life (Rudwick 1976). In his search for possible explanations for extinction, Cuvier called on the discovery of frozen mammoth carcasses within Siberian permafrost. He surmised that an abrupt and permanent change of climate, from warm to freezing cold, was responsible for killing the elephants and for preserving them since. Also, he contemplated the inundation of low-lying regions by a rising sea as a cause for extinction. Thus, in contrast to later workers who emphasized over-hunting (Steinmann 1917; Martin & Klein 1984), Cuvier proposed environmental change as the agent of extinction. In addition, the type of change he envisioned is associated with ice age processes.

Cuvier's notion of a great inundation as a cause for extinction was soon readily adapted into the biblical flood tradition. His other concept, that of severe and sudden cooling, helped generate the idea of the Great Ice Age, which was subsequently so vigorously and successfully promoted by Louis Agassiz. Agassiz assumed that the extinct elephants, rhinoceroses, sabertooth cats and hyenas whose bones are widespread in Eurasia were tropical animals, just like their closest living relatives. Following Cuvier's suggestion, he had these large animals wiped out by the sudden arrival of a Big Freeze, which initiated the Great Ice Age. In a powerful vision, he combined Cuvier's findings with local Alpine lore about the previous large extent of mountain glaciers, to summon the destructive forces of global catastrophe (Agassiz 1866, p. 208):

> The gigantic quadrupeds, the Mastodons, Elephants, Tigers, Lions, Hyenas, Bears, whose remains are found in Europe from its southern promotories to the northernmost limits of Siberia and Scandinavia ... may indeed be said to have possessed the Earth in those days. But their reign was over. A sudden intense winter, that was also to last for ages, fell upon our globe; it spread over the very countries where these tropical animals had their homes, and so suddenly did it come upon them that they were embalmed beneath masses of snow and ice, without time even for the decay which follows death.

Thus, the same frozen carcasses in Siberia that had so intrigued Cuvier (and that had given rise to ancient legends about enormous subterranean life forms in Siberia itself) became a cornerstone of Agassiz's new theory of global glaciation. In Switzerland, where Agassiz held a professorship in Neuchâtel, he could readily verify the effects of greatly extended ice tongues, led by local observers (such as Jean-Pierre Perraudin, a Swiss mountaineer; Ignace Venetz, a highway engineer from Wallis; and Jean de Charpentier, director of the salt mines at Bex; see Imbrie & Imbrie 1979). On a much larger scale, the evidence for former glaciation of vast regions around and well south of the Baltic Sea, mentioned above, was readily available (see Fig. 2). Clearly, the erratic blocks had their origin in Norway and Sweden, and obviously some powerful agent other than rivers had to transport the largest of these. After moving to Harvard, Agassiz was able to inspect even more evidence of former glaciation, and with an even larger extent of ice than that postulated for Scandinavia. Thus, Agassiz became thoroughly convinced of the reality of the Great Ice Age, and his ideas prevailed in spite of early opposition.

The discovery of former widespread glaciation and the associated invention of the Great Ice Age was an important advance in the understanding of the origin of existing landscapes and indeed of the history of the planet. The concept of the Great Ice Age was much superior to then-prevailing ideas on landscape evolution, which relied heavily on the Great Flood. Agassiz's vision of enormous ice sheets burying much of North America and all of Scandinavia including the Baltic Sea and the North Sea was well supported by later findings. The ice sheets, as we know from geophysical evidence involving loading of the continents and their rise after removal of the load, attained a thickness of several kilometres in places. In addition, much of the northern North Atlantic was covered with ice, whether sea ice or icebergs derived from surrounding glaciers. The ground was frozen over much of middle Europe and deep into the Russian plains. The Alps were covered with thick ice, with glacier tongues extending well into Bavaria, France and Italy. It still seems reasonable today to assume, as did Agassiz, that such an environment was unable to support a rich megafauna of elephants, rhinos and bison and their predators.

Nevertheless, the Great Ice Age as promulgated by Agassiz is not really history, but a mixture of science and fantasy. The catastrophe he envisaged did not happen that way: there was no sudden change from a tropical climate to a frozen world. In addition, the onset of the ice ages some three million years ago had nothing to do with the extinction of mammoth, mastodon and woolly rhinoceros. On the contrary: the giant mammals were creatures of the ice ages, not its victims. They died out at the *end* of the last ice age. (The animals that ended up frozen are of widely different age. They had the misfortune to fall into cracks or ponds in the icy ground while foraging; see Vereshchagin 1974; Guthrie 1990.)

The one great idea that has stood the test of time was Agassiz's insistence that there had been a lot of ice around, not too long ago. With this, he set the stage for climate reconstruction in Earth history. Such reconstruction, eventually, gave rise to a geological revolution from the recognition that changes in the orbit of Earth dominate climate evolution on scales of tens of thousands of years (Milankovitch 1930; Imbrie & Imbrie 1979; A. Berger *et al.* 1984).

Recognizing that ice sheets were once widespread is one thing; realizing that ice ages came and went in a long succession is another. That successive ice ages came in regular cycles tied to Earth's orbit has only been accepted in the last few decades. The cycles in question are dominated by a 100 000-year period whose origin is still under discussion, and by regular changes in the tilt of the Earth's axis (41 000-year period), as well as by the precession of the seasons (*c.* 21 000-year period) (A. Berger *et al.* 1984). The basic idea underlying modern understanding of the ice age cycles is due to Milankovitch; he postulated that changes in seasonal contrast in the northern hemisphere represent the crucial factor responsible. The Serbian engineer Milankovitch, building on earlier work by the Scotsman James Croll (1821–1890) and advised and greatly encouraged by the German climate scientist Wladimir Köppen (1846–1940), proposed that the amount of sunlight received during northern summer at 60°N determines whether ice shields can wax or must wane. He calculated the changing intensity of insolation for the last 600 000 years, from astronomical principles governing Earth orbital eccentricity, axis tilt and precession of seasons. Matching his calculations to the observed sequences of glacial deposits, he was satisfied that his hypothesis was supported and that he had found a way to date the deposits.

An important ingredient in Milankovitch's mechanism is the precession of the equinox; that is, the fact that seasonal markers (spring and fall equinox, longest day, shortest day) migrate along an elliptical orbit. Whenever the longest day and the closest approach to the sun coincide, summer insolation is especially strong, and glaciers recede. The precession effect (about 20 minutes per year, and thus measurable in a person's life time even with simple instruments) was known to ancient astronomers and became involved in myth building about the world beyond (Barber & Barber 2004). The concept of great world cycles involving an endless alternation of catastrophic destruction and fruitful creation is familiar from Hindu cosmogony, but the time-scales do not match those of modern ice-age science. Presumably, the Hindu myth illustrates eternity in imaginative but accessible fashion, and the time-scale is chosen to be beyond human experience and comprehension.

Although Hindu myth does not anticipate Milankovitch theory in any meaningful sense, it does anticipate the scientific introduction of a realistic time-scale for geological processes by several thousand years. The originator of infinite time in geology was James Hutton (1726–1797), author of the *Theory of the Earth* (Edinburgh 1975). His rock cycle with its endless manifestations through Earth history ('no vestige of a beginning, no prospect of an end') is based on a grand vision of mythological appeal and power, rather than on observation. An alternative vision is that of the Saxon mining engineer Abraham Werner (1750–1817). In Werner's mind, Earth history moved from primordial conditions (represented by metamorphic and igneous rocks) to conditions ever closer to present ones (represented by sedimentary rocks), in well-defined steps. Werner saw Earth as an evolving system, from one era to another, a view that is in principle superior to that of Hutton's endless cycles. (Nevertheless, textbooks tend to give the nod to the scholarly Hutton over the enthusiastic Werner.)

There is a lesson for ice-age science from this ancient controversy of cycles versus history. It is that the discovery of cycles must not obscure the fact that ice ages evolve (Berger & Jansen 1994). The cycles do not really repeat even though it might seem that way (Berger 1999).

Ice age concepts in the Edda

The references to ice-age processes in Nordic myth, created by people who lived with and next to ice, are of a comparatively simple nature. They imply that ice was once widespread in Scandinavia; that freezing cold prevented settlement of the region; that 'in the beginning' the ice melted and the climate improved; that sea level rose in consequence of the melting, and that large mammals drowned in the ensuing inundation of lowlands.

In these major points, the myths anticipate many of the striking insights of the first part of the nineteenth century. In fact, the myths are closer to the truth in some aspects of ice-age lore, as when they link a sea-level rise to the melting of ice, and in placing the extinction of large mammals (referred to as ancient 'giants') into the proper time period, at the end of the ice age.

The (inferred) geological references are hidden here and there, like fossils in a dingy quarry, within the chaos of fantastic stories and strange beings that make up the world of ancient Nordic myth, as recorded in the skaldic poetry of the 'older' and 'younger' Edda, preserved in Iceland. The songs and stories of the 'older Edda' were written down between around 800 and 1250 AD, by various authors, many of whom are unknown. The 'younger Edda' was written by the poet Snorri Sturluson (1178–1241). He recorded the ancient myths to make them available for a younger generation of bards and poets, but he did so from the perspective of a Christian. There are indications that he may have re-interpreted some of the ancient myths to make them more compatible with a Christian framework (Simek 2003). However, it seems unlikely that a biblical influence could have introduced elements indicative of arctic knowledge. Thus, any ice-related lore may be confidently assigned to ancient Nordic roots.

The language of the Edda (Old Norse or Old Icelandic) is not readily accessible without intensive study. I did not attempt to read the documents in their original versions, but relied heavily on German translations. An important source for Edda poetry in German is the nineteenth-century translation by Karl Simrock, that went through many editions. The latest one of these is a modernized version edited by Manfred Stange (2004; based on Simrock 1882). Additional sources in English, German and Norwegian are listed in an earlier article on geological aspects of the Edda (Berger 1991).

A central figure in the cosmogony of the Edda is the giant *Ymir*, from whose body the world is made, upon his demise. (The concept of a cosmological human body in Indo-European creation myth is explored by Lincoln 1986.) In the Vafthrûdhnismal the origin of the world from Ymir is described thus: 'From Ymir's body was the world made, from his bones the mountains, from the skull of the frosty giant the sky, from his blood the sea.'

The appearance of *Aurgelmir*, ancestor of ice giants, involves the melting of earthy ice and rime (presumably permafrost), by warm winds from the south and by rain (in appropriate animist guise). A reference to stinking rivers (rivers of putrefaction) is reminiscent of the observation of early explorers about the stench created by the decay of giant ice-age animals exhumed in Siberian rivers. (The odour of decay is likewise remarked upon by modern explorers; Pfitzenmayer 1926; Stone 2001, p. 70.) The Edda text is quite explicit about the odious circumstances of the emergence of Aurgelmir: 'From icy ancient streams oozed puss that grew into the [ancestral] ice giant'. (Vafthrûdhnismal, answer to Odin's sixth question.)

The exhumation of seemingly newly dead bodies from the frozen ground, apparently living within the Earth and killed when seeing the Sun or the Moon, must have stimulated myth making over many millennia (Lister & Bahn 1994). Indeed, ice-earth is the site of the origin of the earliest creatures in Edda cosmogony: like Aurgelmir, the ancestors of gods and people (Buri, Burr) emerge from melting permafrost. In addition, a host of giants emerge from the body of Ymir-Aurgelmir. Presumably, the evidence for an ancient time of creation involving an abundance of giants was not difficult to find. After all, people used fossil mammoth bones as building material and for fuel (Haynes 1991).

The modern world begins with the killing of the Ice Giant Ymir-Aurgelmir by Odin and his brothers Vilje and Ve. That is, in the cosmogony of the Edda the ice has to retreat before the world is suited for people and their gods. Ymir's blood (which is explicitly related to water in the sea in the myth; Simek 2003, p. 174) pours out from the wounds and drowns the ancient giants, the children of Ymir. Both sea-level rise and the evidence for enormous floods at the rims of retreating ice sheets may have been involved in creating the myth. Observations available to all would have shown giant bones within ancient flood deposits, as well as teeth and bones along the shores of the North Sea, washed up by the waves, from areas once hosting giant animals but now under water.

According to one version of the myth, Odin and his brothers, after finishing off the primeval Ice Giant, used his body to make the earth we know, with mountains and forests and lakes and rivers and grassy fields: a place for people. To protect the people's land from unwelcome invasions of a new race of ice giants (the latter-day masters of frost), the gods built a wall around Midgard from the eyebrows of Ymir. A wall that fits the description is still clearly visible as the 'Ra' across Sweden and the 'Salpausselkae' in Finland. It is made of the moraines left by retreating ice. The arc-like forested moraines indeed look like giant eyebrows when viewed from a high vantage point. The existence of the wall identifies the geography of Midgard, the abode of people, as well as that of Utgard. Thus, 'Midgard' and 'Utgard' may not have originated as vague references to nowhere in particular (a usage suggested by Simek 2003), although poetic custom may have moved them in that direction through time.

There may be more than one way to divide the land of the ice giants from that of the gods (that is, the people). Besides the 'Wall' there is the river *Ifing*, that never freezes over. The only waterway fitting that description is the Norwegian Sea. On the other side is Greenland. There is no question that Greenland belongs to the ice giants whereas

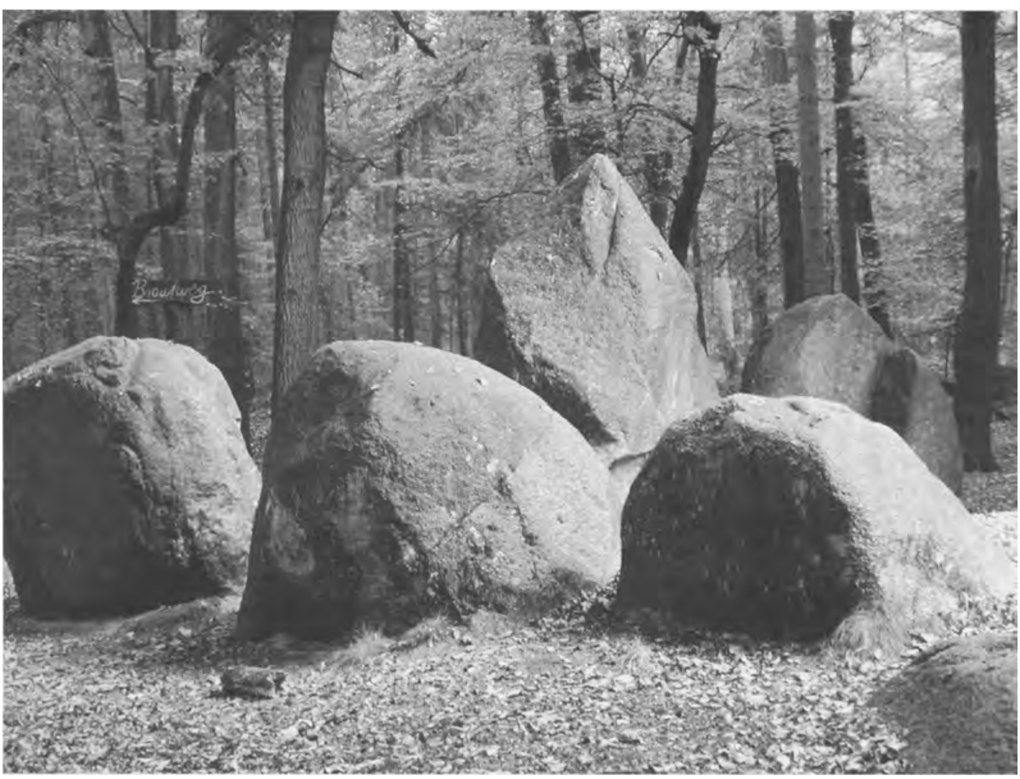

Fig. 2. Characteristically shaped erratic blocks, used in building grave mounds in prehistoric times (*c*. 5000 years ago). The local legend postulates a magic origin for the rows of boulders, which line up as if in a procession. Image W.H.B., near Visbeck, N. Germany.

coastal Norway belongs to the gods (that is, the people) after deglaciation. Thus, although the boundary between Midgard and Utgard is not uniquely defined, it has its origin in reality. Likewise, the location of the rivers of putrefaction can be readily (but somewhat vaguely) assigned to permafrost country. Presumably, this land was to the east of southern Scandinavia, suggesting a memory of an eastern origin for the people settling in Scandinavia in the middle Holocene (or in any case a strong influence of eastern cosmogony).

How old are the myths of the Edda? The answer surely depends on which parts of the collection of myths one is talking about. Like a cathedral in northern lands, the beginnings date much further back than the completion. I have argued elsewhere that at least some of the core elements (that is, cosmogony) are older than 3500 years, based on a naturalistic interpretation of the story of Ragnarok, the prophecy about the end of the world (Berger 1991). Unless evidence for a much older age than 6000 years is found, we must assume that the insights about the demise of the great primeval Ice Giant and the drowning of the giant mammals of the last ice age were derived in the same way as in the nineteenth century: by observation and speculation. By 6000 years ago, the demise of the Ice Giant had run its course and sea level had stabilized (except for isostatic adjustments and local tectonics). Modern science is still debating why the Ice Giant bled twice, with a pause of more than a thousand years separating the melting periods. One widely discussed idea is that the large-scale inflow of melt water during the first phase of melting changed the circulation of the ocean in such a way as to decrease the heat import into the northern North Atlantic, from the tropics (Broecker & Denton 1989). Even now, it seems, the concept of flooding has its uses in the attempt to explain the end of the last ice age.

Conclusions

The bones and frozen carcasses in Siberian permafrost have stimulated thinking and myth making for thousands of years. Pre-scientific thinkers generated ideas on the origin of the world from these observations. Scientists, beginning with Georges Cuvier early in the nineteenth century, were drawn to the concept of large-scale climate change, with Louis Agassiz specifically inventing the 'Great Ice Age', itself a construct of mythical appeal, to explain the observations. The link between myth and science is given by certain features within Nordic legend: the fact that the demise of an enormous ice giant delivers the means for building a new world, the fact that giant creatures emerge from frozen ground, and the reference to stinking rivers (icy rivers oozing puss) which has not been explained properly in the literature. It is the smell of decaying of carcasses emerging in riverbanks in arctic regions of Asia.

In addition, Edda cosmogony anticipates the concept that flooding was important in explaining the demise of an ancient race of giants during the termination of the rule of the Ice Giant Ymir. The core insight here is that the end of the ice age resulted in the extinction of an ancient race of ice giants, quite the opposite of the hypothesis of Louis Agassiz, but fully supported by modern dating methods. In modern science, the grand debate continues, regarding the relative importance of climate change and over-hunting at the end of the last ice age, in causing the extinction of the giant Pleistocene mammals. Presumably both factors were important. In any case, the myths have no reference to hunting; when they first emerged the great ancient giants were already extinct.

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Shepherds' crowns, fairy loaves and thunderstones: the mythology of fossil echinoids in England

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Abstract: The presence of fossil echinoids in archaeological sites in southern England that range from the Palaeolithic through the Neolithic, Bronze and Iron Ages, Romano-British to Anglo-Saxon indicates that humans have long had a propensity for collecting these fossils. The palaeo-ethnological significance of fossil echinoids can be determined from a number of criteria. The fossils may occur with the dead, either in burials or cremations, or be associated with past activities of the living. These include presence on a flint worked as a tool; artificial alteration of the fossil; association with human habitation; or occurrence outside the area of natural geological occurrence. Their archaeological association provides an indication that these fossils have been collected by people for hundreds of thousands of years and, at times, attained a high degree of spiritual significance. Moreover, recent folklore associated with them, particularly their folk names, such as shepherd's crowns, fairy loaves and thunderstones, provides a further insight into the myths that were associated with them. These indicate the use of fossil echinoids in both 'Celtic' and Norse mythologies where they played a role in resurrection myths. The occurrence of fossil echinoids in a medieval church is indicative of retention of 'pagan' belief systems in a Christian context.

Nothing is too small to inspire geomyths

Dorothy Vitaliano, Geology & Myth Symposium, Florence, 2004

People have been collecting fossil echinoids in England for an extremely long time. The earliest evidence for this activity comes from one of the few palaeontological sites in England that has yielded fossilized hominid remains that pre-date *Homo sapiens*: the Middle Pleistocene (Stage 11) gravel deposits in the Barnfield Pit at Swanscombe in Kent (Ashton *et al.* 1995). Among the many Early Palaeolithic flint Acheulian hand axes collected from these deposits (Conway *et al.* 1996), arguably one of the most significant is a partially complete axe that, at its wider base, bears the exposed lower surface of a specimen of the fossil echinoid *Conulus* (Fig. 1). The fossil dominates the axe, occupying about one-third of the face. At the centre of the circular fossil is the peristome, where the animal's mouth was located. Radiating from this, like a five-pointed star, are the five characteristic ambulacra that typify echinoids. This artifact was described by Oakley (1981, 1985) who was in little doubt that whoever knapped the flint had been attracted to it by the presence of the echinoid. What, though, did this person make of this strange shape?

This Acheulian axe is by far the earliest evidence in England of people having a predisposition to collect fossil echinoids. Similar examples have been recorded from penecontemporaneous Palaeolithic deposits in France (Oakley 1985; Poplin 1988; Demnard & Néraudeau 2001). However, there is ample evidence from the archaeological record throughout much of central and western Europe, the Near East and North Africa, that this was just the beginning of peoples' fascination with fossil echinoids. It was a fascination that led to their inclusion into a variety of myths in an attempt to explain their origins. Archaeological deposits provide firm evidence for a prolonged period of fossil echinoid collecting activity by many cultures, ranging from the Palaeolithic through the Neolithic, Bronze and Iron Ages, and into Christian and Islamic times (see Demnard & Néraudeau 2001; McNamara 2002, 2004 for recent reviews).

Exactly what did these ancient collectors make of these attractive star-crossed stones? Oakley (1965) has proposed that human fascination with fossils falls into three distinct phases. 'Although in the earliest phases of culture certain fossils were perhaps just regarded as "lucky", in more advanced phases they would be thought to contain magical power, and then, as animism gives place to belief in gods and ghosts, the fossil became a fetish, or habitat of a god; finally, when the religion decayed or was replaced by another the fetish was no longer an object of specific belief, but degenerated in folk memory to become regarded once again merely as an object conferring "good luck"...' (Oakley 1965: 10). In this chapter I will argue that evidence from the archaeological record, combined

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Fig. 1. Early Palaeolithic Acheulian hand axe with fossil echinoid (*Conulus*), from Swanscombe, Kent. Specimen in Liverpool Museum.

with the folklore associated with fossil echinoids that has been gathered in more recent times, provides some support for Oakley's proposition. Moreover, this analysis of the archaeological context in which fossil echinoids in England occur lends support to observations from elsewhere that in pre-Christian times these fossils were considered as objects of important ritualistic significance and played a part in both Norse and 'Celtic' mythologies.

The principal source of these fossils that have been collected in England from early Palaeolithic times onward are the Cretaceous chalk deposits that extend from the east Yorkshire coast, southwards through Lincolnshire and East Anglia, then southwestwards via the Chilterns and Salisbury Plain, to Devon, with two easternward extensions—the North and South Downs (Owen 1987). Extensive weathering of these deposits has produced a thin veneer of soil rich in insoluble clays and flints, derived from the chalk. It is as flint moulds that many of the fossil echinoids occur. The floor of the chalk seas between about 85 and 70 million years ago, into which one particular group of echinoids, the so-called 'irregular' echinoids, burrowed, was a soft, white ooze. Rather than being covered by only a few large, pointed spines, these irregular forms were quite different. Often egg-shaped, and with a shell (known as a test) just as fragile, these echinoids were covered by hundreds of tiny spines. After death the spines usually fell off and so are rarely found on the fossil. Like all echinoids, the characteristic feature of the test is the set of five ambulacra that radiate out from the centre of the shell, forming a distinctive star-shaped pattern. In life these were crucial to the echinoids as they carried double rows of closely spaced pores that were pierced by fleshy tentacles, called 'tube feet'. These tube feet served a whole range of functions. They were used for respiration, sensory purposes, or for secreting a thin film of mucus that formed a tent around the echinoid in its muddy burrow.

Two main types of irregular echinoids occur as fossils in the chalk deposits. One type has a test that forms a high, domed cone. These are holasteroid echinoids, the most common being species of *Echinocorys* (Fig. 2a). The other group are the spatangoids. These often possessed an almost perfect heart-shape, hence their common name of 'heart urchin'. The most common forms are species of *Micraster* (Fig. 2b). Sometimes the fossil echinoids are preserved as calcitic tests within the chalk. However, more often than not they are found as flint moulds of the hollow inside of the echinoid's dead test. One reason for the frequency with which these echinoid fossils have been found is probably their mode of life. Living completely or partially buried in mud, they were well suited to being transformed into fossils after death. Periodically, silica gel formed on the sea floor and frequently worked its way into the empty echinoid tests, where it hardened to form the flint moulds (Sieveking & Hart 1986).

To be certain that a fossil echinoid found today in an archaeological context had been previously collected at an earlier time, one of a number of specific criteria has to be met. Generally, it is dependent upon context, such as association with skeletal material and/or with artifacts. Otherwise, it is contingent upon the nature of preservation of the fossil, such as with the Swanscombe hand axe, where there is evidence for direct alteration of the rock on which the fossil occurs. Or, there may be alteration of the fossil itself. Deciding whether a fossil echinoid found at an archaeological site that is situated in chalk country was relocated at an earlier time, can sometimes be difficult. If a fossil echinoid typical of derivation from chalk deposits occurs in a

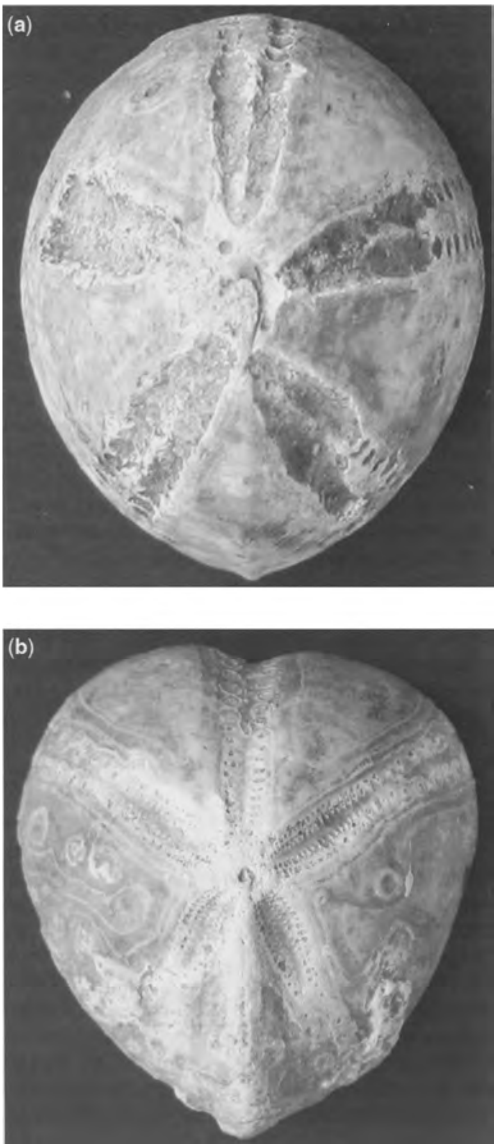

Fig. 2. (**a**) Fossil echinoid, *Echinocorys*, preserved as flint internal mould, collected as a 'shepherd's crown' by A. Smith, Linkenholt, Hampshire. (**b**) Fossil echinoid, *Micraster*, preserved as flint internal mould, collected as a 'shepherd's heart' by A. Smith, Linkenholt, Hampshire.

different geological setting, then a clearer indication of transport of the fossil is indicated. In Britain one such example is known from Scotland (Stevenson 1967), but others are known from continental Europe (Demnard & Néraudeau 2001).

Most of the described archaeological occurrences of fossil echinoids relate to their association with burials, either interments or cremations. This provides direct evidence for some kind of meaning, perhaps of spiritual significance, having been assigned to the objects, either by the deceased person themselves, or by their close associates. Some fossil echinoids show evidence of human modification. The archaeological context itself can also provide an indication of earlier fossil collecting habits. This can take the form either of unusally high accumulations, or the more specific location of the finds in relation to settlements. The archaeological context in which the echinoids are found can even, when considered in conjunction with recent folklore, help in reconstructing the myths that they engendered. McNamara (2004) has recently categorized palaeoethnological occurrences of fossil echinoids in the following way:

- *Occurrence with the dead.* One or a number of fossil echinoids may be found in close association with skeletal remains, or in a burial context. This is indicated either by the fossils occurring in close proximity to skeletal remains in a burial context or associated with cremated remains. They may also occur in so-called remembrance barrows—burial mounds that contain no skeletal remains, but items such as fossil echinoids (Demnard & Néraudeau 2001).
- *Use by the living.* Whether a fossil echinoid was previously collected and used for utilitarian, spiritual or apotropaic purposes can be shown in a number of ways.

  The fossil occurs on a rock adapted for utilitarian use. Flints knapped for use as tools may contain a fossil echinoid within the tool (see Oakley 1981).

  The fossil itself has been altered. This can be in a number of ways. It can be turned into a tool itself (see Oakley 1971; Demnard & Néraudeau 2001, Figs 9.3, 10.2). Many examples of fossil echinoids are known in which holes have been drilled (Demnard & Néraudeau 2001; McNamara 2004). The fossils might have been used as body ornaments, such as necklaces; and perforated echinoids were probably used as spindle whorls. The use of fossils for this purpose may have been as much for spiritual as for utilitarian purposes. Some echinoids show evidence of alteration by deliberate scraping, grinding or colouring (McNamara 2004). The most striking example of a fossil echinoid having been artificially altered is a specimen from Middle Kingdom deposits (about 1800 BC) in Heliopolis in Egypt. It has the name of its finder and the location of its discovery inscribed upon it in hieroglyphs (Scamuzzi 1947; McNamara 2002).

The fossil is found in association with human habitation. This may be with a normal dwelling (Field 1965) or with buildings used for worship, such as a temple (Zammit 1930).

Evidence of transport of the fossil. Here, the echinoid is found as a geologically foreign object. An example of this is the presence of Cretaceous flint echinoids in a Neolithic site at Euzenburg in Germany, which is situated on older Triassic strata (Ankel 1958).

Modification of the fossil by addition of attachments. A number of examples are known, particularly from Iron Age deposits, of fossil echinoids that had been enclosed by metal clasps. They probably served as amulets, conveying apotropaic powers, protecting the individual from evil or misfortune (Oakley 1985).

One of the earliest interpretations of these fossils as having once been living echinoids was given by the French philosopher Bernard Palissy in the sixteenth century (Palissy 1580). He recorded that '... a lawyer showed me two stones exactly similar to the form of the shell of the sea-hedgehog (echinoid). The said lawyer believed the stones to have been shaped by a mason and was much surprised when I gave him to understand that they were natural, for I had already judged them to be shells of sea-hedgehogs which in the course of time had been turned to stone.' In England, although Robert Hooke, in the seventeenth century, clearly understood the organic origin of fossil echinoids, or 'helmet stones' and 'button stones' as he called them (Waller 1705), this view did not permeate popular culture until well into the eighteenth century. Some indication of what people thought these fossils were comes from myths that were associated with them and recorded by folklorists, in particular Herbert Toms in England and Christian Blinkenberg in Denmark, in the early part of the twentieth century. More than any other fossil, echinoids have attracted a wide range of names, some of which may well have persisted for many hundreds, perhaps thousands of years. This diverse nomenclature, including names such as shepherds' crowns, fairy loaves and thunderstones, is indicative of a long heritage for this nomenclature, drawn from many different cultures, differing widely in both space and time. Moreover, it provides a pointer to the beliefs that were attached to these fossils in earlier times and an indication of how they were incorporated into aspects of Norse and 'Celtic' myths.

In this chapter, as well as briefly reviewing the archaeological evidence for an extraordinarily long association between people and fossil echinoids, I examine some of the myths associated with them that can be reconstructed from a combination of their recent folklore and by their archaeological associations. In particular, I describe the first recorded use of echinoids in a Christian context, where 'pagan' attributes of the fossils derived from associated myths were incorporated into the very fabric of a medieval church in Hampshire, and then retained even when the church was demolished and rebuilt in the late nineteenth century. This provides an insight into the perpetutation of folk concepts of these objects within a Christian context. These were objects that the community was likely to have been collecting for thousands of years, and which even today still resonate in the retention of some aspects of the mythology and folklore associated with these strange stones marked with a five-pointed star.

Archaeological evidence

Palaeolithic

Although the Swanscombe Acheulian hand axe is the only Palaeolithic example known of a fossil echinoid collected by a 'human' in England, it is of particular significance in that it represents one of the earliest known objects of any description collected for something other than purely utilitarian use. This was most likely to have been prompted by the collector's attraction to the pentameral symmetry of the fossil. Acheulian hand axes are, by definition, bifacial, being worked on both sides of the pear-shaped tool. However, the fossil-bearing specimen was never completed by its manufacturer. The last blow on one side resulted in part of the fossil being broken off (Fig. 1). Had the other side of the flint also been knapped, more of the fossil would almost certainly have been damaged. This strongly suggests that whoever collected the flint took the conscious decision not to complete the task of turning it into a functional axe, because of the likely destruction of the fossil. As well as providing a vivid insight into the workings of the mind of an individual who almost certainly belonged in a different species from us, such an interpretation implies that whoever chose this particular flint was especially attracted to it by the presence of the fossil. 'One can only speculate', wrote Oakley (1985 p. 28) 'on what significance the fossil had for the Acheulian toolmaker. Did it arouse in him an aesthetic sense, or a feeling of wonder? Did it have symbolic value?' Similarly, an Acheulian hand axe from West Tofts in Norfolk was worked in such a way as to highlight a fossil bivalve that was contained within it (Oakley 1981). Feliks (1998) has suggested that the attraction of fossils to Palaeolithic people may even have been the catalyst for the development of artistic expression that appeared in later Palaeolithic times.

What is perhaps most remarkable about the Swanscombe hand axe with the fossil echinoid is its age. The mollusc fauna that occurs in the gravels with the artifacts indicates that it is of Middle Pleistocene Hoxnian age, more specifically from oxygen isotope stage 11. This interglacial period occurred about 400 000 years ago (Gibbard 1999). The age of the deposits, and of the skeletal hominid remains that occur within them, indicate that this first English fossil collector was a member of *Homo heidelbergensis*, a species perhaps ancestral to both *Homo neanderthalensis* and *Homo sapiens.*

Neolithic

Although the occurrence of fossil echinoids collected in the later Palaeolithic has been documented from mainland Europe (Demnard & Néraudeau 2001), no further Palaeolithic examples have been recorded from England. It is not until the Neolithic that we again see evidence for fossil echinoid collecting. During excavations at the Whitehawk Causewayed Camp in Brighton in 1932–33, Curwen (1934) uncovered two graves. One contained the body of a young woman. Her only grave good was a fossil echinoid. The other grave contained another young woman, along with the remains of a baby. Here, as well as a piece of chalk and an ox bone, were two fossil echinoids, presumably one for the mother, the other for the child (Fig. 3). All three echinoids were the same type, the holasteroid *Echinocorys.* Curwen (1954, p. 82) wrote that '(h)er only "jewelry" consisted of two pieces of chalk bored through near one end so as to be worn as pendants, while two fossil echinoids, with their cruciform markings, were included in the grave, perhaps to act as charms'. Jessup (1970) has argued that evidence from other skeletal remains at the Whitehawk site suggests that cannibalism and the consumption of human brains accompanied what could have been a ritualistic, sacrifical burial of the woman and young child, the two fossil echinoids having played their part in spells or periapts.

Pull (2003*a*) recorded the occurrence of a single fossil echinoid in a barrow at Blackpatch Hill in Sussex, the site of extensive Neolithic to early Bronze Age flint mines. The echinoid was associated with a skeleton found in the barrow. Another barrow at the same site also yielded an echinoid buried with skeletons. These specimens were found by Pull in 1928 during his excavations at the Blackpatch flint mines and barrows. In another excavation in 1933 at the nearby Neoliothic flint mines at Church Hill, Findon, Pull found three echinoids associated with a cremation in a flint mine shaft (Pull 2003*a*).

Fig. 3. Skeleton of female found in Neolithic grave, Whitehawk Causewayed Camp, Brighton, with fossil echinoid (*Echinocorys*). Photo courtesy of Brighton Museum.

Bronze Age

Two examples are known from the Bronze Age. During the excavation of a barrow in 1853 on Ashey Down on the Isle of Wight, by the aptly named Dr Benjamin Barrow, a single fossil echinoid was found, along with some burnt bones and a bronze dagger (Evans 1897). By far the most spectacular find, though, was from a circular Bronze Age barrow on the downs above Dunstable in Bedfordshire (Smith 1894). Early in 1887 Worthington Smith excavated the grave of a young woman who, like those at Whitehawk, was probably aged in her twenties, along with the diaphanous bones of a young child. Accompanying the skeletons were a large number of fossil echinoids, both the heart urchin *Micraster* and *Echinocorys* (Fig. 4). 'At first', wrote Smith (1894, pp. 336–7), 'twelve were detected surrounding the girl, but at last, on extending the grave, nearly 100 were found. On repeatedly shoveling and raking over the earth from the entire tumulus [which had contained a

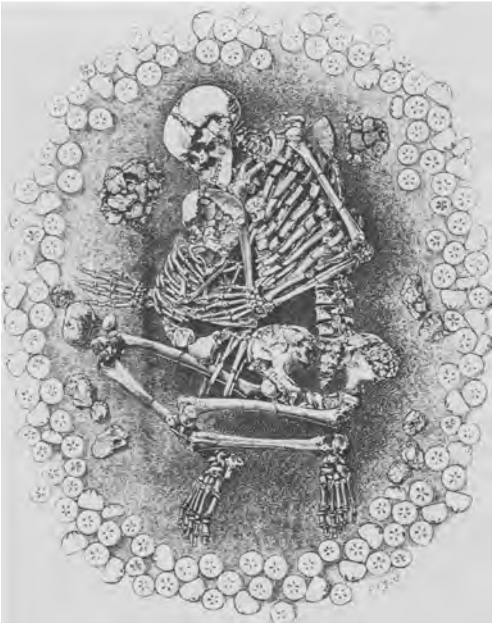

Fig. 4. Skeleton of female and child found in Bronze Age grave on Dunstable Downs with hundreds of fossil echinoids. From Smith (1894).

number of graves], 200 or more were found and most of these, undoubtedly, originally belonged to the girl's grave, as none were found in the other graves.' It is not clear whether the 200 included the original 112 or represent an additional 200, making a total in excess of 300. Either way it is an extremely large number of these fossils to be found associated with one burial. Dyer (1978), in his excellent biography of Smith, records fewer fossils as having been found. Following the discovery of the initial 12, he described Smith as finding 'another 91, making 103 in all' and that these came from 'the earth that was thrown out of the entire barrow'. Interestingly Smith, a meticulous and careful artist, depicts 147 in his engraving of the skeleton (Fig. 4). Dyer (1978, p. 156) considered that 'Smith saw the fossils as charms to keep evil spirits from the barrow'.

Iron Age

The clearest link between an archaeological occurrence of a fossil echinoid and recognizable mythology associated with these objects is from an Iron Age burial site on the outskirts of Tunbridge Wells in Kent. During construction of a house in the first decade of the twentieth century a small grey pot was found, within which were found a fossil heart echinoid assignable to the genus *Micraster*, and a broken polished flint axe (Fig. 5). The catalogue card from the Tunbridge Wells Museum, where these specimens are kept, records the following details:

'Small Pot, 3.5″ × 4″ greyish black coarse paste, softish, found in August 1910 by workmen Mercer & Crittenden 2′6″ below the sirface (sic.) while digging foundations of "Hillgarth" at corner of Powdermill Lane & London road. It held the broken half of a polished flint Axe & a fossil Sea urchin (*Micraster*). Three ft away was a large Urn with burnt bones in it, it was "at least 15 in wide & had a cover" (I saw Mercer in 1930 who confirmed this account J.C.M.G.) The large Urn was retained by the owner of the house & afterwards broke & lost (Tattershall Dod).

The rim was a little deficient in one place. Taken to the British Museum. Mr Reginald Smith who dated it La Tène I circ. 300 BC he had rim repaired.'

In Denmark in the early twentieth century Blinkenburg (1911) recorded that both fossil echinoids and flint axes were known as thunderstones, folklore that also persisted at this time in parts of southern England (Toms 1926; see below). This, perhaps, explains the association of these two seemingly disparate objects.

Romano-British

A number of examples of fossil echinoids have been recovered from Romano-British sites. During his extensive excavations at Cranborne Chase in Wiltshire in the 1890s, Pitt-Rivers' team uncovered a disproportionately high number of fossil echinoids, 42 in total. Pitt-Rivers (1887–1898) was of the opinion that such a concentration far exceeded the likely natural occurrence. He considered that the fossils might have been used as a means of bartering. During the excavation of two pits at the same site that contained human remains, fossil echinoids were found. Again the link with newborn babies is apparent here, for in one grave were found the skeletons of a newborn child and a premature infant, along with a single fossil echinoid; while in the other were the skeletal remains of two adults and a newborn child, plus a fossil echinoid. Coins found at the excavations suggest burial between the first and third centuries AD. Graves of a similar age at Frilford in Berkshire yielded a number of skeletons with which fossil echinoids had apparently been placed, some opposite certain joints of the skeleton (Dudley-Buxton 1920).

At this time people were also placing fossil echinoids in the foundations of their dwellings. Excavations at Studland in Dorset of a number of cottages and huts show that over a period of occupation of about 400 years from the mid-first century through to the fourth century, in a sequence of six dwellings on the same site, fossil echinoids occurred in each dwelling (Field 1965). In one,

Fig. 5. Fossil echinoid (*Micraster*) and broken stone axe and Iron Age pot in which they were found near Tunbridge Wells. Specimens in Tunbridge Wells Museum.

the echinoid was under a stone wedged against an inner post, suggesting deliberate burial. At other levels, echinoids were found directly on top of others placed there at earlier times. This is suggestive of a ritualistic placement of the fossils. It is perhaps significant that all the echinoids were *Echinocorys*, a helmet-shaped echinoid that would have resembled the shape of the huts. Six echinoids found in a settlement of similar age in Arundel Park in Sussex were also probably deliberately placed there (Frazer Hearne 1936).

Anglo-Saxon

By Anglo-Saxon times people were still occasionally being buried with fossil echinoids. Meany (1981) records a grave at a pagan Anglo-Saxon period site at Westgarth, Bury St Edmund's Suffolk. Here, the skeleton of a woman was found clutching a fossil *Echinocorys* in her right hand. Meany also reports the presence of a fossil echinoid in a 'rich woman's grave' at Sarre, Kent; this was dated as from the sixth century AD. In a grave of the same age at Chatham Lines in Kent, Douglas (1793) found a fossil echinoid, which he described as '*Echinus Latoclythus* or button-stone' (but which is probably referable to the regular echinoid *Cyphosoma*; Meany 1981, p. 117) with an amber bead by the side of a skeleton. This is the oldest recorded palaeoethnological example of a fossil echinoid found in England. Douglas believed that it was placed in the grave intentionally: 'On the first discovery of this fossil, I considered it as having been thrown into the grave with the adventitious soil; but as it was a petrefaction of the yellow silex, and therefore heterogeneous to the black siliceous (sic) and white sparry echinites found in the chalk, its native bed having been of loam and gravel; and from its position also in the grave, among other relics deposited with the body, I am inclined to believe it was an amulet carried about the person whilst alive'.

Another example of this type of fossil echinoid (British Museum specimen reg no. 1963, 11–8, 334) was found in a seventh century Anglo-Saxon grave at Buckland, Dover. Attempts were made to bore into the echinoid, perhaps with the intention of wearing it as a bracelet or amulet (Angela Care Evans pers. comm. 6/4/1990).

If a fossil echinoid has been artificially altered it is likely to have been collected previously. The most common form of alteration was by drilling a hole through the centre of the fossil echinoid. This practice was carried out on regular echinoids that had a circular outline. Although only one such specimen has been found in England, they occur commonly in Neolithic to Iron Age deposits in France, north Africa and the Near East (Demnard & Néraudeau 2001; McNamara 2002, 2004). The single English specimen from Gloucestershire was reported by Akerman (1856), as a '*vorticellum*, or Spindle-whirl, formed of the lower portion of the flint cast of an echinus (*Galerites albo-galerus*)'. The age of the deposit from which it was derived is unknown.

Such drilled echinoids were thought to have been used as spindle whorls, rather than as being worn as amulets. It is possible that they served both a practical and a symbolic function (McNamara 2004). This view is supported by the discovery of a spindle whorl of Romano-British age in Woodhouse, Northumberland. Looking remarkably like a cidaroid echinoid, complete with nipple-like tubercles in addition to five sinuous ambulacra. But rather than being the fossil itself, this spindle whorl was made from lead, but manufactured to look like a fossil echinoid (Oakley 1985).

The mythology of fossil echinoids

'Celtic' myths

One way of discovering the meaning behind the symbolism that was attached to fossil echinoids by early people and the myths that were associated with them is from the folklore that has been passed down to more recent generations, and from the names that have been attached to them. Although there is a clear Norse influence in the mythology associated with fossil echinoids, there was another association with what may loosely be termed 'Celtic' myths. These may well have had their origins much earlier, in Bronze Age or even Neolithic times. In England, one of the few people who assiduously collected the folklore associated with these fossil was Herbert Toms, a curator in the Brighton Museum during the first part of the twentieth century. His one publication on the subject was a short article in a newspaper called the *Downland Post* in 1926. However he frequently lectured on this subject and the unpublished notes from one of his lectures (Toms 1940) provide additional information on the folklore attached to fossil echinoids in southern England during the early part of the twentieth century.

Toms (1926, 1940) recorded that probably the most common name applied to these fossils, especially in Sussex, was 'shepherd's crown'. This view was supported by Pull (2003*b*) in a survey of folk belief in fossil echinoids that he carried out in the late 1930s in Sussex. Toms' view at this time was that there was little evidence to suggest that this name was restricted to any one type of echinoid, being generally applied equally to the two most common types, species of the heart-shaped echinoid *Micraster* and the helmet-shaped echinoid *Echinocorys*. However, by the time of his last talk on the subject, in January 1940, he felt that the name was applied more often to the helmet-shaped *Echinocorys scutata*. Use of the name 'shepherd's crown' was widespread across southern England, Toms recording it in Sussex, Dorset, Wiltshire, Hampshire and Berkshire (and indeed it is still used today in some areas, such as northern Hampshire).

Toms posed the question of why these fossils were given such an unlikely name, but could never come up with a satisfactory answer. Neither the heart-shaped *Micraster* nor the helmet-shaped *Echinocorys* show any resemblance to a crown, shepherd's or any other. The only suggestion concerning the derivation of the name 'shepherd's crown' was proferred by Oakley (1985), relating to an eleventh or twelfth century carving from Autun Cathedral in France. The depicted figure is wearing what appears to be a woollen cap. Because of its conical shape it has a vague resemblance to a specimen of *Echinocorys*. This, Oakley considered, is what gave the name 'shepherd's crown' to fossil echinoids. Apparently in the Middle Ages until Tudor times, shepherds often wore such a cap. A major problem with this interpretation is that the areas where sheep generally graze are grasslands, not the most productive areas for yielding fossil echinoids. On the contrary, as Toms (1926) indicated, it was more likely that the fossils would be found in ploughed fields. And why a crown? Fossil echinoids bear little resemblance to a crown. One possible, but unlikely, explanation (Bassett 1982) is that the distinctive pattern of five, radiating rays, most obvious in *Echinocorys*, resembles the supporting arms on crowns worn by the monarchy in medieval England.

Shepherds appeared in other common names for fossil echinoids. Around Ipswich in East Anglia, Toms (1940) found that fossil specimens of *Echinocorys scutata* were more prosaically called 'shepherds' hats'. In Brighton species of the heart echinoid *Micraster* were also known as 'shepherds' hearts'. A conical echinoid from the Chalk deposits, called *Conulus*, was named 'shepherds' knees' in Rodmell in Sussex. Species of *Micraster* were sometimes simply 'knee-caps' in the Burgess Hill district, but 'beggarman's knee-caps', 'beggarman's knees' and 'bishops' knees' in different parts of Sussex. Bishops turn up again in 'bishops' mitres', a name sometimes applied to the dome-shaped *Echinocorys* echinoids in some parts of Devon. Many of the other names applied to fossil echinoids in England were more localized in their usage. In northern Hampshire in 2001 the heart-shaped *Micraster* is sometimes called a 'sheep's heart', a name, as far as I am aware, not previously recorded in the literature. The similarity to 'shepherds' hearts', suggests a possible derivation from this source. In this area only *Echinocorys* is known as a 'shepherd's crown' (B. Smith, pers. comm.).

The other dominant name, apart from 'shepherd' that is associated with fossil echinoids in southern England is 'fairy'. There is, I believe, a link between these two, which provides an insight into the myths that were associated with these fossils. In the Isle of Wight they were once known as 'fairy weights' (Toms 1940). Fairies also appear in a name that was used, particularly in Essex, in relation to *Echinocorys*, as 'fairy loaf', or more rarely 'fairy head'. Toms (1940) recorded this name as having been used in Dorset in the 1870s. Oakley (1985) received a letter in the 1940s pointing out that the name 'fairy loaf' was used to describe flint echinoids found in the gravels in the London area, Berkshire and Surrey at that time. In Suffolk fairies were called 'farisees', thus the fossil echinoids were known as 'fairieses' loaves'. This then became 'Pharisees loaves' and then even 'Paris loaves' (Oakley 1985). Evans (1966) argued that 'pharisee' was derived from 'ferrisheen', which itself was a derivation from the Gaelic 'fear-sidhean' (pronounced 'fear-sheen'), meaning 'fairy men'.

In a letter written to the *Sunday Times* published on Christmas Day 1955, one Beatrice Lubbock recorded being handed a 'Pharisees' loaf' in a public house in an Essex village, and being told that anyone finding such a stone would never want for food. Another version of the fairy was the pixie. In Dorset in the mid-nineteenth century they were called *Pexy* or *Colepexy* and fossil echinoids were sometimes called 'colepexies' heads'. Fossil belemnites were called 'colepexies' fingers' (Keightley 1968).

One of the myths associated with fossil echinoids was that if they were kept in the house there would never be a shortage of bread (Johnson 1908; Toms 1940; Evans 1966). In Suffolk the 'fairy loaves' were used as a charm to ensure that the bread would rise by placing them by the brick oven in the bakery (Evans 1966). 'Fairy loaves' were also considered to have the ability to stop milk from going sour. Belief in this idea has been documented well into the twentieth century from observations of their emplacement on window-sills in dairies. As late as 1940, Toms photographed 10 *Echinocorys* lined up on the window-sill of a cottage at Patching, near Worthing in Sussex (Oakely 1965, Pl. XXII, Fig. b). Pull recorded that in this same area at least 16 cottages had 'shepherds' crowns' on their windowsills. They were kept there because they were thought to be lucky. Another culinary association with fossil echinoids was the use of the name 'sugar loaves' in Kent and Sussex in the early nineteenth century (Mantell 1844).

Although calling fossil echinoids 'fairy loaf' seems to allude to the idea that fossil echinoids may once have been thought of as little loaves of bread that belonged to fairies, it is more likely that this name provides an insight into the significant role that these fossils played in Celtic, and perhaps earlier, myths. To the Celts, fairies were not the sweet little flying creatures of modern day fairy stories. They were creatures to be very wary off, even to be feared. Many of the myths associated with fairies, elves, pixies and goblins in Britain probably have their roots deep in pre-Celtic times. Another word for these creatures was 'urchin'. Keightley (1968) suggested that this termed equated to 'orcneas' in the epic Anglo-Saxon poem *Beowulf*. In more recent literature (Tolkien 1954) this has been transformed into 'orc'. The popular name for echinoids is urchin (sea urchin for the living variety), and this may well have its origins in its association with 'fairy' folk, the name therefore first being used for the fossil. When it was realized that they were the fossilized remains of an echinoid, the name was transferred to the marine variety.

The Celts believed that fairies were the inhabitants of a mystical, enchanted world, known as the Otherworld. It was described to the warrior Oisin by the fairy-woman Niamh of the Golden hair as '...the most delightful land of all that are under the sun; the trees are stooping down with fruit and with leaves and with blossom. Honey and wine are plentiful there; no wasting will come upon you with the wasting away of time; you will never see death or lessening. You will get feasts, playing and drinking; you will get sweet music on the strings; you will get silver and gold and many jewels'. (McInnes 2002). This magical world could be entered through prehistoric burial mounds, the barrows of Neolithic and Bronze Age times. Those who inhabited the mounds were known as *sidhe* (pronounced 'shee'). This name was also used for the barrows. Where the sidhe lived within the barrow was known as the *brugh*. Here lived the sidhe-folk, gods and goddesses of the Otherworld, over time becoming the fairies of folk belief (McInnes 2002). The inhabitants never grew old, nor suffered pain or sickness living in the Otherworld. Within each sidhe was a magic cauldron that produced an endless supply of food. Along with fruit from magic trees, it had the power of restoring the dead to life.

The Otherworld was also believed to be the land of the dead and was ruled by the god Donn, the 'dark one'. Inhabitants of the Otherworld were often thought to be the spirits of the dead, trapped between this world and the next, just waiting to return to mortal life. Taking into account the frequency with which fossil echinoids occur in barrows and burial sites from the Neolithic onwards, along with the many folk names that relate to fairies, it seems probable that fossil echinoids played a role in myths associated with the Otherworld. The ancient tradition, dating back to Neolithic times, of placing fossil echinoids with the dead in graves and barrows, even in barrows without bodies, indicates that they were associated with helping the spirits of the dead on their journey into the Otherworld, or the afterlife. Perhaps fairy loaves were spiritual food that sustained the spirits into the Otherworld, helping to ensure their immortality.

Concerning the derivation of the term 'shepherds' crowns', this name probably has nothing to do with shepherds, but derives, in part, from the Celtic word *sidhe*, pronounced 'shee'. The second half of the word 'shepherd' may stem from *brugh*, the inside of the barrow. Thus *sidhe brugh* ('shee broo') could, over thousands of years, have transformed into 'shepherd'. The close similarity in the shape of the domed *Echinocorys* to a barrow suggests the possibility that the little fossils were emblematic of a barrow. The source of 'crown' in the context of 'shepherds' crowns', is not known.

Because of their association with this idylic Otherworld, fossil echinoids were always considered to be lucky charms. Toms (1926) records how not only in Sussex, but also in Wiltshire and Dorset in the 1920s, people regarded the fossil echinoids that they found as lucky objects. They would be carried home and usually placed either on a window-sill or by the front door. This was for the same reason that people put horseshoes and stones with holes in them near the door—as a charm against witchcraft. More specifically they were considered to be a protection against the Devil, and as such they were thought of as lucky stones. A specimen in the Pitt-Rivers Museum in Oxford, purchased in Sussex in 1911, has recorded with it 'Shepherd's Crown placed on window ledge outside to keep the Devil out'.

The use of fossil echinoids (bearing a five-pointed star) parallels the use of the pentagram symbol in medieval times, when the pentagram was thought to possess apotropaic powers—the ability to ward off demons, witches and devils. Schouten (1968, p. 31) illustrated a woodcut from a book called *Pluemen der Tuget*, published in Germany in 1486, in which a pentagram is shown on the threshold of a byre, to prevent witches from entering. In a similar manner it was frequently used on cradles or bedsteads, or on the walls of houses, on cowshed doors or castle gates, to keep the devil and witches away (Schouten 1968). Indeed, it is possible that the symbolism associated with the pentagram over the last few millenia was itself derived from the symbolism attributed to fossil echinoids over a much longer time-scale.

The use of fossil echinoids for apotropaic purposes probably has an extremely ancient heritage. This is illustrated by the presence of fossil echinoids in the Romano-British deposits in the Cranborne Chase district (Pitt-Rivers 1887–1898), where some were placed with the dead, and the habit in the same district in south Wiltshire in the 1920s of calling them 'lucky stones' (Toms 1926). Toms learnt that when found, a lucky stone would not always be taken home. The finder would spit on it, then throw it over their left shoulder for luck. The same habit was reported to Toms (1940) in Brighton. If the finder didn't do this bad luck would befall them. One unusual habit reported to Toms from the Brighton district was how in the 1870s, after flints had been cleared from a field prior to planting of a crop, they would be built into a mound, and a 'shepherd's crown' would be placed on the top.

Other unusual habits associated with fossil echinoids involved what was done to them after they had been found, collected and taken home. It was reported to Toms (1940) that in Billericay in Essex people would place their fairy loaves on the mantlepiece, 'to ward off evil spirits'. Moreover, the fossils had to be religiously 'blackleaded' once a week, an activity that was taken most seriously. If somebody forgot to do it, Toms was told, 'the housewife would on remembering even get out of bed to descend and blacklead the crowns'. The same practice was carried out in Angmering in Sussex during the late nineteenth century. Toms was never able to discover the reason for this activity. However, there may be some clues from Iron Age cremations in Denmark. Between 500 and 150 BC the standard method of buying the dead in southern Jutland was by cremation (Parker Pearson 1999). The ashes were sometimes placed in miniature round mounds. In some later burials, between 150 and 50 BC, the cremation graves contained, amongst a variety of grave goods, black-burnished pots. It is not clear why they were blackened. However given that fossil echinoids are known to have been placed in pots in cremations at this time, such as the specimen found at Tunbridge Wells, similar blackening being applied to fossil echinoids two thousand years later in southern England might have been an echo of this much earlier practice.

Pull (2003*b*) recorded another piece of folklore associated with fossil echinoids. He was informed that sometimes they were placed on windowsills to give warning of when it was going to rain, because the fossils sometimes 'sweated' before it was going to rain. Pull (2003*b*) suggested that this may have occurred because being preserved as flint on a wooden windowsill they would cool quicker than the surrounding area and any excess moisture in the atmosphere would condense first on the flint fossil.

Norse mythology

In many parts of southern England until the middle of the nineteenth century, another name commonly used for fossil echinoids was 'thunderstone'. This was a name that in all likelihood formed part of another folk tradition that was almost certainly brought to Britain by Danish and Anglo-Saxon invaders more than 1500 years ago. It is a name that was widely used for these fossils in Denmark in the early twentieth century (Blinkenberg 1911), but which probably has its roots deep in Norse mythology. In 1677 Dr Robert Plot, the first Keeper of the Ashmolean Museum in Oxford, published his classic book *The Natural History of Oxfordshire*. Plot recorded that in Oxfordshire what we now call fossil echinoids were called thunderstones, as they were thought to have descended from the heavens during a thunderstorm. In his book he included some discussion on 'Formed Stones', as fossils were known. Although he compared many of these with living organisms, he was not convinced that fossil echinoids were the remains of once living creatures. Plot believed these fossils were '*Lapides sui generis*, naturally produced by some extraordinary plastic virtue latent in the Earth or Quarries where they are found' which 'seem rather to be made for his [man's] admiration than use' (Plot 1677; Adams 1938). Although the name 'thunderstone' was commonly applied to fossil echinoids, it was also applied to more ancient, Neolithic, or even earlier, stone axes. The finding of these two types of thunderstones together, an echinoid and an axe, in association with a cremation urn in Tunbridge Wells (Fig. 5), suggests an ancient heritage for this name. Both types of thunderstone were thought to have come from storms, and as such they were placed in houses in southern England to help protect them against lightning strikes (Pull 2003*b*).

Thunderstones were also attributed with other powers. They were thought to keep trolls and other nasty creatures, such as witches, away from the house, and to keep away evil in general and bring good luck (Blinkenburg 1911). More specifically it was thought that they protected the unchristened child against being 'changed', as well as protecting horses in their stables from having nightmares. They could keep witchcraft out of the dairy, so they were placed in the dairy to keep the milk fresh and to give better cream, and they were put on the churn to produce better butter. Placing them on stable window ledges or over stable doors was thought to protect the cattle against disease and accidents.

A link might be made between the Norse concept of thunderstones and the perceived activities of Thor. The great attribute of Thor was his ability to control the weather, which is why he is most usually thought of as the creator of thunder and lightning. But he was also the Norse fertility god. This is not surprising, given the close link between the weather and harvests, and not just rainfall. An old superstition has it that summer lightning ripens crops, thus Thor ensured the fruitfulness of the crops and the continuity of the seasons. By ensuring rain that makes the fields fertile and the crops bountiful, Thor, like Odin before him, was carrying on the cult of a sky god that extends back at least to the Bronze Age, and maybe even earlier.

Thor was particularly popular with the people because of all the gods it was he who fought most resolutely to defend the world against evil. Not surprisingly he was worshipped mainly by farmers and labourers, more than any other god. To the people, he was trustworthy and was the god of justice and law. By ascribing the formation of fossil echinoids to Thor, and because he was such a good, all-protecting god, the fossils were thought of as being lucky. Keeping one in your pocket, or placing it by a door or on a window-ledge, would protect you and your home from lightning or evil in any form. The thunderstone, after all, was a present from Thor. The presence of fossil echinoids in a succession of Romano-British cottages at Studland in Dorset, as discussed above, may be a reflection of these beliefs.

As a thundergod, Thor wielded his mighty and all-powerful hammer Mjöllnir. In the Statens Historiska Museum in Stockholm, among the thousands of Viking items is a rather strange small bronze brooch. Two animals, thought to be goats flank what is generally considered to be a stylized fossil sea urchin (Fig. 6). Raised, crenulate ridges arch across this conical central structure. They meet at the top of the dome in what is essentially a metallic knot. Another, almost identical brooch of a similar age was found in Denmark and is kept in the collections of the National Museum in Copenhagen. The two goats are Toothgnasher and

Fig. 6. Iron Age brooch found in southern Sweden, thought to represent a fossil echinoid and Thor's goats, Toothgnasher and Gaptooth. Photo courtesy of Statens Historiska Museum, Stockholm.

Gaptooth, who pulled Thor's chariot across the sky. Their presence in a brooch with an idealized fossil echinoid reinforces the close link between thunderstones and Thor.

Thor's hammer, Mjöllnir, was widely used as an amuletic symbol. Small statues of Thor from Viking Age deposits show Thor's hammer coming out of his beard. The cross-shape of the hammer head and the bifurcating shaft emerging from Thor's beard is similar to the pattern of the five ambulacra on the domed surface of fossil echinoids. Thor's hammer was thought to have the power to call up the dead to renewed life. Like the Christian cross, it was symbolic of the power of resurrection, hence its frequent appearance on memorial stones in Scandinavia in the ninth and tenth centuries. Mjöllnir's ability to resurrect life is told in one of the many stories about Thor recounted in Snorri Sturluson's *Prose Edda*, written about 1220 (Ellis Davidson 1964). One night Thor stayed at a farm and killed his goats for supper. This was not because of a shortage of food, rather Thor wanted to impress his host with Mjöllnir's power. Following the meal he collected the bones, placed them on the goatskins and raised his hammer above them. Instantly they came back to life.

Mjöllnir's power to resurrect the dead is also shown in stories about the death of Baldur, Odin's favourite son. Most beloved of gods, he was inadvertently slain by the hand of Odin's other son, the blind Höd, under provocation from the mischievous and evil god Loki, who despised Baldur. At Baldur's funeral, his body was placed upon a pyre on a great ship. Thor laid Mjöllnir on the pyre, perhaps in one last attempt to raise Baldur from the dead. Thus the broken stone axe and a fossil echinoid found in the grave with burnt bones outside Tunbridge Wells may parallel Thor's act of consecrating Balder's funeral pyre with Mjöllnir.

Placing the sign of Mjöllnir, either as a fossil echinoid or as a stone axe, in burials can therefore be seen as an act of symbolizing rebirth after death. Here was the 'Pagan' cross, formed in the heavens and etched onto a stone by the god Thor who had the power of resurrection. One of the other myths surrounding thunderstones in Scandinavia that Blinkenberg (1911) also recorded was the belief that after working its way deep into the ground the thunderstone would remain there for seven years. It would then somehow reappear at the surface, as if reborn. Such beliefs probably had a very long heritage, and may explain why, from the Neolithic through to the Iron Age, people wanted to be accompanied by fossil echinoids on their journey into the after life, to help ensure their rebirth.

Shepherds' crowns, thunderstones and Christianity

In the northwestern part of Hampshire, close to its border with Berkshire and Wiltshire, is the little village of Linkenholt. St Peter's is typical of many of the village churches in this chalk downland country in that its walls are made from flint collected from the nearby fields. The church was erected in 1871, a few hundred metres from where its predecessor had stood for almost 700 years. A small number of items from the original medieval church were retained. Amongst them was a small window. This simple, round-headed window is tucked away on the damp, dark, north side of the church. It is so small that in the perpetual twilight of this side of the church very little light can pass through it. However, it may have been the surrounding decoration, rather than the window itself, that persuaded the nineteenth century rebuilders of the church to retain it, for carefully placed around the window are 22 fossil echinoids.

The flint fossil echinoids, now stained green by algal growth, form three sides of a rectangle. Ten are placed horizontally along the top. A further five extend vertically down on each side of the window, with a final one placed horizontonally next to the last on each side (Fig. 7). All of the fossil echinoids are specimens of the helmet-shaped *Echinocorys* and all are arranged such that the domed surface carrying the five-rayed star is showing.

Given that the Linkenholt chuch was originally built in the thirteenth century, the retention of the fossil echinoids when the church was rebuilt in the nineteenth century suggests that these fossils were of particular significance to the local inhabitants for at least 700 years. One possible reason for such 'pagan' symbols having been set above the window in the first place may have been because of its location on the north side of the church. In medieval and earlier times this was known as the Devil's side of the church. A small door, known as the Devil's Door, was frequently set into this northern wall (Tyack 1899). During the early period of the Christian church, those who still clung to the old pagan beliefs could enter the church through this door, for many still wanted to continue to worship at the old pagan sites that the Christians had built over. The north door was used either as a means of deliberately segregating these heathens from the Christian believers, or perhaps as a way for Pagans to identify

Fig. 7. Medieval window on north side of St Peter's church, Linkenholt, framed by fossil echinoids.

with others of a similar belief, by entering the church through this door. Its identification with the Devil relates to the link that the early Christian church made between the old pagan ideas, which they wished to suppress. Another important use of the 'Devil's Door' is said to have been during baptisms. The north door would be left open so that any spirit of the Devil lurking within the baby left through this door, which was then quickly closed to prevent it coming back into the church and re-entering the baby (Tyack 1899). Given the widespread belief in the apotropaic powers of fossil echinoids, carrying the five-pointed star, symbolic of the power of good over evil, it would not be totally unexpected to find them placed near such a door, where it would have been thought that they would prevent the devil from re-entering the church.

When the church was rebult in 1871 other fossil echinoids were incorporated into the fabric of the church. Immediately to the left of the old medieval doorway, which is now the main entrance to the church, on the SW side of the building, is a window similar to the medieval one on the north side, except for having an arched top. Like the window on the northern side of the church, it too is surrounded by fossil echinoids (Fig. 8).

Fig. 8. Nineteenth century window on south side of St Peter's church, Linkenholt, framed by fossil echinoids.

However, because it is an arched window, the fossils have been set in an arched pattern, crowning the window. There are 25 in all. All, except for a single specimen of *Micraster*, are the echinoid *Echinocorys*, displaying their five-pointed stars on their convex dorsal surfaces. However, the central echinoid, a specimen of *Conulus*, has been placed with its flat, ventral surface showing, as this best displays the five-rayed star pattern. This is the same genus of echinoid as in the 400 000 year old Swanscombe Acheulian hand axe. Why the nineteenth century rebuilders of the Linkenholt church continued the practice of their medieval forebears, in placing fossils echinoids above the window is not known. Perhaps it was because these objects, which are frequently found in the local fields during ploughing, had become so ingrained in the folk culture of the village for such a long period of time. Support for this comes from the occurrence of fossil echinoids in the wall of another building in the village. Shortly after St Peter's was rebuilt, a small, one room school was built nearby. Its architecture mirrors that of the church to such an extent that to the left of the door above an arched window 46 fossil echinoids were inserted (Fig. 9). Even in more recent times, fossil echinoids found in the fields would be collected and placed by the front door of the finder's home (A. & B. Smith pers. comm.). Figures 2 and 3 represent two such examples collected at Linkenholt.

Conclusion

Although there is archaeological evidence that in pre-Christian Britain people collected a range of fossils for literally hundreds of thousands of years, the most common fossils in archaeological sites, as in many parts of Europe and the near East, were fossil echinoids. From forming part of flint tools in early Palaeolithic cultures, where they 'were perhaps just regarded as "lucky"' (Oakley 1965), they took on a greater symbolic significance in younger Neolithic and later cultures, as attested to by their being placed in graves and in barrows. More recent folklore indicates that they were associated with 'Celtic', Norse and probably earlier myths that dealt with the 'Otherworld', and with a thunder god who had the power to bring the dead back to life. Hundreds of specimens placed in a single Bronze Age grave on Dunstable Downs is testament to their great spiritual significance at this time and perhaps belief that they would in some way ensure the deceased would pass safely from this world into the next. But 'when the religion decayed or was replaced by another the fetish was no longer an object of specific belief, but degenerated in folk memory to become regarded once again merely as an object conferring "good luck" . . . ' (Oakley 1965). So fossil echinoids entered into folklore, becoming merely objects that conferred good luck to the owner, and protecting them from lightning and from evil. And it would seem that if St Peter's Church in Linkenholt is any guide, then even the advent of Christianity failed to extinguish belief in the power of these fossils completely.

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Fig. 9. One room school, Linkenholt, built in the 1870s and styled after St Peter's church, with window by front door framed by fossil echinoids.

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Obsidian: sacred glass from the California sky

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Abstract: For at least 13 000 years, California Indians mined and worked obsidian, trading the precious volcanic glass near and far, including obsidian and its uses in their everyday lives and beliefs. The cultural importance of obsidian is emphasized by the fact that a number of tribal groups created myths specifically about obsidian. Not only do the myths illustrate tribal religious beliefs, they help to trace geological and archaeological histories, as well. That obsidian still plays economic, artistic, and religious roles in the lives of today's Californians offers testimony to its qualities the Indians discovered long ago.

A piece of obsidian sitting in the palm of your hand looks so ordinary, particularly if you happen to be at an obsidian quarry surrounded by thousands of similar looking fragments. But for California Indians, obsidian—volcanic glass—held enough importance to influence many parts of their lives. The story of California Indians and obsidian is about the complex beliefs and uses of obsidian by peoples who have lived within the boundaries of today's state for about 13 000 years. It is an ancient story and a modern one, ending with the newest uses of obsidian intertwined with the oldest ones. The oldest information mostly comes from accounts written in the 1870s to 1944, and the modern information from recent publications and personal interviews from 2003 to 2005.

First California Indians and religious beliefs are described. Then geological and archaeological interpretations of obsidian myths are presented, followed by descriptions of obsidian and its uses through time.

California Indians

In 1770 there were about 310 000 Indians living in California, a number that had declined to around 20 000 by 1900 (Cook 1978). The Indians were part of several hundred tribes and tribelets, composed of varying types of family and household groups. Most of the population lived in small tribelet societies of a few hundred members (ranging from between about 100 to nearly 1000) with a modicum of political organization and social structure. The Indians spoke many mutually unintelligible languages (at least 64 and perhaps up to 80) and an unknown but large number of dialects whose mutual intelligibility varied (Heizer & Treganza 1944; Shipley 1978). Fig. 1, although somewhat dated, provides a good sense of the diversity of languages and societies present in California in the 1700s (Kroeber 1925; Heizer & Whipple 1971, tip-in).

The diversity of California Indians also manifested itself in terms of physical stature: the California Mohave were among the tallest in North America and the Yuki the shortest. And as would be expected, the tribes held different world-views. Of pertinence here is the fact that some groups focused on acquiring and holding wealth from rare, natural objects like large, chipped obsidian blades, black or red (Heizer & Elsasser 1980).

Obsidian from the sky and shamanic power

California Indian beliefs concerning the origins of obsidian are tied closely to cosmology and religion. The Yuki Indians said *Milili*, one of two Great Spirits in Yuki mythology:

> ... lives in the sky above the visible one, and owns an enormous block of obsidian of which all obsidians in the world are fragments that he has thrown down. He has the shape of an enormous eagle or condor and controls deer, *mil*, to which his name refers. *Kichil-lamshimi*, obsidian doctors, *mil-lamshimi*, deer doctors, and *mil-lamshimi*, sky doctors ... all derive their power from *Milili* (Kroeber 1925, pp. 196–7).

(How this account may be a metaphor for a Plinian volcanic eruption is discussed later in the 'Mythology and geology' section.)

For Yuki Indians, the different classes of doctors, or shamans, hold different powers:

> The Yuki divide their shamans into those who doctor by singing and those who suck, or perhaps 'diagnosing' and 'extracting' physicians. The two classes correspond more or less with those who derive their power respectively from the two Great Spirits, the *Creator* and *Milili*. Sucking doctors are, however, differentiated into those who extract actual arrowheads from wounds received in battle and those who suck out invisible obsidian points which the spirits have shot into one in lonely places (Kroeber 1925, p. 197).

The latter are the obsidian shamans.

Obsidian shamans, with their elongated, obsidian blades, were central to California Indian life (Fig. 2). Sometimes, while treating diseases, an

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Fig. 1. California Indian tribes, groups, language families, and dialects in 1770. Map adapted by Heizer & Whipple 1971 from Kroeber 1925. Reprinted with permission from *The California Indians. A Source Book*, compiled and edited by R. F. Heizer and M. A. Whipple, second edition, published by the University of California Press, Berkeley, Los Angeles, London.

Fig. 2. A large, ceremonial obsidian blade, Klamath River, California, as drawn by famed artist Thomas Moran (Heizer & Treganza 1944, p. 330). Used with permission, California Department of Conservation, California Geological Survey.

obsidian shaman would build a little funnel of earth, perhaps 61 centimetres long. The patient reclined at one end and at the other, obsidian blades were set up. 'The doctor then blew tobacco smoke through the hole on the sick person' (Kroeber 1925, p. 195).

The double-edged, ceremonial blades were among the largest, flaked obsidian blades in the world and some blades measured over 91 cm long. These and smaller blades up to 61 cm long were objects of wealth and used for ceremonial display in NW California (Rust 1905). Either single- or double-pointed, they probably belonged to shamans and were not used as knives. All the evidence from central California points to this and the Maidu add that such pieces were hung from the neck (Kroeber 1925, p. 418).

Travelling journalist and self-taught ethnologist Stephen Powers saw California obsidian blades in the early 1870s and wrote they were probably passed down as family heirlooms through generations, to be borne aloft as a sort of mace on solemn occasions. He noted the Indians still owned and used the blades in the same ways, but he saw no new ones being made (Powers 1877).

The prestigious obsidian shamans directed an important Yuki ritual called the ceremony of obsidian initiation, *Kichil-woknam* (Kroeber 1925, pp. 192–4). The seven-day ceremony was used to find and perhaps assist the children '... who were or would be endowed with the power of becoming an obsidian doctor'. Each day had its rituals and at night the Indians would dance *Kichil-wok*, the obsidian dance. The first day, '... one of the sky shamans took a long obsidian blade [also called a *sky-obsidian*], believed to have fallen from heaven, from a net sack full of such pieces. He went among the children rattling this sack and lightly striking them with it.' On the seventh day:

> ... seven sticks were counted out for the seven days of the ceremony. Thus the creator did, it is said, and on the seventh day produced water. A shaman now proceeded to do the same. He squatted before a *sky-obsidian* that had been set upright and probed four times in the dry ground with a stick, singing. At the conclusion of his song he drew out the blade and dug the spot where it stood. He dug with his stick perhaps a foot down [30 cm, ed.]. Soon the hole filled with water. The shaman said to the multitude: 'This is from the creator. I am showing you what he did. I do not do this myself. I was taught by him. If you believe this it will be well with you.'

A Yuki shaman recalled the time when he was young and underwent a life-changing event as his tribe held a doctor dance, called *Lamshi-wok*, to train two or three new doctors. He said (Kroeber 1925, pp. 197–8):

> ... when new doctors are receiving their training, still younger ones often first learn of their powers; and so it was with me. The first night of the dance I was sleeping outdoors, between my brother, who has the creator as spirit, and another doctor. Then I, too, dreamed of the creator, *On-uha"k-namlikiat*. I did not see his face or body; but I was in the sky, and saw many colors, like a mass of flowers. In the morning I was bleeding from mouth and nose and badly frightened ... I was so much younger than usual that the people had not thought my bleeding was due to my becoming a doctor. But as my brother also had dreamed of *On-uha"k-namlikiat*, he knew.
>
> When I first saw the creator, he sang a song which I was always to sing. Something like a string stretched from him to my head. He sang another song, and told me to use that also.

After more dreams of the creator, the young shaman's curing powers finally reached all but the highest level of the obsidian shaman and he began ministering to his tribe. He ended by explaining why he never became an obsidian shaman, saying:

I can cure all disease except that caused by spirit obsidians. I did dream of such obsidians once, but did not reply to the spirits who were addressing me, thinking the dream would come to me again and be clearer. Later I was told by the old people that I had made a mistake—that the obsidian spirits never spoke to anyone more than once.

Leo Carpenter, a self-described Hupa-Yurok Karuk traditional man who is following 'a path designed by angels,' said (pers. comm. 2005):

Today obsidian mainly plays a spiritual role in Hupa tribal life. In the past, where the obsidian was and who controlled it were critical factors to how much obsidian a tribe would use. The northern California Hupa was able to get enough obsidian from Glass Mountain, in far northern California, to make ceremonial blades in red and black obsidian. There is a story about what the red color symbolizes that I can't tell you now. The blades are still used today in the White Deerskin Dance and have a specific spiritual purpose.

Obsidian mythology and geology

Much California volcanic activity occurred in Holocene times, from about 12 000 years ago to today. Figure 3 shows the sites of volcanic eruptions in California over the last 10 000 years. Indians witnessed the events and wove them into the myths that today add first-hand observational information to the geological and archaeological records. Five obsidian myths follow, along with possible geological and archaeological interpretations.

Myth 1. How obsidian fell from the sky

The Yuki Indian myth quoted above tells how *Milili*, a supreme spirit in the shape of an enormous eagle or condor, let obsidian fall down from the sky and how the obsidian broke into fragments on hitting the earth, perhaps into the obsidian flows found today. This myth may retell the story of a Plinian volcanic eruption.

To imagine this, think of a Plinian eruption with its vast, paroxysmal, gas-charged emissions of volcanic debris shooting straight up into the sky, reaching heights of 45 km, perhaps up to 80 km, before spreading out into a huge, flat cloud (Duff 1993). The erupted mixture contains magma consisting of partially molten or solid particles, along with magma gases (which can condense to liquids) and pieces of the volcano itself, referred to as 'wall-rock lithics' (Carey & Bursik 2000). These lithics can include obsidian, and obsidian from this provenance may play a role in several myths. In addition, dense pyroclastic flows (*nuée ardente*) often move down volcanic flanks like rock or snow avalanches (Duff 1993).

The myth of *Milili* could reflect the observations of Indians watching a Plinian volcanic eruption in far northern California during one of the many events over the last 1100 years when rhyolitic pumice was ejected from Glass Mountain and Little Glass Mountain on the Medicine Lake Highland, a 25 km shield volcano 55 km east of Mount Shasta (Heiken 1978). In fact, at least 17 eruptions have occurred here in the last 12 000 years (Donnelly-Nolan 1990). The eruptions were followed by extrusions of viscous masses of rhyolitic lava from a chain of at least 13 vents on the eastern rim of the summit caldera. The lava chilled quickly into the glistening black obsidian that gave Glass Mountain its name (Harris 1990).

The vast, dark cloud forming above the vertical column of ejecting material in a Plinian eruption could resemble the wings of an eagle or condor (perhaps those of *Milili*) from the perspective of a viewer (Fig. 4). So with the noise and turmoil of clouds of ash flowing down the volcano and with enormous amounts of erupting pumice (maybe mixed with pieces of previously formed obsidian) streaming up into the sky for kilometres and falling back down, the question of whether or not obsidian forms on the earth or falls from the sky becomes more complex and the answer may be 'both.' For not only can Plinian eruptions include pieces of obsidian raining back to the ground, perhaps sent by *Milili*; but also northern California eruptions are associated with large masses of rhyolitic lavas that never leave the ground and harden to obsidian by vents near the caldera rims.

The myth may also suggest how far the Yuki lived from the Plinian event; close enough to view the eruptive cloud, yet with enough distance to survive it. It is interesting that the Indians in the fourth and fifth myths in this section lived north of the Yuki, perhaps closer to many eruptions, yet their myths seem to connect obsidian with lava flows, not airborne eruptions. The parts of the 'volcanic elephant' people observed and incorporated into their myths may help pinpoint when and where they lived and the aspects of obsidian they valued.

Myth 2. How Glass Mountain was formed

The Wintu Indians lived NE of the Yuki Indians in northern California. This Wintu story of Glass Mountain is by Jo Bender from the Upper Sacramento River area (DuBois & Demetracopoulou 1931, pp. 305–6):

Some people [re]called a time at the flat named *Tok*. They were going to hunt deer. They set snares on the runway at Blood Gap. Adder had real obsidian. The others made their arrows out of just anything. They did not know about obsidian. When deer were caught in snares, Adder shot and ran as fast as he could to

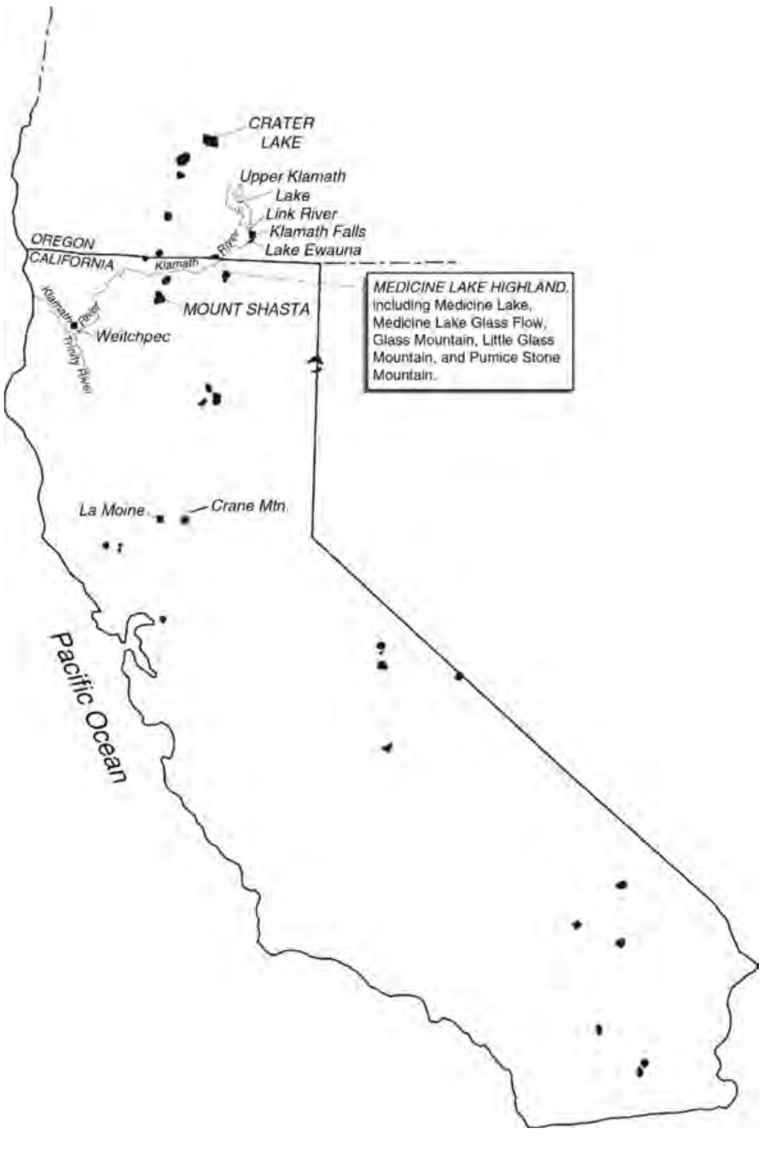


Fig. 3. The small, dark shapes are sites of volcanic eruptions in California and parts of southern Oregon during the last 10 000 years (Luedke & Smith 1981; Smith & Luedke 1984). The map includes the sites of three volcanoes often mentioned in the text: Mount Shasta and Medicine Lake Highland in northern California, and Crater Lake, once called Mt Mazama, in southern Oregon. Other geological and geographical features mentioned in the text are on the map, as well. Eruption sites are reprinted, with permission, from *Studies in Geophysics: A Series*, copyright 1984 by the National Academy of Sciences, courtesy of the National Academies Press, Washington, D.C.

the deer, pulled out the obsidian and hid it in his quiver. The obsidian was very powerful. The others would shoot too, but only sometimes would they kill a deer. Adder always killed them. He killed so many, the blood began running down both sides of the gap into the creeks. That is how the gap got its name. That night they carried the deer back to camp and had a big feast.

The next day the same thing happened. For three or four days this kept on happening. Adder always killed most of the deer. The others became jealous and talked things over among themselves. They decided that Adder must have some very powerful weapon. They told the fast runners like Humming Bird and Fox to watch Adder and race to the deer before Adder could get there.

On the following day the fast runners stationed themselves near Adder. One man called *Puimeminbes* was near. When Adder shot, all began running. *Puimeminbes* got there first. He put his

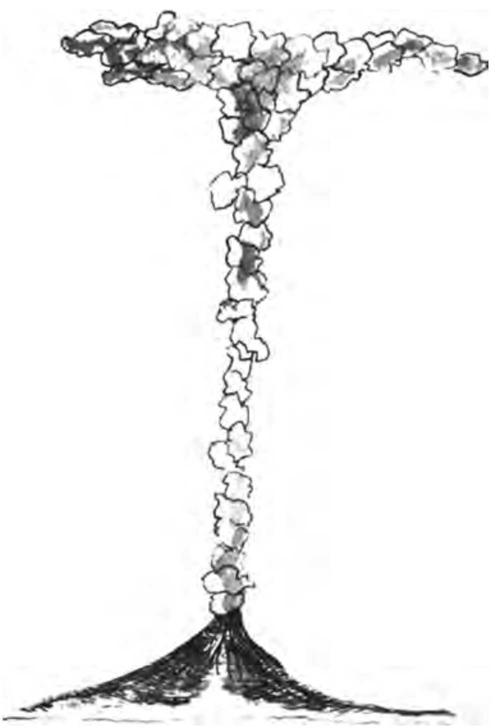


Fig. 4. A typical Plinian volcanic eruption topped by a spreading cloud, perhaps resembling wings. Drawing by S. Hodgson.

hand in the wound and pulled the obsidian out and ran away. When Adder came, he put his fingers in the wound and could not find his obsidian. He knew it had been stolen and he was very angry. He went right back to camp and got his things ready to go back down south from where he had come. He told the others his obsidian had been stolen and he was going to get even with the people who had taken it.

Meanwhile *Puimeminbes* ran up the ridge of Sandhill Crane Mountain. The other people all knew what was going to happen. They knew that Adder was going to set the world on fire. They all got ready to leave.

When *Puimeminbes* got the top of the ridge, Sandhill Crane was there and so was Ground Squirrel who was to run with the obsidian. The obsidian was very large by now. *Puimeminbes* gave Ground Squirrel the pack and told him to run. Sandhill Crane told him to go right away because the fire had already started. He said he would stay on the mountain and watch the fire. He would call to him and tell him how near it was coming. He said, 'When you hear my voice getting dim you will know that you are far enough away.'

So Squirrel started going. He went north, and went north, and went north. He went past Mount Shasta. He could still hear Crane telling him about the fire. He kept on going until he could hardly hear Crane's voice, then he dropped his load. That is where Glass Mountain is today. That is why Ground Squirrel has a black mark on his back. The obsidian got hot and scorched him.

The people left behind were caught by the fire right above their camp. The rocks at Wakpom are those old-time people.

Thus Adder found a piece of obsidian and put it on his arrow. The hunters with cruder points envied the obsidian and stole it. (If you looked down Adder's throat, would it be red, with his body undulating like a stream of molten lava? If he held a piece of cooled, black obsidian in his mouth, would the whole geological process be illustrated? Does a straightened serpent holding a piece of obsidian in its mouth resemble an arrow with an obsidian point?)

Interestingly, although the hunters knew that taking the obsidian meant setting the world on fire, they did so without hesitation. The attitude of inevitability suggests they knew that fire and obsidian come part and parcel. The fact that Adder's piece of obsidian began growing before Ground Squirrel got it also suggests people knew how quickly obsidian hardens from cooling lava.

The hunters wanted the obsidian carried safely away from fire. Did they believe fire harmed obsidian or made it molten again? Lava flows seen at night might have included incandescent blocks that the Indians assumed were obsidian, only to find later that they were not, perhaps leaving an impression that fire could destroy obsidian.

Ground Squirrel ran northward from Sandhill Crane Mountain, carrying the prized obsidian. Where is Sandhill Crane Mountain? It may be Crane Mountain, standing in traditional Wintu territory about eight kilometres east of La Moine (U.S. B.L.M. & California Native American Heritage Commission 1992). La Moine is located on the upper reaches of the Sacramento River, home to Jo Bender who related the myth. Other small mountains in the area are named for birds and animals, and the name *Crane Mountain* may be shortened from *Sandhill Crane Mountain*.

Where had Adder's obsidian come from? It may have fallen to earth in a Plinian eruption further north or come from one of 14 sites not too far east of Crane Mountain, roughly trending north to south, called the Tuscan chemical source group, where lavas flowed and hardened to obsidian (Northwest Research Obsidian Studies 2005). Current studies show artifacts correlating with some of the Tuscan chemical source group sites '... are commonly found throughout northern California and often co-occur with artifacts originating from sources in the Medicine Lake Highland' (Northwest Research Obsidian Studies 2005, website). Thus the Indians who knew about the Tuscan obsidian sites may have known about sites further north at Medicine Lake, including Glass Mountain where Ground Squirrel was headed.

Fig. 5. View to the SW of Little Glass Mountain, the large lava flow without vegetation in the middle of the photo. Beyond this stands Pumice Stone Mountain, a prominent cone in the far centre. Mount Shasta looms in the background. Ground Squirrel ran around Mount Shasta with his load of obsidian, which he left at Glass Mountain, near Little Glass Mountain. Used with permission, California Department of Conservation, California Geological Survey.

Whatever the answer, the myth seems to describe the creation of obsidian at Glass Mountain, for upon passing Mount Shasta and reaching Glass Mountain, Ground Squirrel dropped his load, which had grown larger, heavier, and was still very hot, forever scorching his fur (Fig. 5). The image of Ground Squirrel running from fire while supporting a slowly growing load of obsidian on his back may be a metaphor for fiery lava flowing from a volcanic vent, scorching all around it, and cooling into a growing amount of obsidian. Certainly the people whose myth this was knew the geological truth—that obsidian comes from lava and fire.

Myth 3. Another Ground Squirrel adventure

The Achomawi Indians lived near Medicine Lake and an Achomawi myth, collected in 1900 or 1903, relates further adventures of Ground Squirrel and obsidian. It juxtaposes two everyday uses of obsidian with the difficulties faced obtaining it, allegorically represented by Obsidian-Old-Man. Again Ground Squirrel comes to the rescue (Dixon 1908, pp. 160–1):

Once, people had to hunt with pine-bark points. Only Ground Squirrel knew where the obsidian was—at Medicine Lake, guarded jealously by Obsidian-Old-Man. Ground Squirrel went to Medicine Lake, tricked Obsidian-Old-Man, and returned home with Obsidian-Old-Man's obsidian points and knife. Ground Squirrel showed everyone how to slice meat with the obsidian knife before cooking it, instead of cooking it in lumps. Then he gave everyone obsidian points. All day long people worked, tying them onto arrows. So they threw away all the old arrows with bark points; and when they went hunting, they killed many deer.

Myth 4. Catching obsidian

A Yurok myth, told by Lame Billy of Weitspus in 1902, describes how a young man found obsidian in the Klamath River in northern California. The obsidian, once caught, explains to the man how it will come to be valued, used, and found in larger quantities. The Yurok Indians lived on the Pacific Ocean near the Oregon border. The town of Weitspus, today spelled *Weitchpec*, is at the confluence of the Klamath and Trinity Rivers on the Hoopa Valley Indian Reservation. The myth begins (Kroeber 1976, pp. 45–6):

Every morning a young man sat looking outside his sweathouse on the northern bank of the Klamath River. One day . . . he saw something like fire coming down the middle of the river. Now he thought, 'Tomorrow, I will watch closely'. The next day he saw it coming and . . . it looked like fire passing downstream in the middle of the water. Then he jumped into his boat, thinking, 'I will catch it', and started after it. As soon as he was near, it sank; he could not see it anymore. Then he saw it repeatedly downstream, and pursued it, and each time it sank. Sometimes it crossed the river and then came to the nearer side again. Then it would move on downstream.

He changed places on the river, going to Weitspus to watch for it and set a snare as it came down the Trinity River. Then he realized this was the wrong river and went upstream to set a snare on the Klamath. The first day he was unsuccessful. He crossed the river, took his snare, and went downriver ... He thought, 'I will try once more. It will be the last time'.

Now he had not been there long, with his snare entirely underwater, when it was not moving at all. So he waited. At last he thought, 'I will stop. I will not try anymore. I will take out of the water what I have been using'. He had seen no fire (passing). Then he drew his net into his boat; and then his snare. He thought, 'Why is it so heavy?' Then he saw that he had caught something. The snare held it around the middle, and it seemed pretty. 'That is the one I tried to catch!' he said. He laid it in the boat, and with a basket dipped in water. He thought, 'Let me put in a little more water,' and added until there was enough for it to swim about a little. Then he thought, 'I will hide and see what it will do. It looks as if it were trying to move. It has been accustomed to swim everywhere.' Then he sat down behind his boat.

Soon he heard the water splash as that one moved about in the boat. Whenever it touched the boat, there was a ringing sound. The young man thought, 'It is the one that I wanted!' Then he went to it and saw that it was running in the water like a salmon.

Then he spoke to it. He said, 'Hi! I am glad I caught you. I am surprised to have caught you. I have thought about you for a long time and desired to catch you. I had no one to speak to. I was alone. That is why I caught you.'

Then he saw the water moving again. Then he began to know that it was thinking, 'I will speak to him.' Thereupon he said, 'Yes, that is why I want to keep you, because I have no one to talk with.' Then it said, 'I wanted to go from that place where I grew. I thought no one would know what I was for. Now it is well: I shall be about the world. Sometimes I shall not live in a town (meaning, I shall be so valuable that there will be whole towns without one of me). Sometimes I shall live in a rich town, just one of me, or perhaps two. There will not be many towns with two of me; they will be few. But I shall be all over the world. This is the last time that I shall talk to men. You will keep me. I shall endure as long as human beings dance (as long as the world lasts). I shall be beautiful and valuable. I shall be worth much even if I am only a little piece. I do not like to tell you where I come from.'

The young man said, 'Let it be the same to you. I will keep you. If you tell me where you grew, I shall be able to tell people.' 'Well, then, so be it.' 'Well, what will you tell me?' 'My name is Obsidian. The name of the best of me is Red Obsidian, *Sokto*. I grew upstream, not in the sky, but before one comes there. There is a cold spring there, *Aterpr*. That is where I grew.' That is the last it said to him.

Then the young man took it up to his house. He is the one that caught Obsidian. If it had not been for him there would be no obsidian blades in the world.

This Yurok myth may relate to the eruption of Mt Mazama (today called Crater Lake) about 7000 years ago in southern Oregon, not too far from the California border (Harris 1990, p. 219). Mt Mazama yielded '... the most cataclysmic volcanic eruption to occur in the West since the end of the Ice Age.' During the eruption of Mt Mazama, '... dozens of new vents spewed flows of incandescent pumice, creating rivers of fire down all sides of the volcano. Incinerating all in their path, the pyroclastic flows travelled about 64 km or more from their source.' At first such intense heat would vaporize water it met, but after some cooling, '... some flows poured into Klamath Marsh, and floating rafts of pumice eventually washed down into the Klamath Lakes.' From the Upper Klamath Lake it is only a few kilometres further through the Link River and Lake Ewauna into the Klamath River, from which the rafts could continue southwestwardly down river into northern California where the young man found the obsidian.

Geologically speaking, the pumice rafts could hold wall-rock lithics, with obsidian already in place on the volcano before any pyroclastic ejections began. This obsidian would break off and be entrained in the erupting flow, a process almost analogous to a rip-up clast in a turbidity current.

The pumice rafts, still glowing with heat and holding pieces of obsidian, could remain buoyant from the hot air trapped inside. Eventually the river water would cool down the pumice, which would sink from the weight of the obsidian. The disappearing obsidian might resemble the elusive obsidian pieces described in the myth.

The myth mentions nothing of Plinian volcanic eruptions, and obsidian itself clearly says it comes from a place upstream: '... not in the sky, but before one comes there'. In other words, the obsidian source is high up, but not *that* high, an apt description for obsidian sites found by volcanic crater rims. An example would be the Glass Mountain obsidian, which may be what the Yuroks used, like their eastern neighbours, the Hupa (Carpenter, pers. comm. 2005). With this remark, the myth seems deliberately to refute the idea of a block of obsidian in the sky and directs future generations to look for obsidian on the ground, albeit at high elevations.

The myth only refers to one obsidian object, religious, shamanic blades. In the myth, Obsidian speaks to the lonely young man in tones of a wise shaman to explain its own beauty, worth, and usefulness. Obsidian says it left the place where it grew for one where mankind (represented by the young man) could find and use it. This fits the geology, as the obsidian the young man discovered in the Klamath River had left its place of origin. To collect more obsidian, people would have to go to the source somewhere upstream, high but not as high as the sky.

Myth 5. Kingfisher's obsidian boat

A Yurok myth interweaves oceanic creatures living along the northern California coastline on the Pacific Ocean, with fire and obsidian, explaining why some of the creatures look as if they have been burned (Heizer & Elsasser 1980, pp. 216–7):

> Sea Otter woman was dancing at Omenoku (a town on a small lake or pond just north of the mouth [origin, ed.] of the Klamath River in southern Oregon), learning to become a doctor. Kingfisher was to marry her, but the bride price was so large that he was travelling all around the world to collect the amount. Seal and Sea Lion were in the Omenoku sweathouse singing, 'Kingfisher is going all around the world to collect his bride price. I hope he dies.' Suddenly Kingfisher's boat made of obsidian landed. He heard them, was angry, and in revenge set the sweathouse on fire. Seal and Sea Lion had their arms burned off short, and that is why they have flippers and why Sea Lion is black on the shoulders. Sea Otter was burned a little and that is why her arms are short. She rushed into the river and swam out to sea.

The sweathouse where the fire began was sited inland, NE of the Yurok at the origin of the Klamath River, which today is below Lake Ewauna, south of Klamath Falls, Oregon. Heizer and Elsasser say the myth explains the physiology of some sea creatures the Yurok found along the Pacific Ocean, but questions remain.

Why were the oceanic creatures in the myth at a sweathouse so far from home? All but one of them would never have lived so far inland and upriver. A biologist from the California Department of Fish and Game said the sea otters (rarely seen in the state since the late 1800s because of over-hunting), sea lions, and seals would have stayed far to the west where the mouth of the Klamath River opens into the Pacific Ocean on Yurok lands (Dayton, pers. comm. 2005). They would not have moved upstream beyond the part of the river affected by tides, which ends near the bridge on Highway 101, close to the ocean. However the entire Klamath River basin, including the inland area with the sweathouse and fire was, and remains, home to the kingfisher.

Perhaps the Yurok placed the sweathouse at the Klamath River's source because they imagined it a special place where important events occurred. Kroeber writes in 1925 (p. 15), 'Beyond their Karok neighbors, the Yurok seem to have a sense that the [Klamath River] comes from the east. At least they point in that direction when they refer to the end of the world at the head of the Klamath.' This 'end of the world' is not so far from ancient, volcanic Mt Mazama, whose huge, fiery, destructive eruption was described. Perhaps the burning sweathouse symbolizes such a volcanic event.

Why did Kingfisher, the only creature in the myth actually living in all the lands involved, have an obsidian boat? Did it symbolize the importance of his coming marriage, as obsidian was a sacred, shamanic material and his bride was learning to be a shaman? Did it symbolize Yurok life, for the Yurok made and sold redwood canoes to their neighbours? Did it suggest the duality of volcanic activity, how dangerous, fiery lava hardens into beneficial obsidian? Did it suggest the unrest of human society, how fiery jealousy can lead to injury as it did for sea otter, seal, and sea lion? The metaphor of the obsidian boat may include it all.

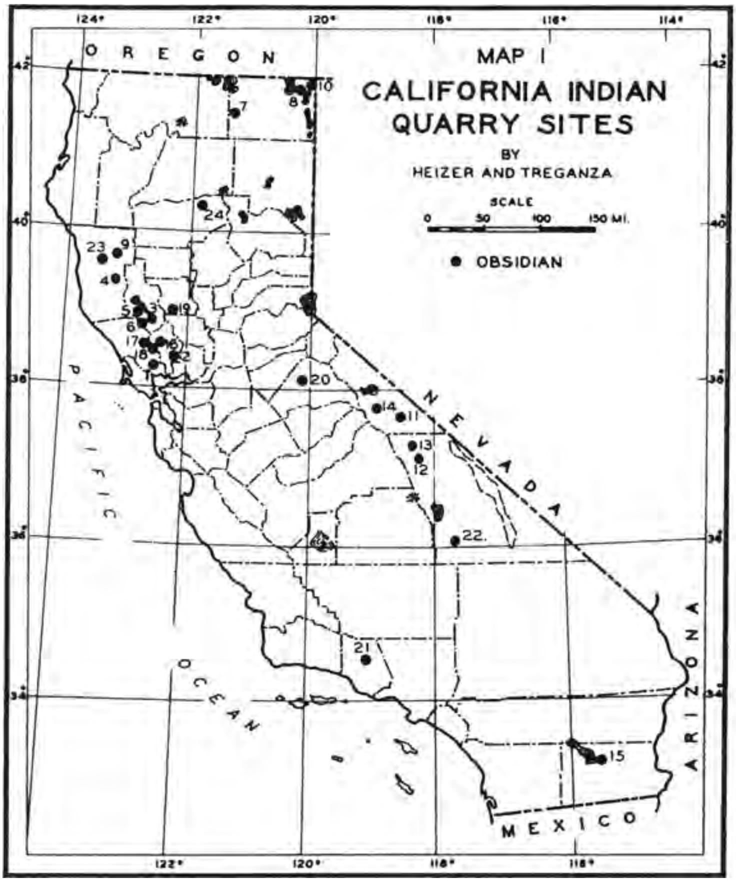
Mining obsidian

Obsidian is a dense, glassy volcanic rock, almost without bubbles or mineral crystals, formed from highly silicic magma ranging from dacite to rhyolite (Harris 1988). It is typically grey or black, although browns and reds are possible, and sometimes it is banded or streaky in appearance (Glascock *et al.* 1998). Jack (1976, p. 184) notes, 'Only obsidian extrusions composed almost wholly of glass of uniform physical properties and nearly free of inclusions were suitable for prehistoric weapon manufacture.' This is true in modern times, as well, for everyone I spoke to working with obsidian seeks material as glassy and pure as possible.

All California Indians knew about obsidian and its practical uses as projectile points, knives, scrapers, shamanic blades, and other tools, though other rock was used, as well. Indians valued the volcanic glass with its conchoidal fractures and edges sharper than surgical steel and found it a rare commodity, even in the 424 000 km^2 of today's California, a large area full of geothermal features like volcanoes and volcanic rocks, hot springs, fumaroles, mud volcanoes, and steam- and hot-water geothermal reservoirs. In fact, Indians fashioned and traded obsidian to such an extent that it became one of California's first widely marketed geothermal resources. Today obsidian still plays a small role in the economy. It is used by doctors, scientists, the artistic community, and hobbyists, and it is important in Indian religious beliefs and archaeological and anthropological studies.

A map of California obsidian quarries prepared by Heizer & Treganza (1944, p. 315, map 1) is depicted as Fig. 6. Although the number and nature of identified quarries has increased and been refined since 1944, this map and the observations of Heizer & Treganza (1944) allow us to discuss pertinent aspects of several of the more important quarry sites.

Location 2 is in NW California on a steep hill near St Helena in the Napa Valley. Occurring as nodules, the obsidian is rarely larger than a fist and imbedded in soft white pumice. The whole hill slope is mantled with at least 2832 m^3 of obsidian flakes mixed with numerous, rejected implement blanks and round hammer stones of sandstone, rhyolite, quartzite, and tuff used to



MAP 1

OBSIDIAN

1. Near Anadel on the Southern Pacific Railroad about 7 miles southeast of Santa Rosa, Sonoma County.
2. East side of Napa River, near St. Helena, Napa County.
3. Big Borax Lake, Lake County.
4. Ridge between Eel and Russian Rivers, Mendocino County.
5. Cole Creek, Lake County.
6. Mount Konocti, Lake County.
7. Glass Mountain, Modoc County.
8. Sugar Hill, Modoc County.
9. Williams Valley, Mendocino County.
10. South end of Cowhead Lake, Modoc County.
11. Glass Mountain between Bishop and Mono Lake, Mono County.
12. Fish Springs, Inyo County.
13. North of Big Pine near Bishop, Inyo County.
14. Bertrand Ranch, 60 miles northwest of Benton, Mono County.
15. Obsidian Butte on southeast shore of Salton Sea, Imperial County.
16. Head of Napa Valley, Napa County.
17. Upper Sonoma Valley, Napa County.
18. Wheatland, Yuba County.
19. Cortina, Colusa County.
20. Mount Kilili near Tuolumne, Tuolumne County.
21. Near Fillmore, Ventura County.
22. Coso Hot Springs at south end of Coso Mountains, Inyo County.
23. Black Rock, Mendocino County.
24. Deer Creek, Tehama County.

Fig. 6. California Indian obsidian quarry sites (Heizer & Treganza 1944). Used with permission, California Department of Conservation, California Geological Survey.

break the obsidian nodules and strike off the flat flakes.

On the hilltop some shallow pits are dug about 2 m in diameter. Once larger and deeper, now they are nearly filled by the deep layer of workshop material found across the ridge. It was probably here where the Indians easily separated the obsidian nodules from a solidly packed, loose aggregate of pumice.

The largest quarry is Location 3 at Big Borax Lake near Clear Lake in northern California. Several thousand tons and thousands of cubic metres of black rhyolitic obsidian debris is scattered over the quarry and workshop area. The exposed obsidian along the western slope of the flow was heavily worked, with nearly a 1 km-long area of debris and hammerstones reaching thicknesses of nearly 3 m. As noted by Heizer & Treganza (1944, p. 304), 'There can be no doubt that we have here an obsidian source of great aboriginal importance, and one that was worked intensively over a long period of time.'

Obsidian from Location 3 was traded very widely north and south, and also east to the Sacramento Valley tribes. In northern California, obsidian came down the Klamath River via the Shasta River and the Karok Indians from the Achomawi, who got it at Medicine Lake, Location 7 (Heizer & Elsasser 1980, p. 206). Location 7 is Glass Mountain in the Medicine Lake Highland, often mentioned in the myths. It is recorded that the Atsugewi, Achomawi, Yana, and McCloud River Wintu all secured implement material from this general location. Betty Lou Hall, a member of the Shasta Nation, has about a one-ton block of obsidian from Glass Mountain in her front yard. When asked why, she replied, 'It was a huge, beautiful obsidian boulder that presented itself to me. Medicine Lake is where our people went and obsidian was sacred to us and that is how I feel about it today' (pers. comm. 2005).

Location 8 is Sugar Hill, a large volcanic mountain with an excellent and important obsidian deposit used by the Achomawi, the Pit River peoples, and their neighbours to the north, the Northern Paiute.

Location 15 is Obsidian Butte on the SE shore of the Salton Sea near the Mexican border. Flaked obsidian is found around the butte and the obsidian here has small gaseous blowholes lined with a deposit of calcium. Similar obsidian has been found at ancient Indian campsites from San Felipe on the Gulf of California in Mexico to Palm Springs, California, and eastward to the Colorado River.

As far as we know, no private, individual site ownership existed for obsidian mines and quarry sites. These sites were considered natural resources owned by the group and everyone shared them. An individual's advantage could come through a special ability to produce finished articles from stone materials. Heizer & Whipple (1971, pp. 355–66) note:

> Rarely, if ever, did a tribe establish a rigid monopoly on a certain material, even though this could have been done by refusing access to the source. The Elem, a tribelet of the Pomo group, controlled the excellent Lake County obsidian quarries. The Elem allowed any Pomo-speaking group and even alien tribes (the Long Valley Wintun and the Coyote Valley Miwok) to visit the quarries and secure implement material.

For example, the Masut group of the Pomo tribe living around Calpella travelled 80 km to Clear Lake for obsidian from the quarries owned by the other Pomo groups. All the groups had to ask permission to quarry the stone but did not pay for the privilege.

Locations 7 and 8, Sugar Hill and Glass Mountain in Modoc County, were visited by most of the northern California tribes every summer to secure some obsidian. Betty Lou Hall of the Shasta Nation indicated that the Indians also held grand conclaves near Glass Mountain at Medicine Lake in the autumn when the surrounding tribes came to trade (pers. comm. 2005). The Medicine Men exchanged medicines and obsidian was gathered, as well. This was neutral ground and Indians from the Canadian Plains met at Walla Walla and continued south to Medicine Lake.

This is not to say there were no conflicts (Kroeber 1928; Heizer & Treganza 1944, p. 300):

> When a neighboring group did not recognize the ownership of an obsidian quarry, and was apprehended in the attempt to steal, warfare was the result . . . Conflicting claims of ownership of quarries which lay near the boundary division of two tribes were also the cause of contention. The Kato and Yuki both claimed the Black Rock obsidian deposit at Location 23, and the disagreement caused open warfare between the two tribes.

The Modoc and Achomawi both claimed the Sugar Hill obsidian quarry at Location 8, and war resulted when the two tribes came into contact (Heizer & Treganza 1944, p. 301):

> Many native mines and quarry sites in California seem to have been worked over a long period of time by different groups or individuals who needed the specific material at the moment. No evidence exists that any tribe had a special class of miner whose sole job was mining raw material. Some evidence suggests that in a few tribes specialists devoted most of their time to producing finished stone articles' (Fig. 7). The Pomo recognized their obsidian chippers, calling the artisans *ce emai tsu donta*, or 'bow-arrow maker'.

Mining obsidian mostly meant breaking down outcrop materials. Sometimes these were solid masses of obsidian and sometimes not, as with the fist-sized nodules found at Location 2. Sometimes large amounts of obsidian were quarried out, such

Fig. 7. California Indians quarrying and chipping obsidian, as drawn by Thomas Moran after a life group in the US National Museum. The seated man is making a large, ceremonial blade, as shown in Figure 2 (Heizer & Treganza 1944). Used with permission, California Department of Conservation, California Geological Survey.

as at the Borax Lake and St Helena obsidian quarries. However intensive mining operations with systematic, large-scale, continuous exploitation of a rock or mineral deposit didn't occur.

Location 22 is Coso Hot Springs at the southern end of the Coso Mountains in SE California. The obsidian quarry, near the crater of an extinct volcano, has abundant chipped rejectage material along the outcrop talus. Subtriangular obsidian hammer stones weighing about a pound were used to quarry obsidian and break it into flat, portable pieces. The pieces would be carried off, perhaps traded, and made into finished objects elsewhere. At Location 24 in northern California, the Yahi Indians collected obsidian boulders to trade with neighbouring tribes.

Breaking rocks with fire was a mining technique known widely among North American Indians. For this reason Heizer & Treganza (1944) speculated that other California tribes may have used the same techniques. However the only statement found on record for mining obsidian with fire concerns the northern Sacramento Valley Wintu, who split off blocks of obsidian from Glass Mountain by building a fire against the rock (Heizer & Whipple 1971, pp. 358–9).

Perhaps so few California references for mining and working obsidian include fire because the Indians knew the results—that fire leaves obsidian with matte finish (that may look like weathering), surface sheen, fine crazing, deep surface cracking, vesiculation, incipient bubbles, and fire fracture, to use modern terminology (Steffen 2002). Higher fire temperatures and lengths of exposure amplify these changes, which may explain why some Indians felt safe just briefly heating the pieces of obsidian they wanted to work on.

For example, in 1877 Stephen Powers watched Indians using fire to prepare pieces of obsidian for chipping. He saw the Viard, in far NW California, process the pieces by heating them in a fire and then cooling them slowly, splitting them into small pieces. The arrow maker chose among the pieces and set to work. In fact, the technique of gently warming the obsidian prior to pressure or percussion chipping was fairly widespread in northern California (Holmes 1919).

The Wintu of the northern Sacramento Valley said they did *not* quarry obsidian that had been exposed to the sun for an exposed surface was weathered and altered so it would not flake properly (Fowke 1896). They believed the sun caused the weathering, but a *weathered appearance* is a sign of burned obsidian, perhaps understood by an archaeologist who wrote in 1935 that the alteration probably came from *more than just sunlight* (DuBois 1935). In fact, a matte finish resembling weathering is one effect of fire on obsidian, and without knowing this, the Indians DuBois referred to may have been avoiding obsidian altered by fire. It may be true that California Indians *did not* use fire to mine obsidian because they knew the results and chose to avoid them (Hodgson 2005).

Attitudes toward obsidian mining were important. Conserving natural resources was a California Indian philosophy running through everything (Heizer & Treganza 1944), including the use of mines and quarries. Mining for obsidian certainly had religious aspects. The Wintu of McCloud River in northern California used obsidian from Glass Mountain. In the summer, two or three men would make a two- to three-day trip NE to the quarry. The men fasted throughout the journey, as the act of obtaining obsidian was seen as a semi-religious quest. Roy Hall of the Shasta Nation indicates that Indians used shoes with elk-hide soles to protect their feet as they walked over the obsidian flows (pers. comm. 2005).

In the more eastern areas of the United States, some quarry sites, including the obsidian cliff at Yellowstone National Park, were recognized by all Indians as neutral ground where tribes who were bitter enemies could meet but not fight. The same concept of neutral ground occurred in California at the obsidian quarries of Clear Lake in northern California, where any hostile group could meet each other and trouble was forbidden. The system worked out of common consent for the mutual good, as there was no other way to enforce it.

Today's archaeologists analyse obsidian to help learn when an obsidian object was made through the use of obsidian hydration studies, and where it came from through the application of X-ray fluorescence spectrometry (Shackley 2005). Interfacing obsidian myths with such studies might help to locate and verify obsidian sources. Long ago, California Indians noted the unique qualities of the flows, their variations in physical and chemical characteristics, such as texture, hardness, cleavage, and colour, and chose the best obsidian for each project. The Pomo Indians of Clear Lake in northern California divided the local obsidian into two types: *batixaga*, or 'arrow obsidian,' from Lower Lake, Location 3; and *dupa xaga*, 'to cut obsidian,' from Cole Creek, Location 5. The first was used for arrow points and the second, which breaks cleanly with sharp edges, for knives and razors (Heizer & Treganza 1944). Roy Hall of the Shasta Nation remembers a Shasta Indian named Sergeant Sambo who worked obsidian in the 1950s. He would take pieces of obsidian and say, 'This good, this not good' (Hall, pers. comm. 2005).

Some California Indians considered obsidian to be extremely poisonous (Heizer & Treganza 1944). A number of California Indian tribes believed in the reputedly toxic properties of obsidian. Location 14 in east-central California is an obsidian deposit in the Owens Valley the Paiute thought poisonous (Steward 1933). Among the Western Achomawi of Modoc County, an arrow point maker carefully inspected chips struck from a block of obsidian, judging if each one was poisonous: one chip might be poisonous and the next one not. Splitting off a flake, he examined it and said, 'This for grizzly bear, this for coyote, this for war' (Wheeler-Voegelin 1942, p. 91). These are the pieces he kept. Wintu arrow points were mostly obsidian, although some were made from other stone. The red and white points were considered supernaturally poisonous, especially the red (DuBois 1935). Why obsidian was considered poisonous is not known, but the effectiveness of obsidian arrowheads in war and hunting may be a reason (Heizer & Treganza 1944).

A final example, though not of obsidian, illustrates the religious aspects of mining. A sacred flint mine was reached through a cave at Table Mountain near Oroville in northern California. The opening was small and a person had to crawl in, throwing ahead offerings like beads or dried meat. Only the amount of flint that could be dislodged with one blow could be carried away on each visit, and the miner had to crawl out backwards (Dixon 1905).

Obsidian tools in everyday life

Projectile points likely constitute the most well-known and discussed obsidian tool. By the second half of the nineteenth century, explorers mostly watched the old men making the points. Stephen Powers (1877, p. 52), in visiting the southern California Yokuts and watching an arrowhead being made, noted that '... even common arrowheads are now manufactured only by old Indians, who cling to the traditions of their forefathers. Old men are usually seen at this employment.' Perhaps making projectile points was a dying skill. However, older men in prehistoric groups may have made the points because longer practice made them better at it and, as age lessened their hunting skills, they needed to exchange projectile points for meat (Titmus 2002).

Paul Schumacher visited the Klamath River Yurok Indians in northern California (1877, pp. 547-9). He wrote:

> I had the good luck to meet the last arrow maker of the tribe, on the right bank and near the mouth of the Klamath River ... He showed me the mode of making stone weapons, of which the following is a description. For the manufacture of arrow and spear points ... and knives ... obsidian and similar stones of conchoidal fracture are used. The rock is first exposed to fire, and, after a thorough heating, rapidly cooled off, when it flakes readily into sherds of different sizes under well directed blows at its cleavage.

The fragments are assorted according to shape and size best corresponding to the weapons desired; the small ones, best fit in shape and thickness, are used for arrowheads; similar sherds, but larger in size, for spear points, and so on.

He says, to make arrowheads, the larger flakes are detached and the rock is roughly shaped into the desired form; then the long flakes that frequently reach the middle of the sherd are broken, producing the ridge points. Now the smaller chips of the cutting edge are worked, going from the point, the more fragile part of the weapon, toward the stronger end. To work out the barbs and projections, a bone needle about 10–12 cm long is used.

Spears, too, were important. Making crude but effective spears, the Miwoks used sinews to bind large obsidian spearheads to the ends of smooth, mountain mahogany poles about 2 m long (Barrett & Gifford 1933). The spears were used mainly for war.

Today people still make obsidian projectile points in many sizes for many purposes, at all levels of artistry and skill, and exhibit and market them widely. Both modern and traditional methods are used and many groups and organizations are dedicated to the purpose. Projectile points are made as works of art, as a hobby, for hunting, and for learning more about Indian cultures—a motive of many, including archaeologists and anthropologists. Dr Errett Callahan, a reconstructive archaeologist, only uses traditional methods for making projectile points. Learning to do this, he says, has meant spending '... 20 years working my way through the Palaeolithic, Palaeo-Indian, Archaic, and Woodland levels and another five years working through the Mesolithic' (pers. comm. 2005).

Archaeologist Mike Frank says that from learning to make points:

I now can pick up a 10 000-year-old stone tool and instantly feel the decisions of the maker ... the cores make instant sense. I understand the obsidian cores, how they were shaped, including where mistakes were made—the same ones I try to avoid. Without having done this myself, I never would have understood this (pers. comm. 2005).

To make a bow, the Central Miwok hacked a cedar bough from a tree and roughly trimmed it with a sharp-edged stone. They scraped it with a flake of black obsidian or a split deer leg bone and rubbed it with a stone like emery and a piece of scouring rush (Barrett & Gifford 1933). In battle, the Miwoks used bows, arrows, and spears. Neither shields nor armour were used. A warrior's safety depended upon dodging the missiles of his enemy. One member of each band of warriors worked behind the fighting line collecting arrows shot by the enemy. These were shot back at them.

Stephen Powers (1877) reported that the northern California Yurok valued obsidian knives for cutting and skinning. In southern California, knife blades were of different lengths and chipped to an edge on both sides. The hunters used long, slim, sharp, pointed ones (Patencio 1943).

The Atsugewi and Mountain Maidu of northern California sometimes affixed wooden handles to their obsidian knives, as did the Yokuts in southern California (Schulz 1954; Dixon 1905). The Northern Maidu made knife handles by tying together two pieces of wood and securing them with pitch. Shasta Indian knives often seemed to be without hafting, although sometimes a piece of buckskin was wrapped around one end (Dixon 1907).

Scrapers, a variation of the knife, very often were made of red obsidian by the Shasta Indians (Dixon 1907). Roy Hall of the Shasta Nation says obsidian scrapers always have been very effective for scraping animal hides (pers. comm. 2005). Archaeologist Mike Frank notes that he has skinned a deer with an obsidian blade that was dulled just a little by the end of the project (pers. comm. 2005). After killing an animal with an obsidian point, Indians used obsidian to cut through hide, bone, and muscle (CalTrans 2002).

Today obsidian knives are made as works of art and for medical and scientific use. 'The literature says that obsidian may be up to 500 times sharper than steel. Statements on edge thickness vary between one molecule, 10 molecules, and 30 angstroms' (Callahan, pers. comm. 2005). Dr Lee A. Green says, 'Electron micrographs show a remarkable difference: steel scalpels "bite" because microscopically their edges are really rather crude saws. Obsidian is smooth to only slightly wavy even at extreme magnification' (pers. comm. 2003).

Jeff Wiley is Manager for Marketing and Technical Support for Fine Science Tools in Foster City, California, a company that has sold obsidian knives for 10 to 20 years (pers. comm. 2005). The obsidian blades are used for fine surgery or dissection work when a stainless scalpel blade is not useful, either because of metals in it or because it isn't sharp enough. Some plastic surgeons say obsidian blades cut so finely that the skin heals without as much scarring. Also, no trace elements are left in the tissue as may happen from a metal blade as trace metal analysis of the tissue can show. Neurosurgeons use obsidian because it is electrically non-conductive and the neurons are not interfered with. The blades have maple dowelling for handles and a special epoxy coating sealing the joint between the blade and the handle. This allows the knife to be autoclaved.

Dr Green (mentioned above) an Associate Professor of Family Practice at the University of

Fig. 8. Pomo Indian basketry language for obsidian chips. Courtesy of the Department of Conservation, Division of Oil, Gas, and Geothermal Resources.

Michigan Medical Center, uses obsidian blades for removing moles, reconstructing torn earlobes, and breast biopsies. The blades can be used 10 to 20 times before being discarded. Dr Green keeps his blades in a cold sterilizing solution to preserve their sharpness (Green 1997). He said:

> I like the obsidian knife because it is very sharp and very smooth at the microscopic level. It traumatizes the tissue less. Electron micrographs have shown what I suspect is the reason why obsidian scalpels seem to cause less scarring. The used steel scalpels have lost their 'teeth.' They've left microscopic bits of metal in the tissue they've cut. Nickel is a component of stainless steel, and is a known tissue irritant in some people. I suspect the fact that obsidian contains no nickel and doesn't leave bits behind may be part of its benefit (pers. comm. 2003).

Dave Galloway, who makes obsidian projectile points and blades, described the sharpness of obsidian, saying, 'The little slivers are wicked. You don't see them going in, you only notice the bleeding' (pers. comm. 2005). Once after cutting his finger on an obsidian edge, he could notice nothing wrong except for the bleeding.

Baskets were an important Indian object, and obsidian was part of the basket-making process, both as a design and a tool. An elegant, repeating design of obsidian blades was Pomo Indian basketry language for *obsidian chips* (Fig. 8). Note the unrelentingly sharp edges of obsidian.

An obsidian tool was used by Indian women to prepare willow stems for weaving into baskets. Betty Lou Hall (pers. comm. 2005), of the Shasta Nation in northern California, said that her daughter, Mary, uses a willow bark stripper of obsidian. Mary gathers willow stems to weave into baskets at a site on Willow Creek. The larger stems are cut off. A notched area in the obsidian blade is where the willows are pulled through. All Indian women knew to do this, including her husband's mother.

Obsidian tools were used to create personal adornment. Miwok men and women, usually between the ages of 12 and 15 years, practiced decorative tattooing (Fig. 9). Normally the design extended from the edge of the lower lip to the umbilicus and other designs were placed on the shoulders, arms, hands, chest, stomach, and thighs. To tattoo, the black ashes from the root of a plant called *ku'ya*, probably angelica, supplied the pigment. The scarring instrument was a sharp point of obsidian set in the end of stick about the size of a pencil. After the area to be tattooed was pricked thoroughly and the blood freely flowed, the black ashes were mixed with blood and rubbed into the tiny wounds. Tattooing also was medicinal when the skin directly over a severe pain was tattooed. A Central Miwok woman, observed in 1913, had lines tattooed on her neck, reputed to have cured consumption (Barrett & Gifford 1933).

Obsidian was also used for scaring and scars were made intentionally with obsidian flakes. Chicago's Field Museum of Natural History has an obsidian flake—its largest dimension is 27 mm—used by the southern California Miwok for making scars in sickness and grief (Barrett & Gifford 1933). Scarring by some northern California Indians was undertaken with small, sharp flakes of obsidian to strengthen the arms and legs of men about to go out on a hunt (Schulz 1954). The practice was known to Ishi, perhaps the last of the Yahi Indians (Kroeber 1961, p. 173).

Obsidian was also symbolic and 'Stockton curves' were used by the Central Miwok. These were identified as imitation bear claws, or *tisus uzumatiñ*, and worn on the left hand by dancers of the *uzumati* or grizzly bear dance. Four of the curves were attached to sticks that were lashed to the four fingers (Barrett & Gifford 1933).

Fig. 9. Huchnom tattooing in northern California (Powers 1877, fig. 16).

Obsidian tools were needed in times of grief. The most sorrowful mourners at an Atsugewi's death were the deceased's close relatives, but friends mourned, too. A close watch was kept to prevent anyone from committing suicide. Among the most common methods was to swallow small bits of obsidian (Schulz 1954). When I mentioned the custom to someone who works with obsidian, he recalled the piles of tiny slivers of obsidian he produces, calling them brutally sharp. He said that if anyone took a mouthful of those, it would be lethal.

Miwok Indians cut their hair with an obsidian knife as a sign of mourning for a close relative. The knife was hidden or buried with the corpse to prevent a malicious shaman from finding it and causing illness or even death by '... placing certain medicines upon it and performing special ceremonies over it' (Barrett & Gifford 1933, p. 222).

Obsidian's value

Trading was mostly a matter of individual barter and it was difficult to prepare a list of equivalent values for objects. In Yowlumne territory in southern California, obsidian could be traded for anything and had a very high trading value (Latta 1949). Some Indians found the longest ceremonial obsidian blades so valuable that no price was ever set upon them (Rust 1905). The following valuation list, related approximately to the year 1880, was collected from several northern California Wintu Indians and published in 1935 (DuBois):

A deer hide: a *loptci* of rope
Basket: a similar basket
Sack of wheat flour: 20 or 30 salmon
Woodcock head: $1
Woodpecker scalp: 25 cents
Pestle: $5
Very good storage basket: $10
Cooking baskets: $1 to $4
1 pound lump of obsidian: $20

Thus for millennia and at least until 1880, California Indians valued obsidian above many other things.

Obsidian in museums

Obsidian collections are important to California's Indian museums. Sherri Smith-Ferri, a Dry Creek Pomo Indian and Director of the Grace Hudson Museum in Ukiah, California, said (pers. comm. 2005):

> Obsidian is common and preserved in a way that a lot of things are not. Obsidian objects are an important category of tools used by a lot of California Indians. They are quite useful for learning trade routes and occupations, routes of contact, and relative dating. This gives us a sense of time and changes in hunting technology. People are definitely relearning the technology of how to work obsidian. It is nice to have a diverse collection in the museum for people to look at as they learn flaking techniques.

Michael Tucker, Curator for the California State Indian Museum, noted:

> As we put obsidian on display, we didn't think of it as a focal point of our exhibit. We thought of it as belonging to the stories we are trying to tell—and obsidian is a part of many stories. Our displays of religious ceremonies, trails and trade, and hunting all include obsidian objects. In our case on Ishi, the last Yahi Indian, we include arrowheads he made from bottle glass. By then the trade routes had shut down and the Indians had substituted manufactured glass for obsidian (pers. comm. 2005).

Ishi

Ishi's use of obsidian and manufactured glass brings us full circle, to an ending of the story of California Indians and obsidian, and to a beginning. Ishi, who may have been the last Yahi Indian, was a northern California man who wandered half-starving from the wilderness to the corral of a slaughterhouse near Oroville, California, in 1911. After a few days he was placed under the care of Professor A. L. Kroeber at the University of California. Ishi lived and worked at the university's Museum of Anthropology in San Francisco (now the Phoebe A. Hearst Museum of Anthropology in Berkeley) until his death in 1916 from tuberculosis.

Back at his home in Deer Creek, Ishi had gathered bottles discarded near settlements, chipping the manufactured glass into projectile points, for the obsidian trade routes were long gone and obsidian was scarce, although some was found and used. Ishi made points of manufactured glass with the same skill he applied to obsidian (Kroeber 1961, p. 182). The one, known point that Ishi made in his pre-museum days is now part of the Phoebe A. Hearst Museum collection. However, while living at the museum, Ishi made many points, some during countless public demonstrations, from obsidian and from manufactured glass (Fig. 10). Many are at the museum (Shackley 2003).

Shackley wrote that considerable differences in style exist among the projectile points Ishi made before and after arriving at the museum and those made by his assumed direct Yahi and Yana ancestors; and considerable similarities exist between historic Wintu/Nomlaki points and those Ishi produced at the museum. He said, 'What emerges ... is a picture of an amalgam culture by the early to mid-nineteenth century, where a Wintu/Nomlaki-Yahi boy learned to produce projectile points as a Wintu/Nomlaki but lived the life of a Yahi in the

Fig. 10. Ishi employing direct, hard-hammer percussion on obsidian cobbles during a 1914 trip back to Deer Creek with his friends from the museum. 'Both Nelson (1916) and Pope (1918) observed that Ishi also reduced obsidian cores by throwing a nodule against another stone and reducing the pieces through indirect percussion using an antler punch' (Shackley 2003). Courtesy of the Phoebe Apperson Hearst Museum of Anthropology and the Regents of the University of California, photographed by A. L. Kroeber.

Lassen foothills until no more Yahi remained' (Shackley 2003, p. 193). Here is an example of an archaeologist using obsidian and glass projectile point data to help make cultural inferences.

Errett Callahan (pers. comm. 2005) notes:

All of Ishi's points were of the highest quality, made with the highest degree of regularity, including the expanded notches that are difficult to form. The points were efficient, aerodynamic, and excellent cutting tools. Ishi's life had been untouched by outside cultures and his points were worked with a higher degree of skill than found in points from different cultures around the country at that time. Many Indians had left stonework as soon as they could and the skills were lost. Ishi's cultural group was hidden so their skills remained unadulterated by outside influences.

A year after Ishi moved to the museum, he met Saxton Pope, a medical doctor working in the building next door. The two became fast friends who enjoyed sharing their mutual interests in bows, arrows, and points. Pope learned all he could about hunting from Ishi (Kroeber 1961, pp. 152–153). Errett Callahan points out that, 'Pope noted that Ishi's points penetrated 25 percent further than his own steel broadheads. Today's modern archery movement is founded on Pope's replication of points made to the same width and length ratios Ishi used in his points of glass and obsidian' (pers. comm. 2005).

Beautiful examples of Ishi's points from obsidian and manufactured glass are on display at the Phoebe A. Hearst Museum of Anthropology, in Berkeley, and the California State Indian Museum, in Sacramento (Fig. 11). How Ishi and other California Indians thought about and used obsidian, and how people do today, testify to the amazing, and evolving, roles of volcanic glass in our lives. This, in turn, leads us to marvel anew at the observational geological wisdom found in the California Indian obsidian myths from so long ago.

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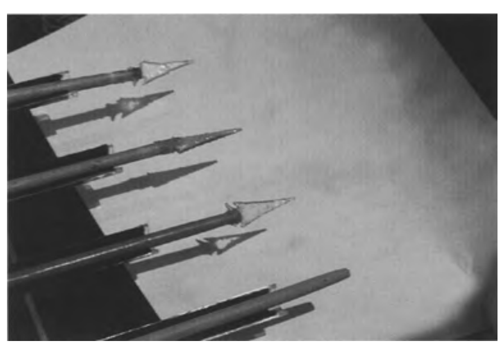

Fig. 11. Ishi made these projectile points from manufactured glass and bound them to shafts he had made. Courtesy of the California State Indian Museum, photographed by S. Hodgson.

Natural History Association, Inc. Quotations from *The California Indians, A Source Book*, edited by Heizer and Whipple; *The Natural World of the California Indians*, by Heizer & Elsasser; *Yurok Myths*, by A. L. Kroeber; *Wintu Myths* by DuBois and Demetracopoulou; and *The California Indians, A Source Book*, by Heizer and Whipple are copyrighted by the Regents of the University of California. The citations from these publications are used with permission.

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Erratic blocks: from protector beings to geosites to be protected

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Abstract: Erratic blocks are the main geosites in Turin's suburban area. Today, they are a symbol of the 'landscape to be saved' even for those who are barely aware of their geological importance. This is because the blocks are the subject of myths (based on their geomorphological characters), such as: interpretation of weathering as altars or runic writing; attribution of strange shapes, noises, lairs, to petrified supernatural beings; interpretation of isolated blocks as dwellings of protector beings; use of the blocks for boulders; supposed reports of UFOs and 'disappeared civilizations'. In ancient times, erratic blocks were at the centre of religious practices. However, most myths are in fact recent. The Barbarian invasions and the fight against Paganism destroyed the ancient myths. The creation of new myths proves that erratic blocks are able to attract mankind's attention in every epoch. When the geologist proposes blocks as protected geosites, he must show the connection between geomorphology and myths, maintaining the suggestive impact of the myths. Myths, including recent and altered ones, can work together with scientific explanation to make it easier for the public to understand the true importance of erratic blocks. By exploiting the power and appeal of myth, the community will more easily accept the need to preserve scientifically valuable geosites.

Nothing is more noble and terrifying than the majestic rock, the audaciously erected block of granite. The stone, first of all, is (Eliade 1954).

The morainic amphitheatre of Rivoli–Avigliana extends along the outlet of Val Susa, west of the city of Turin. The landscape is rich in glacial forms of the mid-upper Pleistocene, such as the morainic hills, the lakes of Avigliana and Caselette, the peat mosses of Piana dei Mareschi and Trana and a network of glacial dischargers. Erratic blocks are the most characteristic small forms. Currently, the law protects only a small part of this region from the environmental viewpoint. Only the areas near the lakes and the peat mosses, and the botany biotopes of Moncuni and of the slopes of the Musiné are protected areas. In the early twentieth century, the blocks were one of the very few protected environmental assets in Italy, precursors of today's geosites (areas that are protected for their geological value).

The naturalistic importance of the erratic blocks derived from their role in the discovery of the glacial origin of morainic amphitheatres. In the mid-nineteenth century, geologists believed that the large blocks of the Po River Plain derived from grandiose floods. Gastaldi (1851, 1871, 1874) affirmed the equivalence between the masses of the Rivoli–Avigliana hills and those left in historical times by Alpine glaciers: the hills arranged like an amphitheatre at the opening into the Po River Plain of some Alpine valleys, such as the Susa Valley, were moraines abandoned by enormous glaciers. The Roc di Pianezza was one of the subjects of debate in the dispute between Gastaldi and the other Italian geologists. This block, the largest one in the Susa Valley amphitheatre with its 5000 m^3, today is Masso Gastaldi, honouring the scientist (Fig. 1). Once the geological importance of the erratic blocks was recognized, the first law protecting them was enacted in 1922. The law was followed by a census and the tagging of some blocks (still preserved and legible on many of them), protected by special agreements with their owners (Sacco 1928).

Subsequently, since the origin of the morainic amphitheatre was taken for granted (Sacco 1887, 1921, 1938), the interest in the blocks progressively diminished. Only many years later were they studied anew by geologists, in their surveys for the second edition of the Geological Chart of Italy (Petrucci 1970; Bortolami 1976). The safeguarding law was abolished by 1939, which identified with markedly aesthetic criteria the natural attractions to be protected. In turn, this law was incorporated in the Law Decree 490 of 29 October 1999. It does not specifically protect erratic blocks, except if they are recognized as geosites.

Between Gastaldi's times and 1922, a great number of blocks disappeared. In some areas where they used to be abundant, for example the area once called Region of the Stones, today

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Fig. 1. Dedication of the Roc di Pianezza to Gastaldi. Translation of the plaque: 'To Bartolomeo Gastaldi, geologist, deep investigator of the history of glaciers, this erratic block was dedicated by the Italian Alpine Club, with the authorization of the Town government'.

blocks are completely absent, having been destroyed to facilitate ploughing the fields. Many were removed for use in construction. Nearly all those made of valuable rock, like the 'Verde Alpi' gabbro flaser, have been destroyed (Grassi 1980). Of the poorly usable serpentinite blocks, a small number have instead survived (Grassi 1982). In spite of their small size, erratic blocks attracted quarrymen in centuries past, because of the compactness of the rock and the proximity to the sites where it would be used. In the past, the high incidence of transportation costs over total costs favoured quarries near large cities, and the erratic blocks were the outcrops nearer the cities of the plain. The 1992 law for the environmental safeguarding, prohibiting the use of erratic blocks as construction material, definitively killed off a declining business that has been replaced by modern excavation in Alpine valleys.

However, the quarrymen's disappearance did not eliminate the risk of destruction of the blocks. Since the 1950s, morainic amphitheatres, which once were marginal and scarcely inhabited areas, have undergone intense urban development. Most of the territory is now occupied by townhouses or condominiums, an extension of Turin's suburbs. The blocks, seen as a hindrance to development projects, are gradually disappearing, along with the rest of the rural landscape. As they are one of the most characteristic features of the morainic amphitheatre, the blocks have recently become the symbol of the 'landscape to be saved', to preserve the beauty of the surrounding territory. They have thus become an essential element of the territory even for those who are only superficially aware, or are unaware, of their geological importance. Understanding this apparent contradiction involves considering them cultural as well as geological assets. Many are the subject of myths and traditions, based on geological and geomorphological characters. Understanding the relationships between geology and myth-making can shed light on some of the most obscure aspects on which society decides whether or not to safeguard a geosite.

Cupels, honeycomb weathering and landmarks

Professor S. Piolti (1881), following the ideas of Desor (1879), Keller, De Chaumont and other nineteenth century scholars, affirmed that the 'cup-shaped' erratic blocks of Monsagnasco, Casalegno del Pozzetto and Pera d'la Spina (Fig. 2) are 'monumental stones of prehistoric humans, primitive sacrificial altars with cavities and ducts to collect the victims' blood'. Shortly after this, Pera d'le Sacoce was added to the list of the cupel-shaped stones of the amphitheatre. *Sacoce* ('pockets' in Piedmontese) which give the block its name, are bowls of various shapes and sizes, positioned mostly on the vertical sides. They were recognized as natural weathering forms, akin to *tafoni*, in the early twentieth century (Sacco 1922*a*,*b*). Both *sacoce*, and the alleged cupels of Pera d'la Spina, can be referred to as honeycomb weathering (Robinson & Williams 1994; Mottershead 1994). The surface of the Casalegno del Pozzetto 'cup-shaped' block, which in fact has no cupels but etchings similar to grooves, is worked by weathering (flutes; Robinson & Williams 1994; Williams & Robinson 1994) and not by human hands. Only the recesses present on the Monsagnasco blocks could actually be cupels. Near them, other cupels of a yet more doubtful nature, were recently noted (GRCM 2000 with references).

Current scholars are reluctant to interpret the Monsagnasco blocks as sacrificial stones, even if the cavities really are cupels, produced by human hand alone, for these shapes occur in a very different context from those that definitely had sacrificial purposes (Fig. 3). For instance, those of Panoias (Vila Real, Northern Portugal) are accompanied by access stairs, rectangular tanks, mutually connected channels, and Latin inscriptions of the third century AD, describing their use for animal sacrifices. Areas of this kind are not wholly absent in Piedmont. In Susa, on a rock by the side of the Celtic road to the Gauls, and covered by 'Terme Graziane' (a Roman aqueduct of the third century AD), sixteen cupels and vats, connected by ducts, are accurately etched (GRCM 2000). This rock, already known by Piolti, has all the characteristics of a Celtic sacrificial area, and it is interpreted as such to this day. Therefore, the problem of the Monsagnasco cupels, whose age is hypothetically referred to the Celtic age or the Neolithic (Costa & Perotti 2002*a*), remains unsolved. However, the news that blocks might have been used as altars for bloody sacrifices immediately struck the imagination of the inhabitants of nearby towns, giving rise to a veritable myth.

Just five years after Piolti's observation, a local guide of the town of Villarbasse assigned a definite druidic origin to the cupels, and considered the sparse wood where the blocks were immersed to be 'highly suitable for the celebration of religious rites attended by whole population'. Clearly, the origin of the myth lies in the 'altar-like' shape of the blocks. This is explicit in the case of the morainic amphitheatre of the Dora Baltea (Northern Piedmont): the Pera Cunca, similar to the Monsagnasco blocks, is interpreted as a sacrificial altar (Jovis 2001). This suggestion is linked to various popular reminiscences of ancient magic practices, if not actual cults, involving the blocks in Roman times. A definite historical mention is found in sermons by Bishop Saint Maximus, founder of the diocese of Turin (who was born around the mid-fourth century and died between 408 and 423 AD) who hurled invectives against the rocks or 'the devil's altars'.

The demonstration that an apparently ancient myth can in fact be very recent comes from the nearby Biellese area (Northern Piedmont). Here, the sculptor Giuseppe Maffei (1821–1901) made a drawing of the surface of an erratic block of mica schist with weak honeycomb weathering, located in the Cervetto gorge. The sculptor had the copy examined by an aunt of his, who was a medium. She interpreted it as a runic funeral epigraph of a Scandinavian princess, who lived partly as a female, partly as a male warrior. Maffei then sculpted an identical mica schist block, making it a 'copy of an inscription in the Cervetto gorge', and placed it in the Rosazza public park (G. Calleri in Gavazzi, 1994; Fig. 4).

On the other hand, crosses, arrows, lines and other conventional signs are undoubtedly signs created by human hands, present on several erratic blocks in the amphitheatre. Sometimes they can be dated, like the one near the Monsagnasco blocks, which bears the etching date: 1330 AD (Rimondotto & Rimondotto 1998). Their meaning is exemplified by the very name of one of the erratic blocks in the amphitheatre: the Pera Ciavoira. *Pere ciavoire* (closing stones in Piedmontese), which are often integral parts of walls made with stones removed from the fields in order to cultivate, are landmarks of great value in the rural civilization (Fig. 5). This use of the rocks has certainly contributed to the myth of the sacred value of erratic blocks, without an actual cult being necessarily instituted (for example in Pera Crusà, the crossed stone, located on the highest point in the Rivalta territory: Rimondotto & Rimondotto 1998). According to De Coulanges (1972), 'the mark set in the soil was, therefore, in some way the home religion planted in the soil, to indicate that this land was, forevermore, the family's property. Use of landmarks or sacred limits for the fields appears to have been universal in the Indo-European race'.

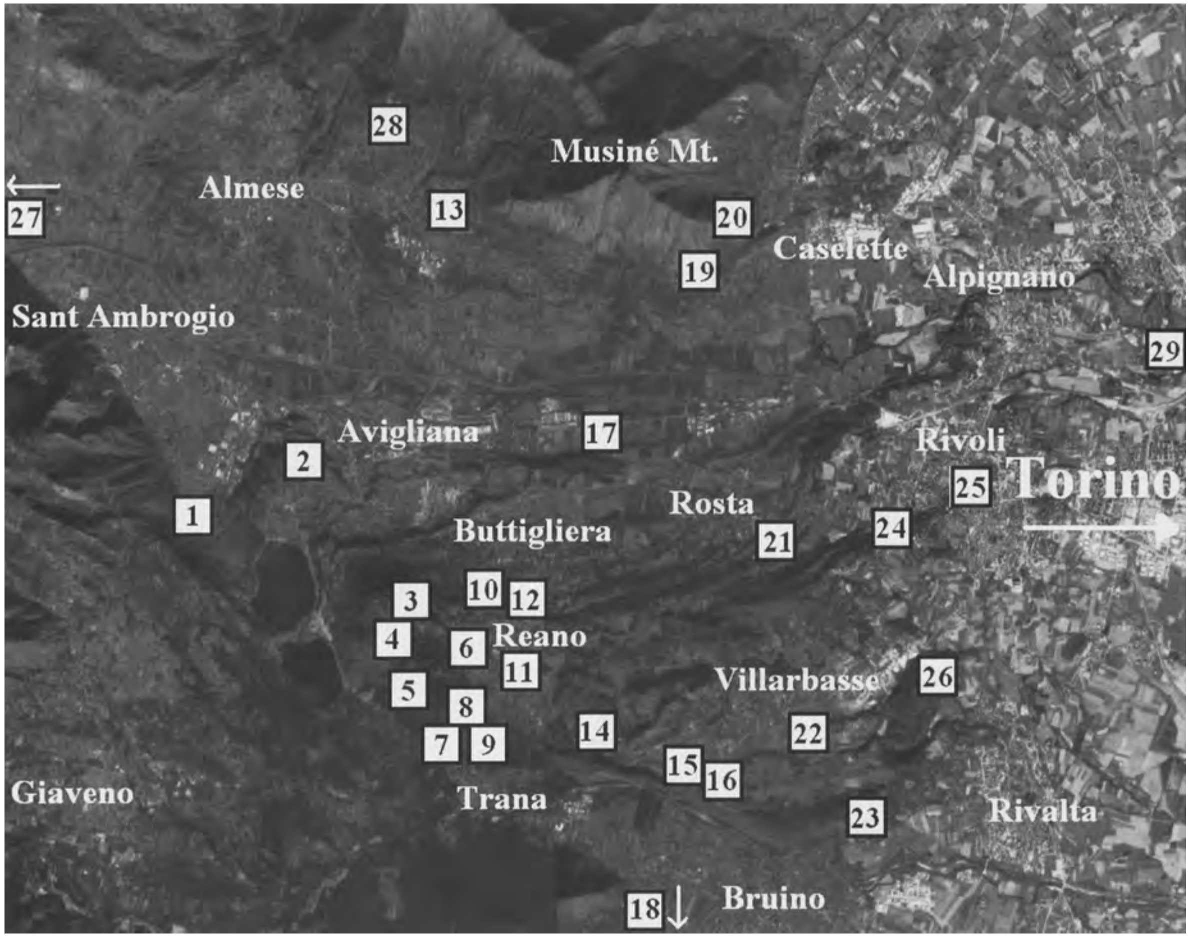

Fig. 2. Position of mentioned blocks in the morainic amphitheatre. 1, Pera Filbert; 2, Block of Case la Cucurda; 3, Pera Luvera; 4, Pera d'le Masche and Roc d'l Picapera; 5, Roc d'le Tume; 6, Block of Case Maresco; 7, The Menhir; 8, The Altare; 9, Pietra del Tempio and Pietra Salomone; 10, Pera Garoira; 11, Pera Morera; 12, Roc Mufi; 13, Pera Masnà; 14, Pera d'la Spina; 15, Roc Penn; 16, Pera d'le Sacoce; 17, Block of San Antonio di Ranverso; 18, Pera Caval; 19, Roc d'la Bula; 20, 'Menhir' of the Musiné; 21, Pera Chiavoira; 22, Blocks of Villarbasse; 23, Pera Crusà; 24, 'Pietra a scodelle' of Piolti; 25, Roc San Giorgio; 26, Blocks of Monsagnasco; 27, Block of the Conte Verde Castle; 28, Rocca Pinta; 29, Block of Pianezza.

Fig. 3. The surface of the best known among the Monsagnasco Blocks.

Homes for demons and saints

Pietra Salomone (Solomon's stone) is one of the largest erratic blocks in the moraines amphitheatre (Fig. 6). In Hebraic tradition, Solomon, David's son and successor on the throne of Israel, was the wisest man in the world, also in Italian tradition. 'He described plant life, from the cedar of Lebanon to the hyssop that grows out of walls. He also taught about animals and birds, reptiles and fishes' (1 Kings 4:33). He knew life and men: he is the author of the book of Proverbs, and protagonist of the medieval dialogue *Salomon et Marcolfus*. According to Western tradition, and also to the Koran (34:13), Solomon had demons at his orders to build the Temple in Jerusalem. So he commanded them to transport Pietra Salomone from far away. Why the demons would have abandoned the block near Reano is highly mysterious. The myth takes into account the large size of the block, its sacred nature and the use as a stone quarry. We like to think that even 'back then' people wondered about the origin of erratic blocks, and to solve the

Fig. 5. The *pera ciavoira* located in the courtyard of the Castle of the Green Earl; it marked the border between the Longobard Kingdom and the Kingdom of the Franks.

conundrum they invoked the devil's work. Pera Morera (the Moors' stone) is another block in the amphitheatre. The Saracens, a real and highly feared presence in tenth century Piedmont (they pillaged the Novalesa abbey), in folklore become the demonic Moors, who gathered near this block or magically brought it here from some faraway place. Another Pietra Salomone is located near Palazzo Adriano (Sosio Valley, Sicily). It is part of a group of five isolated rocks, one of them called Pietra dei Saracini (Saracens' stone, in Sicilian), showing that the myth was widely known throughout Italy.

There is an alternative myth on Pera Morera. The Moors did not gather near the block or bring it from afar, but they settled and actually lived in it. Contrary to what many texts allege, very little is known about what the blocks really meant to the Celtic-Ligurian populations, the amphitheatre's first historical inhabitants. However, Eliade (1954) recalls that for a great many peoples the blocks may in fact have represented a temporary or symbolic dwelling for spirits, and that these notions led to the custom of erecting monuments and engraving tombstones for the deceased. In the blocks, the ancestor, the

Fig. 4. The sculpture by Maffei, sole example of artistic copy of an erratic block.

Fig. 6. The Pietra Salomone is a block that was split in two by freeze–thaw action, as if it were broken when it fell to the ground.

deceased person fixed in the stone, was transformed from a presence filled with rancour towards the living to an instrument for defending and enhancing life. Thus the Samoyeds prayed and offered gold to the *pyl-paja*, the rock woman. In the continental Celtic area, relics of the faith in fertilizing rocks survived in the tradition of *glisse* (sliding) on a boulder, done by women wanting to have children, and in the friction (rubbing) of newly-weds against a boulder (citations of Saintyves, Sébillot, Lang, Sartori, De Vasconcellos, in Eliade 1954). In Finistère, in the Middle Ages, the clergy and the king issued numerous laws against the stone cult, newly-weds' coupling on rocks when the Moon was full, and other sexual practices near the blocks (citations of le Pontois in Eliade 1954). In Carnac, the authorities went so far as to plant a cross on the Creuz-Moquem menhir, to prevent a rite similar to friction. In Piedmont, at the Chapel of the Stone in Oropa, there was a variant of friction whereby newly-weds would hit the boulder with their buttocks; this tradition lasted until the last century (Sacco 1928). In the area once inhabited by Ligurian populations, anthropomorphic stones, possibly dedicated to ancestors, were erected in pre-Roman times: for instance, the renowned ones in Val Magra. In the Eastern, non Celtic, Alpine area, the myth of the petrifaction of supernatural entities is known as well. For example, the blocks of Val Rendena (Alto Adige), according to local traditions, are the petrifaction of Balajal, devil king, and of his assistants Coa de Caval, Pontirol, Palpadegastro, Basadone, Barzola, Calcarot and Manarot (Lapucci 1991). In Central Alps there are 34 'massi avelli', that are graves dug in the erratic blocks and covered from one slab. They were carved by the Barbarians (Goths or Franks) in the fifth or sixth century AD.

Thus, the petrifaction of the Moors in the Pera Morera is only one of the many examples of a myth that was widespread throughout the Alpine area and the surrounding regions. This myth probably originated in peculiarities of the block, which was 'animated'. Sacco, discussing the 'bowls' of Pera d'la Spina, recalls that 'today (1922) young people sometimes put their heads in them to hear strange noises'. Obviously, this natural curiosity created a myth: inside the block, a dragon guards a treasure, making the strange noises. Pera Morera, Pera d'la Spina and other erratic blocks in the amphitheatre were thought of as dwellings of more or less friendly spirits guarding the sites. The belief was occasionally confirmed by the name of the block. This is obvious when the name recalls an animal that inhabits it (e.g. Pera Filbert, Fox Stone: Sacco 1922*c*). In this case, the myth derives from the repeated observation of the same animal near a block (permanent dwellers like foxes, snakes, badgers) coupled with the belief that demons can be incarnated in some 'harmful' animals (Sprenger & Institor 'Kramer' 1486; Guaccio 1626). According to a well known legend, the Sicilian Pietra Salomone was the final dwelling of a lost soul, whom the biblical king fixed in the block to prevent further trouble for local inhabitants. The adjacent blocks were given the name of objects they vaguely resembled, hence 'petrified' in them. As any tourist can verify, the custom of recognizing silhouettes resembling the human form or objects is timeless. Among the blocks in the amphitheatre, Roc d'le Tume resembles a stack of *toma* cheeses; Roc d'la Bula (i.e. Ball Rock) looks like a big ball. Connected to the presence of a beneficial entity in the block, is the tradition of 'holed stones' through which children are made to go to assure their good health. This custom was widespread in Europe, from England to Greece (Eliade 1954), and very probably also at the Rivoli–Avigliana amphitheatre. Where there are pairs of erratic blocks naturally close to form a tunnel (Masso della Veneria, Pera Morera; Fig. 7) or a narrow pass (Massi di Case

Fig. 7. At the base of the Pera Morera, there is a characteristic tunnel, artificially cleaned.

Maresco) the space between the blocks was thoroughly cleared of all debris and dirt in ancient times.

The myth of inhabited blocks did not die out with the advent of Christianity. In medieval times, many blocks became actual or symbolic dwellings for saints and hermits. Their ascetic life was thought to protect the surrounding populations: thus, the block of San Grato in Aosta (the saint's motto was *chasser le mal et promouvoir le bien*, chase away evil and promote good) and the Roc San Giorgio (Saint George, of course, being the champion of good against evil) in Rivoli (Fig. 8).

The blocks and religion

In his brief '*I massi erratici e il sentimento religioso*' (*Erratic Blocks and Religious Feeling*), Sacco (1922*a*) notes a small number of erratic blocks with superposed religious paintings (Rocca Pinta), niches built as a result of vows (block of S. Antonio di Ranverso, block near Case La Cucurda at Avigliana), chapels (Roc di Pianezza, Rocca Pinta). With the example of Roc di Pianezza, he stresses that these blocks attracted cultural elements, from which 'one could look out quite far over the surrounding region'. The custom of erecting chapels, religious statuettes (Pera Morera), crosses, or just giving a block the name of a saint (S. Pancrazio, S. Luigi, S. Giorgio) is always lively. Pera Caval is a rock of modest height, with a well polished and slightly inclined wall, where sliding is amusing and not dangerous. Pera Caval is one of the few blocks where the *glisse* may have been practised, even as a child's pastime, i.e. sliding. The same name in the feminine gender, Stone Mare, has been given to a large rock in Saint-Renan (Finistère), on which women who wanted to have a child would lie for three nights in a row. We do not know whether Bosco delle Faie (Fairy Wood) was so named because it was sacred, or because it was the venue for a fecundity rite similar to those described above. *Faie* are feminine supernatural beings, of very ancient origin, whose name is associated with rocks in the Valle di Susa that are etched with petroglyphs, like Roca d'le Faie (i.e. the Fairy Rock; see Defazio 2000; GRCM 2000) and Molar d'la Fai (i.e. the Fairy's Millstone). The *faia*, in pagan mythology, was the *fauna* or *fatua*, the fawns' mate, able to foretell the future and preside on human events. In the Middle Ages, the name was assimilated to *fatica*, synonym for 'wild woman', i.e. woman of the woods, of the waters, and of the natural world in general. Thus *faie* are metamorphic beings, capable of changing others' appearance, and at the same time they frequent caves, rocks, hills, woods and springs. They are ready to rush to the aid of the innocent and persecuted, but they can also be malignant and vindictive (Zilli 2004*a*).

Fig. 8. The ancient painting of the dragon's slaying, near Roc San Giorgio.

The cavity of a block adjacent to Pera Caval contains a statuette, a copy of Our Lady of Rocciamelone. This Madonna is shown imparting a benediction from atop a block, which represents both, in the strictest sense, the Rocciamelone itself (the highest mountain in Valle di Susa) and, in a broader sense, all mountains and blocks, because the Blessed Virgin is the protector of mountaineers. The area has therefore always been sacred and not, as in the cases described below, as a result of a forced Christianization of pagan sacred areas: the original statue of the Madonna was erected during the Holy Year of 1900, much later than the abandonment of pagan rituals. The reason for the placing of the copy near Pera Caval should be sought in the suggestive nature of the area's geomorphology. The block, isolated in a meadow surrounded by dark woods, suggests a sacred protection and invites meditation and prayer.

In other cases, continuity between superstition and the Christian religion entailed the intentional Christianization of sacred pagan sites. Some examples are the practice of sculpting crosses or Christian symbols on the tip of *menhirs* in Brittany, on the Piedmontese blocks of the Path of Souls at Traversella (Ferrero 1994), on the block of S. Antonio di Ranverso (Giuliano & Vaschetto 1981) in the amphitheatre. However, in most cases Christians erected religious symbols as the first appropriation of marginal territories. These 'off limits' places, as the morainic hill still is today, were felt as a favoured field for evil spirits. In this regard, the veneration of St George from Lydda, slayer of the dragon that inhabited solitary places is significant. At the start of the most isolated part of the ancient Rivoli–Avigliana road (so infested by robbers in the twelfth century it was called *fura*, i.e. of the thieves: Sergi 1981, 1996), which passes by Pera Garoira, there is a small chapel dedicated to this saint (Fig. 9).

Also emblematic is the case of the Pera Luvera (i.e. stone of the wolves' place): a veritable 'wolves' place', and not only an imaginary one, since the Piedmontese wolves use the cavities at the base of the blocks as lairs (Borgia 2003). In a 1622 edict, Carlo Emanuele of Savoy authorized the inhabitants of the morainic amphitheatre to carry harquebuses and rifles, waiving the strict general prohibition, to defend themselves against the many wolves infesting the area. Evil dwellers of the blocks, therefore, were not just fantastic or imaginary, and the saints were far from useless.

Bouldering

Bernard Amy, one of the pioneers of modern rock climbing, used to preach that 'if you reach a boulder without moving a blade of grass, the boulder will become a mountain, and you will be on its summit'. Before him, the smooth, compact walls of the blocks had already been used sporadically as a training ground for Alpine climbs. In the 1970s, the myth of the possibility of becoming one with the nature you faced induced climbers to tackle erratic blocks (Fig. 10). From a simple training ground, the blocks became teachers which, treated with respect and devotion, developed climbing perfection. The analogy with the myth of the ancestor enclosed in the block proves the continuity of the collective subconscience throughout history. The novelty is a sort of symbiosis between man and the rock: the climber learns from the block, and pays it back by protecting it against the harm caused by urban sprawl, linked to Turin's suburban development. The climbers give an identity to the last blocks left without a name, to defend them from those who consider them no more than obstacles against development. Names are inspired by popular tradition, sometimes imagined, because it is lost or unknown, and hence reconstructed with the imagination and felt with nostalgia. There is proliferation of names written in an unlikely Piedmontese (Pera Masnà, Roc Mufi), fantasy 'Celtic' names are given (Roc Penn, the Altar, the Menhir: Motta & Motta 2004). The urge to give names is not limited to the blocks. Every sequence of holds found on one of them, often just a few tens of centimetres from the neighbouring sequences, becomes a route and is given a name (Grassi 1980; 1982). In the early 1970s these names were influenced by the 'Alpine' conquest logic, which saw a boulder as a miniature mountain. Thus the easiest routes are 'normal', the others hint at progressively growing seventy: for example, 'classic corner', 'modern corner'.

In the wake of the climbs on enormous American walls, described in specialized journals as psychedelic trips, the names of the routes become '*peyotes*', '*mescalito*', 'slab of the multicoloured caterpillars' or direct translations of the famous Californian routes. The *sassismo* became bouldering (Tejada-Flores 1967), and it reached a crossroads: ever more athletic passages ('overhang of Fortinbras') or playing for its own sake ('Disneyland')? In the mid-1980s, the names of the routes

Fig. 9. Rocca Pinta is one of the sites where continuity existed between superstition and Christianity: from the *glisse* to religious paintings and niches erected to honour vows.

Fig. 10. Today, bouldering is the main use for erratic blocks. (Pietra del Tempio, Stone of the Temple).

Fig. 11. The Musiné stele: a new myth, created as a prank or to gain fame.

became ridiculous, with the dissolution of mythical values (*gioco fricchettone senza pretese*, i.e. 'a silly game without any ambition'), following the same process that had led to a veritable boom of inscriptions on city walls.

The new myths

At the foot of Mount Musiné, archaeologists have long known a morainic plateau, thanks to the presence of some ancient cupels etched in the rock outcrops (GRCM 2000). On the Musiné, someone erected like a stele a rock fallen from the mountain, to make it look like the small erratic blocks of the area. On a smooth face, they etched it with two flying saucers, crosses and a pointed circle (Fig. 11). In the 1970s, journalists and 'ufologists' identified the block as a representation of the cult of the sun (various articles on newspapers *Gazzetta del Popolo* and *Domenica del Corriere* 1972) or a silent witness of 'close encounters' (Kolosimo 1972; Ansante Dembech 1976). Some schools even devoted field trips to it, until, during the following decade, it was proved to be a fake (GRCM 2000 with references; Arcà 1990). A short distance away, strange monuments made of galvanized iron were claimed to be antennae to communicate with entities from other worlds and dimensions (Ansante Dembech 1978).

In the Susa Valley, according to an ancient legend, Herod, after ordering the massacre of the innocents, was damned for all eternity. He had to travel round the world enclosed in a red hot iron carriage. To free himself from his torment, Herod tried to smash the carriage against the rocks he met on his way. Some of these rocks were located between St Antonino and Vaie (a few kilometres upstream of Mount Musiné). Here, at night, the carriage shot off smoke and sparked as it hit the rocks, until Herod gave up and disappeared (Lapucci 1991).

Recently, Ansante Dembech (1976, 1996) transported the site of the legend on Monte Musiné, replacing the fallen rocks of Vaie with the suggestive erratic blocks. The alteration of the legend enabled its interpretation as a myth derived from ancient UFO sightings. The selection of Mount Musiné as a venue for 'close encounters' is curious. A contribution to this 'new myth' has come from the importance given to the mountain by geologists, due to the probable origin of the rock from the Earth's mantle. For example, this has also created a myth in which Mount Musiné is an extinct volcano, but housing mysterious 'internal works' (Gariani 2004). Erratic blocks are also involved in this confused 'new age' picture. Dry walls or accumulations resulting from stone clearing, incorporating erratic blocks, are identified with certainty as the megalithic walls of 'cyclopic' cities (Barbadoro 2004); with the addition of a little paint, flutes draw fantastic temple friezes, cupels and honeycomb weathering are star charts (Rimondotto & Rimondotto 1998; GRCM 2000) or maps to find buried treasure (Barbadoro 2004). The myth that has best withstood obvious criticism, exceeding the narrow circle of the most fanatical ufologists, involves Pera Luvera. Allegedly, this block was a sort of meteorite, transported from an outer space. It is also, relatively speaking, the most ancient myth, attested to by an inscribed stone laid in 1921 by Société Urania, the first association of Piedmontese astrophiles. Although young, these are veritable myths. They explain in fantastic terms some features of the blocks whose true origin is known only to scientists, or was deformed while passing from the scientific to the popular field (like the myth of Mount Musiné as an extinct volcano). In this sense, the myth of Herod in the version of Ansante Dembech is original, as an allegorical explanation of a non-existing phenomenon.

Modern Satanism also uses the blocks, building myths around them. This practice apparently has ancient roots, being linked to St Maximus' invectives against the blocks as 'the devil's altars'. The bishop's invectives in fact were aimed at pagan, not satanic, rites. Use of the blocks as true devil's altars is a recent innovation by modern satanic sects and groups, more or less organized (and dangerous!). The sects use clear reference to recent myths, such as those built around Mount Musiné. The parts of the blocks used in rites obviously derive from the myth of the block as 'druidic altar': cupels and tafoni house black candles and the smooth vertical walls are painted with satanic symbols. Even the selection of the blocks is an evident link with the other new myths. Suitable sites are those that evoke dark legends or mysterious entities. The Pietra Alta (High Rock) evokes the mysterious beings at work within the 'extinct volcano' of Musiné; the block located in the Castle of Conte Verde (Green Earl) evokes the legend (dating back to the nineteenth century) of the Countess unfaithful, buried alive in the walls of the cursed castle. These blocks are also the most accessible at night. Reaching the blocks on foot, at night, in the dark woods of the amphitheatre, scares even the devil.

Myths aimed at protection

In the same locations where bouldering is practised, environmental protection associations are working more and more intensely. To enhance the value of the territory, in spite of the scientists, they imbue simple occurrences with a legendary aura, or they retrieve and often 'complete' or wholly made-up legends. The last quarryman of the Avigliana area became a legend with the name of *il Cricca* (a play on words between 'the breaker' and 'the crack'). To complete the legend, an erratic block with the signs of quarrymen's wedges thus became the Roc d'l Picapera (The Quarryman's Rock in Piedmontese; Fig. 12). Thus a marginal local historical fact becomes a myth, explaining why many blocks appear to have been split cleanly. In fact, some of them were broken by natural causes, such as freeze–thaw (Sacco 1928). The new myth replaced a more ancient one, in which the splits in the blocks were attributed to the paladin Roland, made furious by Angelica's betrayal (Roland block near Villarfocchiardo; Defazio 2000).

Pera Garaira has one dark side, the other one marked with long white streaks, put there by the nails of *masche* (witches) while engaged in their favourite game, i.e. sliding (*glisse*). The myth, repeated by various books and web sites together with other legends, explains the different coloured streaks, formed by ionic micro-migrations linked with weathering. The elements of the myth have different origins, showing that their composition is recent and aimed at enhancing the value of a stop on a tourist itinerary, in addition to the true origin of the erratic block. The original name, Pera Garoira (akin to the French *carrière*, quarry, i.e. a source of stones, and Piedmontese *carra*, rock), was made more similar to the Italian *gara*, competition (etymology mentioned in Zilli 2004*b*). The notion of the slide clearly derives from the *glisse*; but in Pera Garoira the fallen side of the block is so rough and irregular that it could never possibly

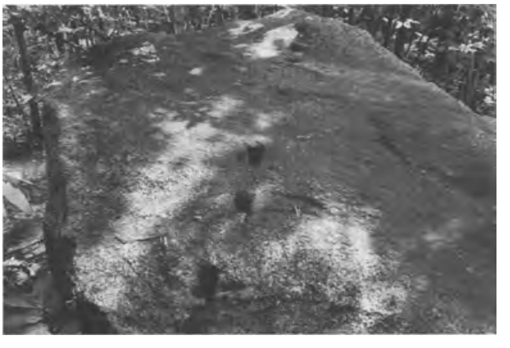

Fig. 12. The Roc d'l Picapera. 'The art is impeccable: they used wet apple wood stakes, drilled along the weak veins of the rock until it split. The last of the *picapera*, called Cricca, made all sorts of stone objects, still on display in old homes . . .' (Fornasero & Rimondotto 1994; Rimondotto & Rimondotto 1997).

serve as a slide. *Masche* were witches in the Occitan dialect. Today, they are widely employed to create folklore: in the amphitheatre, on the Moncuni, they recently (twentieth century) also inspired the name of Pera d'le Masche, taking the name from the underlying Susmaschi, whose name has a medieval origin and can be interpreted as 'Plain of the Males', or according to Rimondotto & Rimondotto (1998) as a clearing for the *bal d'ij Maschi* (dance of witches, *maschi* being the plural of *masca*). In this case, according to one interpretation (reported in a sign erected in the clearing) the myth would explain the shimmering of the air near the warm soil, which allegedly creates dancing figures. According to another interpretation, it would explain the flutes (very common forms of weathering on the blocks of the amphitheatre) and glacial striæ.

These artificial myths add to the environmental value and awareness of such sites. Every Piedmontese knows the geological value of the erratic blocks. But in Italy the geological value may not be sufficient for protection, because the Italians place the cultural value above the scientific value. Effective geosite protection should include both the myth storyline as well as the geological features that inspired the myth.

Discussion

The myths on which current legends and traditions about erratic blocks are based are not at all ancient, but rather, for the most part, quite recent (Table 1). That is not to say that no myths about the erratic blocks existed in the past. Magic practices involving the blocks (friction, *glisse*) are founded on ancient myths, which have been lost both because of the crumbling away of the Roman peasant world, caused by the Barbarians' invasions, and because of the Catholic religion's fight against superstitions. The continuing generation of new myths thus proves beyond any doubt the myth-making ability of erratic blocks, able to strike the attention of hurried modern humans as much as of ancient Piedmontese populations. This definitely has fundamental importance in the process of recognizing the value of erratic blocks. It is evident that the erratic blocks recognized in Italy as geosites have benefited more from their cultural value than from their geological importance. Hence currently, only the blocks of Villarbasse (Costa & Perotti 2002*b*) and Bard (Aosta Valley; Regione Autonoma Valle d'Aosta 2001) have exclusively geological importance. The other protected blocks are those of Monsagnasco (the only ones with probable cupels) and of the Castle of Conte Verde, *pera ciavoira* marking the border of the Longobard kingdom. They are small blocks, whose geological interest alone would definitely not be sufficient to enable safeguarding action from the Italian legislation. Even ongoing safeguarding initiatives try to increase the sacred and mythical value of the blocks. The preservation of ancient legends or the invention of new ones, beyond the cultural or scientific value, focuses on a marginal landscape element, attacked by the progressive urban development of rural areas. The phenomenon is positive for the real (and not merely legislative) preservation of natural assets, and is encouraged rather than tolerated (by rigorous scientists), in spite of its manifest cultural fragility. The presence of the erratic blocks, with their sacred and myth-making value, in addition to their naturalistic value, in this sense is a gift from Providence, a life saver for the natural environment of the Rivoli–Avigliana morainic amphitheatre. The advantages of instituting geosites transcend the mere protection of a geological asset. In areas with poor biological value, such as the outskirts of Turin, this institution currently provides the only opportunity for preservation. It enables the creation of protected areas, allowing people to move away

Table 1.

Myth	Explained natural phenomenon	Likely age of origin in the current form
Solomon and the Moors	Isolation of the erratic blocks	Subsequent to the tenth century
Druidic rites	Honeycomb weathering	1887
Runic inscriptions	Honeycomb weathering, flutes	1899
Scratches by *masche* (witches) or the devil, *masche* competitions	Flutes, superficial ionic micro-migrations	nineteenth century
Block = small mountains	Fractal dimension of geomorphological shapes	1960–1980
Meteoric origin	Difference of the rock from the surrounding ones	1921
Picapere	Freeze–thaw (when the split is natural)	Late twentieth century

from the unbreathable metropolis, mentally as well as physically.

Conclusions

For centuries, geologists have discriminated between legend and scientific truth if it does not openly despise it, the scientific mind views with suspicion, any mixture between scientific and legendary, or even merely popular, aspects. This is a hindrance when geologists want to bring the problem of geosite conservation to a community's attention. Describing the scientific aspects of the geosite, geologists often use a language that is understandable only to their colleagues. This is particularly obvious in southern Europe, in which humanities always have been considered more important than natural sciences.

The emphasized features of the geosite are often peculiarities that only interest specialists, but cannot be understood by the general public. As an obvious consequence, the public is indifferent to the issue of geosite conservation. The few geological reservations described here often remain merely on paper, and fail to attract sufficient influx of tourists. Sometimes, even the local population ignores their existence.

In the few cases, such as that of erratic blocks, when a sizeable part of the community is in favour of protection, geological interest is only secondary. As we have shown in this paper, the ability to generate myth is essential to enhance the value of a cultural, not environmental asset. But, to our knowledge, in southern Europe only one geological reserve (Haute Provence, France) exploits this opportunity, presenting a part of it as the 'valley of fossil Sirens' (*Sirenidae*; Art en Provence 2004). Therefore, geologists should expand their cultural horizon. It is not just a matter of using a language that is accessible to all, or to collect legends. In a commonly accepted definition, the myth is the allegorical explanation of unexplainable natural aspects. Geologists must not just explain natural aspects with modern tools, but show their link with the myth, without ridiculing it and preserving its fascination. In other words, they must show that strictly geological aspects are the meeting point of manifold cultural aspects. Under these conditions, the geosite will appear to be important and worthy of protection to everyone.

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The contribution of the 'Sibilla Appenninica' legend to karst knowledge in the Sibillini Mountains (Central Apennines, Italy)

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Abstract: Geological studies of the Sibillini Mountains carried out mainly during the last century, provided evidence of a hypogeal karst characterized by a small number of caves of limited extent. The only one mentioned by numerous ancient authors is the 'Grotta della Sibilla', on account of its legendary references. This cave is the keeper of one of the most fascinating secrets of the Apennines, having been both a place of mountain cult as far back as pre-historical times and the home of the fortune-telling prophetess 'Sibilla'. Historical sources tell of the presence of someone mysterious at the site from the time of the Romans but amongst the historical descriptions, the testimony of Antoine de la Sale is most notable: he visited the cave in 1420 and described it as a good-sized cavity within the bowels of the mountain. Nothing about this setting is mentioned in the geological literature or in topographic descriptions, made for the first time at the beginning of the 1940s, when a regular but small cave was revealed. Today rockfall deposits completely obstruct the entrance.

On the basis of the above-mentioned legendary references, geomorphological and geophysical studies started helping to define the real extent of the cave. The planimetric trend of the electromagnetic anomalies surveyed allow us to make hypotheses about the presence of a vast hypogeal system.

The myth of the 'Sibilla Appenninica'

Different values and meanings have been given to myth, the earliest being *c.* 11 000 years ago, in the area of the Fertile Crescent. Myth is understood as being a 'subordinate or deformed product of intellectual activity'; in the history of western thought, myth is opposed to *logos* in Aristotle's sense of the term, whereas Plato, considered it a defective and different way of approaching the world of ideas, and gave it a certain moral and religious validity.

Myth implicates co-operation with the historical investigation of a people, systematic and scientific studies of the mythical-narrative sources with the contribution of the earth sciences, of the human sciences and of the social sciences, that in 'transversal and integrative' synergy are able to promote a new scientific language. Due to their own narrative continuity, their mediation between man, nature and the cosmos, and to their content of tradition, knowledge, values and wisdom, they can be considered inter-cultural elements.

The territory of the Sibillini Mountains, which gave rise to this myth and where the cave of the Sibilla is located, constitutes a natural watershed between Umbria and the Marches (Fig. 1). The landscape characterizing this mountainous group is dotted with places of notable natural suggestiveness that have influenced popular imagination for a long time. Place names such as Peak of the Devil, Summit of the Redeemer, Cave of the Fairies, Gorge of Hell, Rock of the Miracle, to name only some, testify to the coexistence of a tenacious pagan history on these mountains.

In the morphology of this Apennine area, characterized by reliefs of particular shapes and profiles, the roots and persistence of the myths and legends of the Sibilla are to be found. If in the past this spellbound landscape was attractive for human settlement, recently it has been employed to trace of the boundaries of a national park, not only to protect the ecosystem of a still miraculously intact area, but also to save a cultural heritage made up of traditions and reports, handed down orally by way of myths and popular legends, or picked up in this place and set into the framework of medieval, Renaissance and contemporary literature. The Piceno area of the Sibillini Park is, in particular, a very rugged and wild area (Fig. 1). It is called the magic slope, and confers extra enchantment on the park, thereby increasing its attraction, differentiating it from other purely natural parks and rendering it worthy of the attribute 'legendary' (the Legendary Park of Europe).

The mountain and the cave of the Sibilla, located in the Umbro-Marchean Apennines, archaic symbols of never disclosed mysteries, both physical and metaphysical, local and universal, sacred and

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Fig. 1. The Sibillini Mountains and the valley of Pilato Lake.

profane, so beloved and so ignored, constitute the mythical omphalos of this central-Italian area, the meeting place for contact with and access to the celestial universe and the chthonian world. In the Myth, the Sibilla, who is a femme fatale archetype not only for the classical prophetic role of the woman of the time, that represents present, future and past, but also for that of the fairy (from the Latin *for-faris*, to speak, to narrate) and therefore as narrator of mystery, values, wisdom and knowledge, is in close interaction with the geophysical and geographical reality of the mountain and the foothills in which she exists.

The existence, now verified through geological investigation of an archaic hypogeal site about 600 m long, placed at a height of nearly 2000 m a.s.l. under the rugged 'crown' of the Sibilla Mountain and about 15 m underground, made up of labyrinthine tunnels and great unexplored chambers, testifies to the places and scenery so dear to the myth. The universal archetype of the labyrinth, that of the mountain, of the cave, of the lake (the nearby Lacum Sibillae, later called Lake of Pilate, due to the introduction of a post-Christian legend), here dominate the scene with their symbolic and mysterious references to the collective subconscience and their reminders of early pilgrimage.

In accordance with the authoritative opinion of the anthropologist Tullio Seppilli (Piscitelli 2001), this 'myth' is the result of the memory of a cave divination cult and therefore of the participation of people, not immediately close to any built-up area and in a context in which these zones were much more central with respect to the roads of communication (Ristori & Carobbi 1999). The memory of this well developed and articulated hypogeal system would otherwise not have been preserved for so long, nor would the popular legend which has come down to us have taken shape so strongly. Therefore, cave, femininity and divination, are the three key-points of the sibylline myth and it can be assumed that the persistence of such a vivid memory, in the Umbro-Marchean Apennines, is to be accredited to the presence of a Sibilla, a priestess, who made divinations and prophecies in a cave, the memory of which remains only thanks to oral tradition.

Among the essential elements of the sibylline myth emerges the mysterious wisdom of the archaic magic of the Neolithic cave cults (Lucentini 2001). The intrinsic mystery of the initiatory cults practised in caves, and in particular in the high-altitude hypogeal site of the Sibilla mountain (known throughout Europe in ancient times as the centre of the Apennine oracle), as well as having been transmitted from the Middle Ages onwards through 'cult' narration, has been kept alive by the large number of pilgrims that have passed by here in time, and has been narrated orally both by the local people, as a heritage of their own anthropological and cultural roots, and by visitors that have come to the land of the Sibilla for very different reasons.

In the sibylline territory, the mostly oral popular tradition of the myth of the 'Sibilla Appenninica', could never have been separated from the environmental context (mountain, cave, lake, nature, mountainous and agricultural-pastoral civilization) where it was born and from where it was handed down. Here the respect for nature, the cohabitation with its indomitable forces (earthquakes, avalanches, bad weather, rigid winters, and so on ...) and with that seasonal rhythm that regulates the tasks and the daily flow of time, are still a reality today.

The fame of the cave spread all over Europe in the Middle Ages, transmitted by the chivalrous literature concerning it, by the novel written by Andrea da Barberino, by the manuscript of the travel account of the knight of 'Provence' Antoine de la Sale (Fig. 2; Piscitelli 1999), by the transcriptions that followed, up to the novels interspersed with autobiographic 'licence' by more recent authors. The many faceted character of the Apennine Sibilla, the immortal lady of the myth, and the prophetic cave that, with its arcane mysteries constitutes the 'symbol', represent tangible proof of the persistence of the lay rendering of a very ancient myth, in a narrative style typical of different periods.

Chronology of main historical notes on the cave of the Sibilla

In 69 BC, Suetonius reported that Vitellius 'celebrated a sacred vigil on the Apennine ridges'; later, in 270 AD, Trebellius Pollio in '*Scriptores Historiae Augustae*' wrote that Clodius II the Goth consulted in that year the Apennine oracle; to 820 AD can be dated back to the examination of the cave by an anonymous knight, the same one described in the first years of the fifteenth century by Andrea da Barberino in his novel Guerin Meschino. During the period 1320–1340, a probable closing of the cave occurred due to natural

Fig. 2. Sketch of Sibilla Mountain by Antoine de la Sale in 1420 (after a gothic edition of 1521, National Library of Paris).

causes (the terrible earthquake of 1328; Blumetti *et al.* 1990), or to political-religious causes reported by the historical notes (struggles between Guelph and Ghibelline factions of Umbria and the Marches, and between heretics and Dominicans; an ordinance of the church to oppose the heresies of Templars, Alchemists, Spirituals, Cathars, Patareni etc. whose survivors had found shelter in the land of the Sibilla). The visit of the German knight Hans van Bamburg, subsequently named by Antoine de la Sale in his travel diary, dates back to 1338. Later on, in the years 1420–1450, Antoine de la Sale examined the sibylline cave twice leaving in his diary manuscript, dedicated to his agent, Agnese de Bourbon-Bourgogne, a description and detailed and realistic drawing of the natural morphology of the place and of the sibylline chamber (Piscitelli 1999; Fig. 2).

There are various significant reports: for example that of the historical archives of the town of Montemonaco, in parchment No. 40, in which knights coming from all over Europe visited the land, lake and cave of the Sibilla to practise alchemy and consecrate books on magic is documented in 1452; or that of 1578, a date carved on a rock overlooking the currently collapsed vestibule and still clearly visible today. This date, that is oddly connected to the legend of the birth of Christian Rosenkreuz, would be symptomatic as well of the presence of Rosicrucians in the land of the Sibilla. In more recent times (1610–1612), Martino Bonfini frescoed in the ancient sanctuary of Our Lady of Ambro, at the foot of the Sibilla mountain, a cycle of twelve Sibyls among which one that was a chemist or alchemist.

Important events followed during the nineteenth century: the attempted speleological exploration, without any particular result, by the Caponecchi brothers, called the Vezzanesi, in 1870; the climbing to the cave in the hope of finding the continuation of the tunnel after the vestibule by G. B. Miliani, the forerunner of modern speleologists, in 1885; after an excursion to the cave in 1897, the opening of the cultural debate on the Sibilla by the intellectuals Pio Rajna and Gaston Paris, that, in the midst of publications and conferences and increasingly rich scientific data, has been continued to the present day; and in 1889 the arrangement of the entry to the cave by a committee of alpinists.

Significant events happened in the last century. In 1920 an expedition led by Falzetti, went into the vestibule, and apparently identified a probable continuation of the cave by way of a descending tunnel; an attempt at excavation by unknown persons followed between the years 1921 and 1925, when Falzetti returned to the cave he discovered the modifications effected by the incompetent explorers and the disappearance, under rock-fall deposits, of the supposed descending tunnel (Falzetti 1954). In 1926, the superintendent of archaeological findings, Dr Moretti, obtained the first technical scientific data on the state of the chamber of the time: 'The chamber, that across an unusual open fissure along the oblique seam of rock is not more than eight metres long, four in width and three in height, does not have other access to tunnels or to rooms in the inside abysses. The only open space that is left is the vestibule from which a hole lets us suppose that there once existed or still exists, not only the rooms that the legend attributed to the heaven of the Sibyls, but at least some other chambers of which the present one is the vestibule'.

There then followed numerous expeditions and examinations of the site: in 1929–1930 by the Belgian philologist Fernand Desonay and by Falzetti again, without result; in 1946 by the Marchean poet Tullio Colsalvatico who made an excavation on his own which was interrupted by the superintendency on the basis of an unfounded suspicion of the use of explosives to enlarge the chamber. He was followed by the geologist Lippi Boncampi who, in a report dedicated to karstification in the Sibillini Mountains, furnished the first official document on the hypogeal development of the cave of the Sibilla, illustrated by topographical surveys, sections, planimetric models and other technical data. In 1952, General Emidio Santanché, water diviner and president of the tourist office of Ascoli Piceno, effected a reconnaissance, that did not yield results, together with members of the Forestry Corps probably aimed at a reopening of the chamber for purposes of tourism; in 1953, Annibali, the superintendent of archaeological findings, gave permission for an excavation that was more ambitious than any tried before. But the inadequacy of his techniques worsened the obstruction of the chamber adding deposits to the previous deposits.

Later during the period 1953–1965, the cave's vestibule collapsed completely and certain singnificant remains, including a stone carved with illegible characters, were stolen. Subsequently, in 1968, the geologist Odescalchi from Pesaro, with the aid of geoelectrical instrumentation, succeeded in surveying anomalies, probably evidence of the existence of a tunnel. Recently (1983–1984) the Speleological Group of the Marches from Ancona, led by the speleologist Giuseppe Antonini, made repeated attempts to identify the descending tunnel indicated by Odescalchi, through systematic prospecting particularly on the 'crown' of the Sibilla mountain and guided digging. But the precarious working conditions forced the speleologists to abandon the enterprise, when they were probably close to discovering the access to the tunnel.

A scientific debate on the Apennine Sibilla and her cave was reopened in the years 1997–2001, encouraged by the scientific committee of the cultural project 'Elissa' of Montemonaco, presided by Paolo Aldo Rossi of the University of Genoa. Three main conferences were organized, to which researchers of national and international fame came to the Piceno region. Besides establishing the historical, literary and anthropological data of the myth, they called for geological and geophysical investigations that aimed at denying or confirming the hypotheses formulated. As a result, in 2000 the committee for the 'Cave of the Apennine Sibilla', backed up by the presence in the field of Nora Lucentini, Gilberto Pambianchi and Angelo Beano, promoted the geological and geophysical investigation on the site of the 'Cave of the Sibilla' (Pambianchi 2001; Beano 2001; published in the Proceedings of the Conference 'Sibyl, Shaman of the mountain and the Apennine Cave').

The chronology of the visits to the cave reported above provides evidence of the close connection between man (curious believer, historian, or scientist) and the territory; there is a close relationship between myth on the one hand and geography and geology on the other, in a little-known territory, which all the same is a site with strong cultural ties. The reasons for this close relationship perhaps lie in the apparent majesty displayed by the mountains, even from some distance away, or else in the impressive feature offered to the visitor of mountain slopes spread almost menacingly on the crests of the chain, and bordered by precipices. In particular, it is the unknown potential of the cave development that brought the questions regarding the world of myth and the aims of the scientific community together. After the initial and historical setting in geography, a deeper geological knowledge about this place of religious cult is seen to be the only tool able to overcome the barrier of limitations imposed on the spatial setting and to throw light back in time. In fact, geological information is able to establish a solid scientific point of contact between a new spatial element (in this case a hypogeal one) and its history, thereby demonstrating (or not) the truth of what has been handed down orally through time.

Geological and geomorphological features

The Umbro-Marchean Apennines are made up of a sedimentary stratigraphic sequence (having a thickness of up to 2500 m) primarily calcareous at the bottom and with limestone alternations, marly-limestone and marl, in the remaining upper portion. In the first phases of the Jurassic age, in the great gulf of the Tethys Sea, that divided the African continent from the Eurasian one, the Calcare massiccio formation, with a thickness of up to 1000 m, the most ancient one known in the Umbro-Marchean area, was deposited, in a shallow sea and in a carbonate platform environment. Toward the end of the Lias, the carbonate platform began to sink slowly, associated with the extensional tectonics that separated Africa from Europe and produced in the gulf of Tethys numerous and deep sedimentary basins, including the Umbro-Marchean one. Afterwards, from middle Jurassic up to middle Eocene, during a relative tectonic calm, about 2000 m thickness of primarily calcareous rocks (flinty calcareous, marly calcareous and marly) were deposited. Between the middle Cretaceous and the middle Eocene, the marly calcareous formation of Scaglia rosata was deposited in the Umbro-Marchean sedimentary basins. This formation constitutes the upper skeleton of the Sibilla Mountain that has sub-horizontal bedding where the beds are locally affected by intense folds, connected to inter-formational slumpings, and to calcarenitic benches with thicknesses of tens of metres, the thickest in the area (Chiocchini *et al.* 1976). The big calcarenitic pack forms the characteristic and fascinating 'crown' of the Sibilla Mountain (Fig. 3). The inter-formational slumpings were formed on a sea bottom which was neither uniform nor stable; the calcarenitic benches were tied to turbiditic flows that pushed northwards from the Abruzzi carbonate platform towards the Umbro-Marchean sedimentary basin.

After the deposition of the Scaglia rosata in the upper Eocene, the collision between the African and European–Asian plates caused extension of the emerged areas. In the Umbro-Marchean sedimentary basin (narrowed by the surrounding continental areas) mainly clayey sedimentation began and continued throughout the Pliocene. During this period, the structure of the Umbro-Marchean Apennine chain, characterized by thrusts and folds, developed, producing two large ridges: the Marchean and the Umbro-Marchean (Fig. 4).

Fig. 3. The Sibilla Mountain and its characteristic 'crown'.

In central Italy between the upper Pliocene and lower Pleistocene, there was a low-lying continental landscape. The traces of this ancient landscape are represented by wide flat spaces (erosion surfaces) formed in an arid environment that can be found on the Apennines and pre-Apennine reliefs. In the late stages of the lower Pleistocene, there was intense and general tectonic uplift, connected with the collision of Africa and Europe, that broke up the earlier landscape and was subjected to rapid uplifted (Gentili & Pambianchi 1999).

The most intensely karstified rock formations are those at the base of the statigraphic sequence that are made of pure limestone from the carbonate platform (Calcare massiccio, Hettangian-Sinemurian). Minor karst phenomena affect the following calcareous and marly-calcareous formations of the Maiolica (upper Titonic–lower Aptian) and of the Scaglia rosata (Cenomanian p.p.–middle Eocene p.p.) cropping out on Mount Sibilla.

In the Umbro-Marchean Apennines the outcrops of the calcareous formations are extensive and the karst phenomena are commonly of a different type, affecting the two Apennine ridges: the Umbro-Marchean Ridge and the Marchean ridge, located slightly further to the east (Fig. 4).

The speleogenesis that may affect the calcareous formations in the central Apennines may be explained by the interaction of several factors: a) erosion from the infiltration of waters, the action of CO_2 of superficial derivation; b) hyperkarstic processes connected to the mixing of different waters and to the oxidation of H_2S both in the phreatic environment and in the atmosphere, caused by the action of sulphurous steam; c) the interaction of H_2SO_4, produced by the metabolism of certain bacteria on the calcareous surfaces of the hollows (Galdenzi & Sarbu 2000).

The northern portion of the Apennine ridges do not have relevant karst phenomena, with the

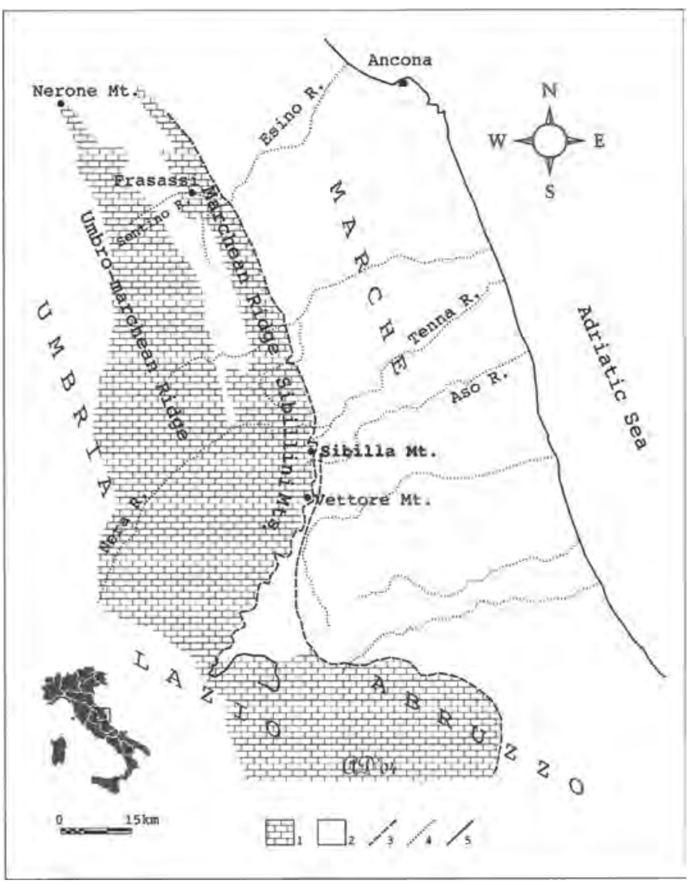

Fig. 4. Geological sketch of the central Apennines: 1, limestones; 2, marls and terrigenous sediments; 3, main thrusts; 4, rivers; 5, coastline.

exception of the mountain group of Mount Nerone (1525 m a.s.l.; Fig. 4), where cavities and natural arcs are carved in the Calcare massiccio along the steep walls. Here the Grotta delle Tassare is found, the deepest cave of the Marches; one of the deepest caves in Italy lies a short distance to the south, in the Cucco Mountain (1566 m a.s.l.), in Umbrian, part of the same formation (Bisci & Dramis 1991).

In the middle portion of the Marchean Ridge, is the best known and developed hypogeal karst system of the region: the Frasassi Caves (Figs 4 & 5). They are set in an anticlinal core constituted by the formation of the Calcare massiccio cropping out on the inside of a narrow and deep valley. This area is characterized by a sub-continental mountain climate, with an average temperature of about 13 °C and precipitation of about 1000 mm a^{-1}, and the surface karst forms are little diffused. Numerous caves with a general development of over 25 km open at heights of between 200 m (the level of the Sentino river) and 500 m a.s.l. In this karst system phreatic morphologies generally prevail; the vertical variations of the water table have played a determinate role. Large and deep pits connect chambers with hundreds or thousands of cubic metres in volume at different levels, showing a clear hypogenic origin (Bocchini & Coltorti 1990; Galdenzi & Menichetti 1995).

In the central area of the Umbro-Marchean Apennines, relatively important karst phenomena characterize the inter-mountain tectonic basins as well (Castelluccio, Norcia, Colfiorito, Montelago, etc.); there are numerous sinkholes that drain the water from the surface (Scarsella 1947; Bisci & Dramis 1991; Gentili 2002).

The Sibillini Mountains constitute the southern joining area of the two mountainous ridges and exhibit the highest reliefs (Mt Vettore, 2476 m a.s.l.). Here the superficial karstification, however

Fig. 5. The Frasassi Caves.

limited, reaches its maximum regional diffusion with karrenkampfs, streamsinks, and dolines (Bisci & Dramis 1991; Gentili 2002).

In the Sibillini Mountains area, the hypogeal, karst phenomena are much rarer and are mainly associated with the Calcare massiccio formation, in which the karst system is made up of small caves, channels and sinks, with horizontal, vertical and oblique development. The horizontal cavities are located in the lower portion of deep valley incisions, the vertical ones are less developed and located in the upper portion of the relief where calcareous formations (aquifers) occur with impermeable marly units at the base (Gentili 2002). More interesting caves, wells and natural tunnels are found along the Rio Garrafo (labyrinth system) on nearby Mount Bove (the 'Cave of Sin' or the 'Cave of the Devil') and Mount Patino (the'Cave of Patino'). The highest known cave of all in the Sibillini Mountains, famous for its legends which has given rise to the vast historical, romantic and poetic literature regarding it, is the Cave of the Sibilla located almost at the top of the mountain bearing this name.

The Sibilla Mountain with its height of 2173 m. a.s.l. is one of the most important mountains in the group of the Sibillini Mountains; the summit is characterized by a rocky crest, developed in a roughly east–west direction, that causes very steep slopes that erode northwards into the Tenna River Valley and southwards into that of the Aso River (Fig. 3).

The main lithotypes that crop out from the valley floor, are made up of the micritic limestone of the Maiolica formation (upper Titonic–lower Aptian) and by the marly calcareous formation of the Marne a Fucoidi (Aptian p.p.–Cenomanian p.p.) and, near the top, of the Scaglia rosata (Cenomanian p.p.–middle Eocene p.p.) that are essentially in a subhorizontal bedding or locally characterized by minor folds or slumping.

The minor folds, for example those observed at the entrance of the cave, also affect the less thick calcarenitic layer. Here, the fallings have pointed to a structure of recumbent folds, where the major fold probably constituted the roof of the cavity and corresponded to the vestibule described by Lippi-Boncambi (1948) (Fig. 6). The fallings of

Fig. 6. Slumping fold near the cave entrance where the location of the roof of vestibule (A–A), today collapsed (A′–A′), may be reconstructed.

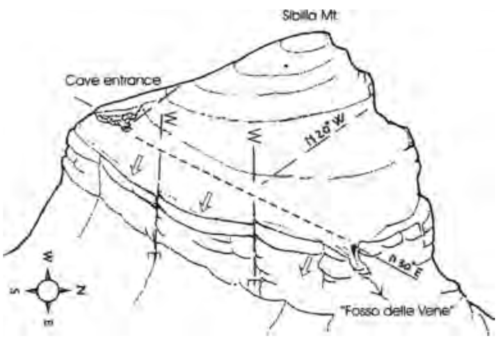

Fig. 7. Sketch of the summit portion of the Sibilla Mountain: main joint direction in dashed lines and relaxing direction of calcareous plates with arrows.

the vestibule are surely attributable to tampering by man, as well as to the strong earthquakes that characterize this area.

Detailed geological surveys, recently carried out at the cave's entrance and neighbourhood, enabled the authors to define different geological and geomorphological characters around the site (Fig. 7). They identified faults and fractures oriented in an approximately N 30° E direction where probable phenomena of left-strike slip have produced widening of the plicate structure. The system of faults and fractures continues towards the 'Fosso delle Vene' with a development of about 1 km. Tectonic action on the bedrock favoured the infiltration of meteoric waters, and karstification has developed preferentially in the calcarenitic layers. The widening of underground chambers has also been aided by gravitational phenomena with regard to the summit portion of the relief (Fig. 7). Translational slide phenomena, valleyward of the cave entrance were recognized; these affect the Scaglia rosata layers along the bedding. The decimetric marly-calcareous level acts as a shear plane. It has been strongly fractured by gravitational movement and in some places the bedding (crush breccia levels) can no longer be identified. On the Sibilla's relief and on surrounding slopes, gravitational phenomena developed. Deep-seated gravitational slope deformations (of which evident double crest is a basic diagnostic element) and vast landslides have been favoured by the lithostratigraphic setting. These can be identified by: 1) the overlaying of lithotypes with rigid deformation (limestones) on ductile deformation levels (marls); 2) the rapid Quaternary tectonic uplifting and consequent deepening of hydrographic system, that produced high relief; 3) glacial-decompression phenomena, related to the melting of Pleistocene glaciers; and 4) numerous and strong earthquakes (Aringoli *et al.* 1996; Dramis *et al.* 2002).

Geophysical investigation

The present research was backed up by a detailed geophysical investigation that started in 2000 (Beano 2001). The purpose of this field survey was to confirm the first geological hypothesis regarding the localization of hypogeal structures in the area surrounding the vestibule of the Sibilla cave and along the line (in N 30° E direction) that connects the entry of the cave to the 'Fosso delle Vene' spring (Fig. 8). The zone is not large; it is encircled by precipices, and lies on a very steep slope, which is difficult to reach; therefore, the use of seismic, and geoelectrical methods was excluded. The authors considered a georadar analysis to be the most appropriate method for this kind of survey, to maintain data quality, completeness of information, and easy transportation of equipment to the site. Although 'geoelectrics' allows a generic identification of a situation, georadar is able to reconstruct with greater precision, in this particular litho-stratigraphic setting, to a much greater depth. To estimate the reflected radar signal attenuation, and therefore the radar penetration depth, two geoelectrical tomography surveys were carried out to check the effective radar prospecting. The maximum depth that could be achieved was about 40 m below the surface level. The georadar data were also calibrated at a depth of 10 m, the depth found during excavations in the 1980s.

The present field programme consisted of a series of measurements along longitudinal and transverse lines to the slope and, where possible, in a grid of lines spaced 2.5 m one from another for a total length of 8975 m.

The electro-stratigraphic sequence, shown by the geological profiles, confirms the presence of a maximum in the superficial area, and at greater depth, reveals a fold of material of medium resistivity (marls or calcareous marls) overlying a medium–high resistivity core (marly limestone). Geoelectrical tomography was carried out to evaluate the attenuation of electromagnetic signals irradiated by the georadar techniques; in a preliminary phase it was possible to attest that an adequate surveying depth of about −25 m could be reached, and therefore it was decided to proceed with the survey using georadar. The authors were concerned about the penetration capability of the electromagnetic waves (with a good quality of recorded data) from the georadar and the possibility of identifying any hypogeal structures, of a limited 'horizontal' extension at a depth of 10–20 m. A set of profiles, allowing all the uncertainties to be settled, was therefore obtained in the vicinity of the (collapsed) chamber. It was then possible to proceed to the systematic acquisition of data.

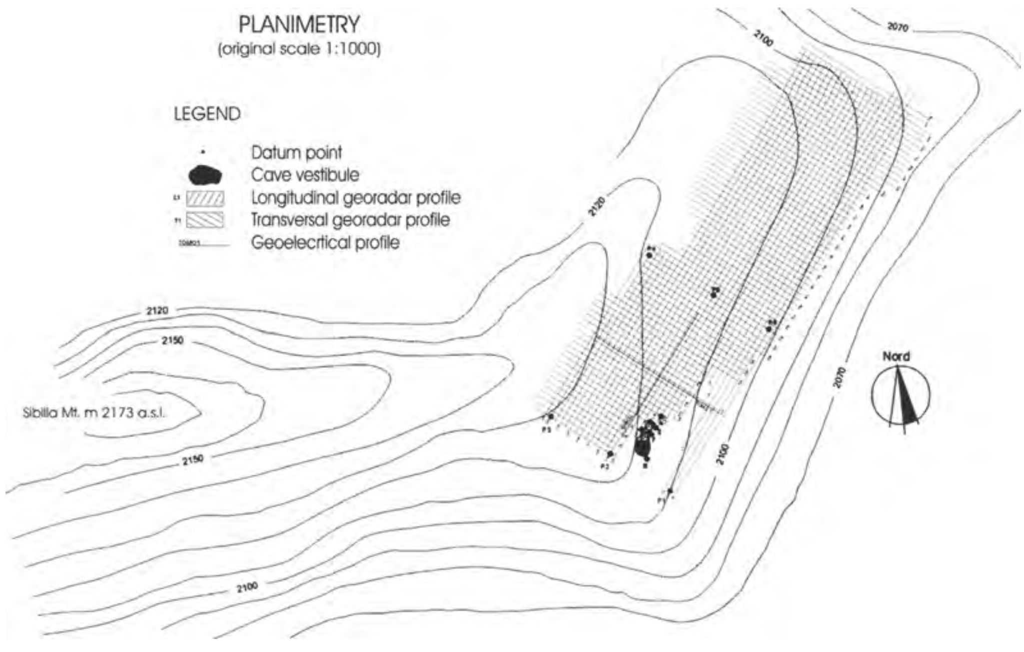

Fig. 8. Planimetry of the investigated area on the basis of geophysical prospecting.

During the subsequent phase of data elaboration, after a long process of normalization, filtration and amplification of recorded signals, three types of electromagnetic anomalies ('A', 'B', and 'C') were scanned and identified. The type 'A' anomalies (Fig. 9) are characterized by strong signal reflection due to the transit between two media having a very different dielectric constant (high reflection coefficient) as would happen in this case, in the event of contact between rock and

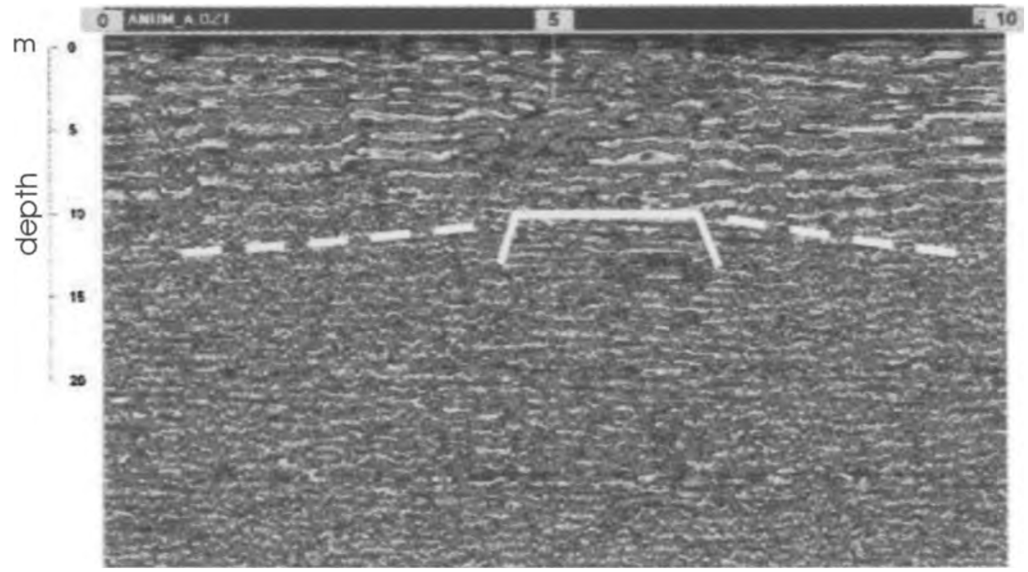

Fig. 9. 'A' anomaly radargram; the white dashed line shows the roof of the cave.

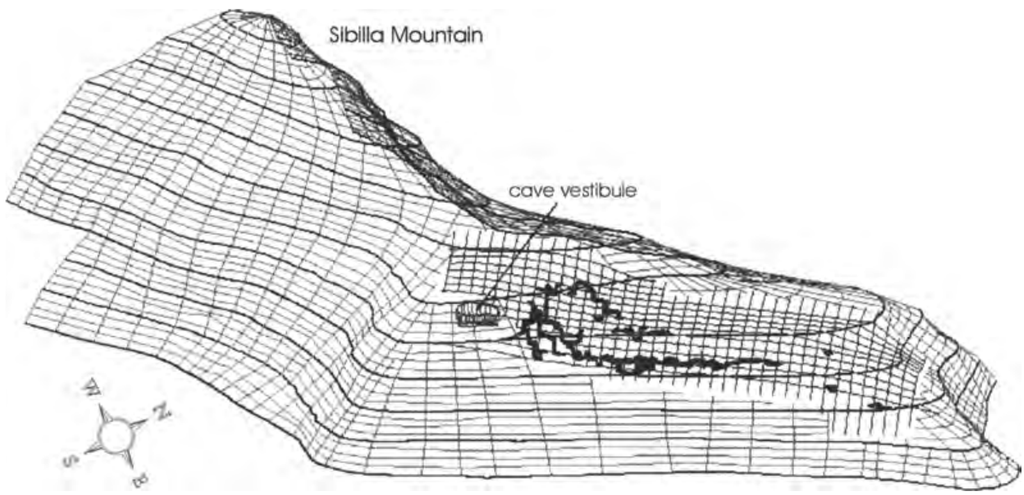

Fig. 10. Three-dimensional view of the investigated area: in black, the anomaly's contour.

air (hypogeal structures), while, the two observed 'tails' are produced by the particular form (arch) of the side walls and of the roof. The type 'B' anomalies are similar to those mentioned previously, but they are less evident due to different factors: a low reflection coefficient, reverberation of the signals on the side walls (sub-vertical) and/or the presence of chaotic and/or fractured material. The 'C' type anomalies are easily recognizable on the net radargrams because of two or more parallel and inclined bands: they have been correlated to fractures and/or open surface discontinuity (in accordance with geological–tectonic information for the area).

Many type 'A' and 'B' anomalies are located close to or on the projection of the type 'C' ones (fractures). All the sets of 'A' and 'B' anomalies, placed preferentially along tectonic alignments surveyed on the surface (N 30° E, the prevailing direction) have been contoured to identify the distribution of underground voids better.

The anomalies examined clearly show an underground fracture, stretching in an east–west direction and emerging to the south. The surface geological surveys confirm the presence of a similar preferential orientation (east–west and NE–SW) of the different tectonic structures. As far as the dimensions of the identified cavities are concerned, they are both horizontal and vertical, with an average width of about 2 m (increasing to a width of 8 m), located at varying depths of between of 10 and 14 m.

The compilation of an elaborate three dimensional graph viewed from the SE (Fig. 10) allows a spatial image of all the sets of anomalies that is related to the 'roof' or upper portion of the objects that produce it.

Conclusions

The myth of the Sibilla, already well established before the birth of Christ, has attracted people to this area from all over Europe for centuries. Even among researchers of different disciplines, it has aroused intense interest and in particular has furnished earth science researchers with interesting material for thought and a challenge: to verify the physical setting, that has been recorded by historical documents or legend, or else handed down orally throughout the ages.

The geological-geomorphological and geophysical studies in this paper seem to confirm this general setting. They point to a high-elevation karst system (up to about 2000 m) which has well developed horizontal levels at different altitudes, that are joined by vertical and inclined caves. In accordance with the geophysical data, that confirm the geological surface information, the system develops for about 600 m mostly following a preferential N 30° E direction, (starting) from the entrance of the cave to the 'Fosso delle Vene' spring. The karstified levels with horizontal development reach a maximum size of about 300 m, with tunnels a few metres in diameter, located at different depths, from 10–14 m underground. These karst forms, with prevailing horizontal development, represent a rare episode, if not the only one, in the more elevated areas for the Umbro-Marchean Apennines, generally characterized by karstification in vertical development.

This karst episode, pertaining to the classical typology of the calcareous rocks of the Umbro-Marchean sequence, can be explained by considering different geological features. In particular, the presence, in the Scaglia rosata formation, of very thick (30–40 m) calcarenitic benches in a subhorizontal bedding, that alternate with calcareous-marly and marly levels, allowed the establishment of a suspended aquifer, that persisted in time entrapped in the numerous slumped folds. The calcarenitic material, present in the pelagic formations of the Umbro-Marchean sedimentary basin (in this particular case in the Scaglia rosata), characterize the area of the 'Sibillini' that, in the Mesozoic, bordered the 'Lazio-Abruzzo' carbonate platform to the north. Further northwards, the Umbro-Marchean sedimentary basin was an open sea, without detritic turbiditic material. The calcarenites in this area are the thickest, since the palaeogeographic data reveal this area as a sediment depocentre.

The karst phenomenon is imposed on the calcarenitic levels, favoured by the presence of a stagnant aquifer and following a fault with N 30° E direction. This fault and the other sub-orthogonal ones, broken up the Scaglia rosata formation, creating blocks with different dimensions, that were subsequently deformed by translational mass movements. Such gravitational phenomena enlarged the fractures, and increased the rate of movement.

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