Chapter 2

The Archaeology and Anthropology of Quaternary Period Cosmic Impact

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2.1 Introduction

Humans and cosmic impacts have had a long and intimate relationship. People live in ancient impact craters, such as at Ries and Steinheim in Germany, and use impact breccias for building material. People historically witnessed and venerated fallen meteorites, in some cases the meteorites becoming among the most sacred of objects – such as that kept in the Kaaba at Mecca. People made tools from meteoritic iron, including certain examples from the objects named the "tent," "woman," and "dog" by the Greenland Eskimos. And in one of the more peculiar ironies linking humans and cosmic impacts, people carved a portion of an ancient Ohio impact crater into the shape of a Great Serpent. This act not only created one of the more spectacular archaeological sites in North America, but also depicted a symbol used by a number of cultures to represent comets, the very source of some impact craters on the Earth.

Despite the close relationship between people and things that fall from the sky, archaeologists and anthropologists thus far have played little role in research and issues concerning cosmic impact. This situation reflects modeling by the NEO community (… those planetary scientists who study potentially-threatening near Earth objects) that "globally catastrophic" impacts – i.e. impacts capable of directly or indirectly killing a quarter of the Earth's human population (Chapman and Morrison 1994) currently estimated at an impact energy of around 10^6 megatons (MT) or slightly less – occur on the average of about once every 500 000 to a million years (Toon et al. 1997; Morrison et al. 2003; papers in this volume). A less reasonable notion by the NEO community has been that although major catastrophic impacts can occur at any time, few if any humans during the period of recorded history have ever been killed by a cosmic impact. Fortunately, at least some astrophysicists and geologists have begun to recognize the human toll (e.g. Lewis 1996).

The Quaternary period represents the interval of oscillating climatic extremes (glacial and interglacial periods) beginning about 2.6 million years ago (2.6 Ma) to the present. This encompasses the Gelasian stage of the late Pliocene geological epoch (2.6 to 1.8 Ma), the Pleistocene epoch (1.8 Ma to 10 000 years ago [10 ka]), and our present Holocene epoch of the past 10 000 years. The Quaternary contains critical developmental episodes of hominid biological and cultural evolution, including the development of urban societies during the Holocene. The Quaternary also contains a number of significant cosmic impacts that – for reasons discussed below – have yet to be identified and/or thoroughly studied. Ironically, the Quaternary may have begun with a hugely catastrophic oceanic asteroid impact (Eltanin), whereas the last sustained climatic oscillation some 4 800 to 5 000 years ago (the middle/late Holocene boundary) was possibly driven, I argue, by a sizable oceanic comet impact.

Archaeologists, paleoanthropologists, and anthropologists are largely unaware of both the nature and the potential of cosmic impact to explain much that is presently mysterious about the archaeological and paleoenvironmental record of the Quaternary, including our own Holocene period. A notable exception to this ignorance is the work of anthropologist and historian Benny J. Peiser, who not only looked closely at the topics of cosmic impact and rapid environmental change during the Holocene (e.g. Peiser et al. 1998; Peiser 2002), but who also maintains the CCNet, a scholarly electronic network servicing these broad topics throughout Earth history. Many of the contributors to the present volume have used the CCNet to help facilitate their own research and interests. Ironically, of the 1 800 subscribers to the website, only a small number, certainly less than 50, are actually professional archaeologists and anthropologists (Peiser 2004).

The paper is divided into three general parts excluding the introduction. The first (Sect. 2.2) examines the Quaternary record of known and hypothesized cosmic impact. Each subsection is presented in descending levels of relative certainty, beginning with the most concrete evidence for Quaternary period impact (Sect. 2.2.1 and 2.2.2) and working toward more uncertain and hypothetical evidence for impact (Sect. 2.2.3–2.2.5). Despite such ordering, it should not be automatically construed that the former present a clear and unequivocal picture of the impact record and the associated risks and hazards from such impacts, and that the latter are automatically suspect and should be dismissed out of hand. Rather, the only thing that is certain is that the hypothesized impacts presented in the latter sections require more study, better quality data, and a much greater effort at validation. The purpose of this paper is to provide a sample of both accepted and hypothesized impact events that serves to highlight data potentially relevant to issues of effects on human society, as well as addressing problems attendant to the recognition and validation of impact events.

Section 2.3, while more speculative builds on recent successful attempts by archaeologists, geologists, and astronomers to systematically use mythology and oral tradition to identify and productively study past major natural events (e.g., Barber and Barber 2005; Piccardi and Masse, in press). These methods are applied to Holocene cosmic impacts in South America, including some possibly responsible for regional mass fires, and for a preliminary assessment of a likely globally catastrophic mid-Holocene oceanic comet impact. Section 2.4, an epilog formulated after the ICSU workshop, presents evidence for a young potential abyssal impact structure in the Indian Ocean that may relate to the hypothesized mid-Holocene oceanic comet impact. It also highlights the dichotomy that exists between the archaeological and anthropological record of impact and current astrophysical models of the risk and effects of cosmic impact.

2.2 The Quaternary Period Cosmic Impact Record

2.2.1 Documented Impact Structures

As of June 2005, the Crater Inventory of the Earth Impact Database, maintained by the Planetary and Space Science Centre of the University of New Brunswick, contained a total of 172 identified and corroborated cosmic impact craters (University of New Brunswick 2005), although as suggested in this paper, the Argentine Rio Cuarto "craters" should require additional validation. Of this total, 27 are estimated to date to the past 2.6 Ma of the Quaternary period. A number of other potential impact locations are still undergoing study and validation. The database does not reflect airbursts nor tektite/glass melt strewn fields for which a crater has not yet been identified.

Table 2.1 depicts these 27 impacts in chronological order from most recent (Sikhote Alin) back to the beginning of the Pleistocene (Karikioselkä), and continues back to the gap between the Karikioselkä impact and those of Aouelloul and Telemzane at around 3 Ma. Several aspects of this list demand attention. Most compelling is that all listed impacts are in terrestrial settings. Because more than 70% of the earth is covered by water, including 14% terrestrial glaciers and sea ice (Dypvik et al. 2004), the table is likely missing two-thirds of the actual impacts during this time period. This situation calls into question how representative the validated terrestrial impacts are of the entire range of magnitude of all Quaternary impacts, especially given that current estimations of cratering rates model an average of three to six globally catastrophic impacts to have occurred during these three million years. Only two impact craters, Zhamanshin and Bosumtwi, approach the minimum size (10^4–10^5 MT) thought necessary for large-scale continent-wide effects (Toon et al. 1997), which would suggest that three or more larger impacts occurred in the world's oceans.

This sampling problem is compounded by the presence of large temporal gaps between cratering events. Particularly noticeable are the gaps between 100–220 ka, between 300–900 ka (one event), between 1.07–1.80 Ma (one event), and the large gap between 1.88–3.00 Ma. These gaps are the result of many different processes and do not necessarily reflect actual flux in the impact cratering rate. For example, in addition to the absence of known oceanic impacts, other perturbing forces include the scouring of land surfaces by glacial ice and the obscuration created by tropical forest canopies, shifting desert sands, and active alluvial settings. Table 2.1 illustrates the tendency for smaller craters (under about 200 m in diameter) to be more quickly obscured by the passage of time in contrast with larger craters, as can be seen both in the diameters of recorded craters and those cases including multiple small impacts.

Also, some terrestrial regions of the world have been poorly studied, whereas others such as Fennoscandia (Finland and surrounding countries) are particularly well studied. Fennoscandia has a disproportionately large number of validated craters (28 total) in the Earth Impact Database as compared with, for example, the region of China, Tibet, and Mongolia (1 total). There are at least 60 other potential craters in Fennoscandia

Table 2.1. Documented Quaternary Period cosmic impact structures on the Earth – adapted from the Earth Impact Database (University of New Brunswick 2005)

Impact structure name	Location of impact structure[a]	Diameter in km of largest crater (and number of known associated craters)	Estimated date of impact years before present (A.D. 2005)
Sikhote Alin	Russia (T)	0.027 (122)	58
Wabar	Saudi Arabia (T)	0.116 (3)	301
Sobolev	Russia (T)	0.053 (1)	<1 000
Haviland	USA (T)	0.015 (1)	<1 000
Kaalijärv	Estonia (T)	0.110 (9)	2 400 to 2 800?
Campo del Cielo	Argentina (T)	0.050 (20)	4 200 to 4 700
Henbury	Australia (T)	0.157 (11)	<4 700
Macha	Russia (T)	0.300 (1)	<7 000
Ilumetsa	Estonia (T)	0.080 (3)	7 400 to 7 700
Tenoumer	Mauritania (T)	1.900 (1)	21 400
Barringer	USA (T)	1.186 (1)	49 000
Odessa	USA (T)	0.168 (7)	<50 000
Lonar	India (T)	1.830 (1)	52 000
Rio Cuarto	Argentina (T)	Not craters?	<100 000
Morasko	Poland (T)	0.100 (8)	<100 000
Amguid	Algeria (T)	0.450 (1)	100 000
Tswaing	South Africa (T)	1.130 (1)	220 000
Dalgaranga	Australia (T)	0.024 (1)	270 000
Wolfe Creek	Australia (T)	0.080 (1)	<300 000
Boxhole	Australia (T)	0.170 (1)	540 000
Zhamanshin	Kazakhstan (T)	14.000 (1)	900 000
Veevers	Australia (T)	0.080 (1)	<1 000 000
Monturaqui	Chile (T)	0.460 (1)	<1 000 000
Bosumtwi	Ghana (T)	10.500 (1)	1 070 000
New Quebec	Canada (T)	3.440 (1)	1 400 000
Kalkkop	South Africa (T)	0.640 (1)	<1 800 000
Karikioselkä	Finland (T)	1.500 (1)	<1 880 000
Aouelloul	Mauritania (T)	0.390 (1)	<3 000 000
Telemzane	Algeria (T)	1.750 (1)	<3 000 000

[a] *T:* terrestrial; *O:* oceanic.

awaiting validation (University of Helsinki 2005), including at least two other Holocene craters in Estonia (Simuna, Tsõõrikmäe) in addition to Ilumetsa and Kaali discussed below (Veski et al. 2007, Chapter 15 of this volume).

Taking into account that the Americas likely were not occupied before about 20 ka and that Australia was not occupied before 60 ka, it should still be apparent from Table 2.1 that comet/asteroid impacts conceivably played a significant role in aspects of human history.

2.2.2
Validated Holocene Crater-Forming Impact Events

2.2.2.1
Kaali and Ilumetsa, Estonia

The Kaali meteorite impact crater field on Saaremaa Island in Estonia is the most studied impact site to date in terms of potential effects on contemporary human occupants and in the region surrounding Saaremaa Island (Veski et al. 2001, 2004, 2007 [Chapter 15 of this volume]). There is a single large lake-filled crater surrounded by eight smaller craters. The large crater is about 110 m in diameter, and collectively all the craters cover an area of about half a square kilometer.

The Kaali meteorite was a coarse octahedrite, with surviving fragments being only a few grams in weight. Despite the intensity of investigation both inside the craters and outside in nearby peat bogs, the actual date of the impact has been estimated at four widely spaced times: 6400 BC based on microspherules in peat (Raukas 2000); 5000 BC on similar evidence (Tiirmaa and Czegka 1996); 1740–1620 BC based on bulk sediment samples from the near the bottom of the crater lake, or a similar 1690–1510 BC date based on associated terrestrial macrofossils from the deepest part of the lake (Veski et al. 2004); and 800–400 BC based on peat associated with impact ejecta and iridium in nearby bogs (Veski et al. 2004). Veski and his colleagues argue for the calibrated date range of around 800–400 BC, speculating that the microspherules possibly relate to a separate earlier impact event.

The 800–400 BC date for the Kaali impact places it in a densely populated region (Veski et al. 2004), thus the estimated energy release – 20 kilotons, the magnitude of the Hiroshima and Nagasaki bombs – indicates a high probability of fatalities. It is emphasized, however, that even the earlier modeled dates coincide with known human habitation beginning by at least 5800 BC on Saaremaa Island (Veski et al. 2004). Evidence from settlement patterns and from medieval written sources suggests that Kaali was considered sacred. Myths recorded early in the 13^{th} century describe a god that flew to Saaremaa along the reconstructed path of the impactor; likewise the Finnish national epic Kalevala has an episode where the Sun falls into a lake burning everything on its way (Veski et al. 2004). Similarly northern Estonian myths describe the time when the island of Saaremaa burned. The fortified village of Asva, about 20 km from Kaali, burned at about the same time as the date for the impact event modeled by Veski and his colleagues, although a connection has not yet been proven beyond reasonable doubt. Paleoenvironmental techniques applied in the vicinity of the impact craters suggest that farming, cultivation, and seemingly human habitation ceased in the area for several human generations after the modeled impact date of 800–400 BC (Veski et al. 2001).

The Ilumetsa crater field in southeastern Estonia contains a series of at least three and likely five or more probable impact craters (Raukas et al. 2001). The largest crater is approximately 80 m in diameter and 12.5 m deep, with the second largest crater being about 50 m in diameter and 4.5 m deep. A distance of approximately one kilometer separates the two largest craters. Fragments of the original meteorite have yet to be recovered.

Radiocarbon dating of the lowest layer of organic materials in the largest crater yielded a calibrated date range of between 4500 and 5200 BC, whereas the dating of peat layers containing glassy impact spherules in a nearby bog yielded a date range of around 5400 to 5700 BC, the latter was preferred by Raukas and his colleagues. This would place the impact at around 7 500 years ago, at a time when south-eastern Estonia was known to be inhabited. Raukas et al. (2001) note that the three largest craters associated with the Ilumetsa event have names that translate as Hell's Grave, Deep Grave and Devil's Grave. They further suggest that this is consistent with an oral tradition preserving the original observation of the fall and the fact that earlier people thought of meteorites and bolides as living entities – apparently evil celestial beings who met their deaths in forming the Ilumetsa craters.

2.2.2.2
Wabar, Saudi Arabia

Situated in the dune fields of southern Saudi Arabia is Wabar, a set of three small craters in an area covering about half a square kilometer. The largest crater is 116 m across, the others much smaller, with additional craters possibly being buried by the surrounding sand dunes (Wynn and Shoemaker 1998). The craters contain bits of white shocked sandstone (impactite) created by compression of the dune sand during the impact, black melted slag and small chunks of nickel and iron from the original medium octahedrite meteorite. The energy release was estimated at 12 kilotons.

The Wabar impact is of interest not because of known harm done to humans, or work actually performed by archaeologists and anthropologists, but rather because it was witnessed from a considerable distance and appears in contemporary Arabic poems and thus can be dated to January 9, 1704 (Basurah 2003). Recent luminescence dating of the impactite and slag approximates this date (Prescott et al. 2004). The importance of this observation is to reinforce the notion that there have been a number of impact events during the past several thousand years that are undoubtedly captured in various written documents, including myths, local histories and dynastic records. For example, the famous Chinese Bamboo Annals, dating to the 3rd century BC, may contain dateable references to cosmic impacts and other natural phenomena (Masse 1998, Table 2.2).

2.2.2.3
Campo del Cielo, Argentina

Work by William Cassidy and his colleagues at the Campo del Cielo iron meteorite impact site in northern Argentina (Cassidy et al. 1965; Cassidy and Renard 1996) has been a model for the study of a low velocity impact. Campo del Cielo ("Field of the Sky") contains at least 26 known slightly elongated craters, the largest being 115 × 91 m. The crater field itself covers an area about 3 km wide and 19.2 km long, with an associated strewn field of small meteorites extending about 60 km beyond the main crater field. A number of sizeable fragments of the original octahedrite meteorite survived the impact, the largest being more than a meter in diameter and weighing about 37 tonnes. The original impactor was estimated to be minimally about 4 m in diameter (Liberman et al. 2002).

Cassidy excavated two of the craters in order to gauge the size, angle, and speed of each impactor. He also collected charcoal samples and obtained an approximate calibrated age for the impact at around 2200 to 2700 BC. It is difficult to gauge the degree to which Cassidy used the archaeological techniques of microstratigraphy, but such study on a regional scale in and around the impact site would likely be productive. Unfortunately, because of the increasing worldwide popularity of the Campo del Cielo meteorites since the 1965 report by Cassidy and his colleagues, damage to the area has occurred due to the illicit excavation and removal of meteorite fragments.

Cassidy and Renard (1996) also reported on a myth collected and reported by the medical doctor and historian Antenor Álavarez in 1926 that appears to relate to the impact:

> 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 marvellous 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.

Giménez Benítez et al. (2000) have recently conducted a detailed study of the myths of the tribes of this general region of the Gran Chaco to see what relationship they may have to the Campo del Cielo impact event. They note that Álavarez, in addition to the myth noted above, was convinced that several tribes had oral historical knowledge of the impact, believing that the meteorite had detached from the Sun. Álavarez also noted that there were a number of pilgrimage paths to the crater field, covering an area of about 200 square kilometers. Giménez Benítez and his colleagues note that little archaeological work has been done around Campo del Cielo but that it needs to be done. They also note there has been little meaningful dialog between anthropologists and the astronomy community regarding the myths and the physical aspects of the impact site.

2.2.2.4
Henbury, Australia

The Henbury crater field is a series of at least 12 known craters situated in the virtual center of Australia, approximately 145 km southwest of Alice Springs (Hodge 1994, pp 67–70). The craters are scattered over an area slightly larger than 0.5 km^2, with the largest crater (possibly an eroded double crater) having dimensions of 180 m by 140 m, with the next largest crater being about half that size. The site contains shocked sandstone and impact glass melts, and more than 500 kg of nickel-iron fragments of the original medium octahedrite meteorite have been documented as being collected from the area.

The Henbury impact event has been radiocarbon dated at around 2700 BC or slightly younger, and various Aboriginal groups along the path of the impactor (coming from the southwest) would have witnessed its fall. An Aboriginal name for the crater field translates to "sun walk fire devil rock" indicative of an observed event (Grego 1998). Aboriginal myths were collected in the 1990s regarding the Henbury crater field and the sacred site therein (Parks and Wildlife Commission of the Northern Territory 1999), but such myths and sites are sensitive sacred knowledge not easily shared with the outside world.

Published Aboriginal myths about the powerful deity Rainbow Serpent are indicative of the relationship of a cosmic impactor with the great flood (see Sect. 2.3.3.5). The witnessing in the 1950s of a daylight-visible bolide near the town of Wilcannia in New South Wales was used as a teaching device to tell an ancient Aboriginal myth about a smoking "falling star" impactor that killed a number of people camped in the same vicinity and to describe ritual landscapes associated with the event (Jones 1989). The myth goes on to note details about what appears to be the great flood, but it is uncertain as to whether the myth being told is an actual great flood story (as described in Sect. 2.3.3) or is a separate witnessed impact event ... or both.

2.2.3 Airbursts, Tektites, and Impact Glass Melts

The 1908 airburst event over the Tunguska region of Siberia provided unmistakable evidence of the force that can be delivered by a cosmic impact that fails to leave lasting evidence of an impact crater on the ground. Similar but smaller and less well-studied airbursts occurred in Brazil in 1930 (Bailey et al. 1995) and Guyana in 1935 (Steel 1996). Estimates for the magnitude of the Tunguska impact range between about 3 MT and 10–15 MT (Morrison et al. 2003; Longo, this volume). Given the evidence for the destruction of approximately 2 000 km^2 of Siberian forest by the Tunguska event, airbursts have received considerable attention in terms of the attempt to model their nature and frequency. Some modeling has indicated airbursts much larger than Tunguska are possible (Wasson 2003).

Several aspects of airbursts are relevant to our discussion. The first is the lack of visible evidence for impact cratering, thus airbursts are difficult to define archaeologically without recourse to signatures other than cratering. The second is the potential association of impact glass melts and other physical signatures with at least some airbursts. The third is the possibility that airbursts can cause significant ground fires (Sect. 2.3.2).

2.2.3.1 *Rio Cuarto, Argentina*

Schultz and Lianza (1992) published a cover-story article in *Nature* regarding a uniquely low-angle Holocene impact crater field in the Pampas of Argentina. Rather than simply remaining the stunning finding that such a discovery should engender, Rio Cuarto has turned into a case study for the difficulty of proving an extraterrestrial impact origin for a set of depressions on the Earth.

As originally defined, the Rio Cuarto "crater field" consists of a series of oblong rimmed depressions strung out over a distance of 50 km, the largest of which was 4.5×1.1 km. Schultz and Lianza (1992) also found highly vesicular glass melt fragments that were considered of impact origin. To their credit, they recognized that the depressions of the individual craters in their defined crater field were not so very different from aeolian depressions elsewhere on the Pampas.

Other scientists have disputed the impact origin of the Rio Cuarto structures, and have concluded that they are instead aeolian deflation features associated with predominate winds at different times within the late Quaternary period (Cione et al. 2002; Bland et al. 2002). Large numbers of similar structures exist throughout the Argentine Pampas, and the floors of some of the Rio Cuarto structures allegedly contain evidence of late Pleistocene fossils and caliche. Thus the structures themselves are of dubious origin. Nevertheless, Schultz and his colleagues (2004) presented reasonable counter arguments that appear to keep the impact crater debate alive.

Curiously, Cione et al. (2002) also had problems with an impact origin for the glass melts. These melts ("escorias") are glassy vesicular slabs found widely throughout the Pampas, and they point out that a number of researchers consider the escorias to be the product of normal anthropogenic fires created by intentional burning of fields. This topic is explored in Sect. 2.3.2 in the context of myths of mass fire from the Brazilian Highlands, and I suggest that these melts are indeed of impact origin, a position also subscribed to by Bland et al. (2002).

Schultz et al. (2004) conducted the most thorough study of the Argentine glass melts and were able to identify several separate Quaternary impact events, including one identified by Bland et al. (2002). Four of these are dated by $^{40}Ar/^{39}Ar$ ratios: 570 ± 100 ka, 445 ± 21 ka, 230 ± 30 ka, and 114 ± 26 ka. The 570 ka and 114 ka specimens are found specifically at Rio Cuarto. Of particular interest is recent glass at Rio Cuarto dated by three different techniques. By pure geological context they date to the early or middle Holocene (4–10 ka), by fission track to 2.3 ± 1.6 ka, and by $^{40}Ar/^{39}Ar$ to 6 ± 2 ka; the composite preferred date is about 1000 to 4000 BC. This is roughly similar to the previously noted age for the Campo del Cielo impact.

The extraordinary record of impact glasses in the Argentine Pampas is the result of suitable fine sandy soils (loess) high in silicates and thus suitable for the formation of impact glass, with these soils also serving to protect and to enhance the visibility of the glass layers. There are as yet no known impact structures associated with these five different glass melts. Wasson (2003) hypothesizes it may be possible to have large airbursts create immense distributions of glassy layered tektites perhaps covering areas of up to 70 000 km^2 as part of sheet melt of loess and sand from an incandescent sky. The Argentine Holocene glass melts are stated as extending at least 150 km southwest from Rio Cuarto (Schultz et al. 2004), thus covering an area considerably larger than that devastated by the Tunguska impact. It is of considerable interest that the Holocene airburst event coincides with a widespread human population replacement in the south-eastern Argentine Pampas – based on archaeological, osteological and paleoecological evidence – that took place sometime between 4000 and 1000 BC (Barrientos and Perez 2005). The airburst and the oceanic comet impact described in Sect. 2.3.3 should be given serious consideration as potential factors in this population replacement.

2.2.3.2
Australasian Tektite Strewn Field – ca. 0.8 Ma

Australasian tektites and microtektites cover more than 10% of the Earth's surface, including nearly all of Australia, island and continental Southeast Asia, the Southern Ocean below Australia, and much of the Indian Ocean as far west as Madagascar. Somewhere lurking in Thailand or perhaps off the eastern coast of Vietnam is a presently undocumented crater variously estimated at between 32 and 116 km in diameter

(Haines et al. 2004; Ma et al. 2004). Alternatively, Wasson (2003) has modeled an airburst to explain the sizeable distribution of layered tektites within the overall distribution of Australasian tektites.

There are a couple of notable aspects relating to this event, in addition to the impressive size of the impact during the middle of the Pleistocene. First, there is substantive evidence to suggest that massive flooding and other major regional environmental disturbances (such as deforestation) took place immediately after the impact (Haines et al. 2004), which together with the impact itself would have had a profound effect on ancestral human populations in Southeast Asia. Researchers suggest that the impact, believed by some to be one of the largest of the past few million years, was of such a magnitude that it "must have had serious consequences for the paleoenvironment and biogeographical history (perhaps including local hominid evolution) of Southeast Asia" (Langbroek and Roebroeks 2000).

Also intriguing is the near coincidence between the dating of the impact and the Matuyama-Brunhes boundary (MMB) that marks the last magnetic reversal in Earth history (Pillans 2003), and which has been well dated to around 780 ka. Current stratigraphic evidence suggests a separation of around 12 000 to 16 500 years between the impact and the subsequent magnetic reversal. There needs to be further study of the effects on ancestral human populations of both the impact and the MMB, including further consideration of a potential relationship between the two geophysical events, particularly if the impact crater proves to be at the larger end of the estimated size range.

2.2.4 A Sample of Current Studies of Potential Late Quaternary–Holocene Period Terrestrial Impact Sites

Potential cosmic impact site locations are proposed every year, usually based on some sort of aerial or satellite imagery. Some eventually are validated and are included in formal directories such as the University of New Brunswick's Earth Impact Database. Others can be the objects of contentious debate for years, particularly in the absence of identifiable shocked rock and other undisputed signatures of impacts. The following brief review of six interesting candidates is instructive in terms of the challenges that face field verification.

2.2.4.1 *Middle East – ca. 2350 BC – the Fall of the Akkadian Empire*

Archaeologists are sometimes confronted with evidence for what appears to be rapid destruction within individual archaeological sites and occasionally across large regions. The typical default conclusion is that this represents the destructive forces of a conquering army and/or some other concurrent destructive natural forces such as large-scale earthquakes and massive volcanic eruptions or perhaps rapid climate change. A prime example of such an abrupt event is that associated with the end of the Akkadian empire at around 2200 BC (commonly referred to as the "4 000 BP event"). A number of large urban cities contain evidence of widespread and apparently synchronous social collapse and destruction at around this time period (±200 years). This had been modeled as abrupt climate change (aridification) associated with volcanic ash fall as represented in a thin but widespread dust layer (Weiss et al. 1993). However, a number of researchers and archaeologists have raised serious doubts about the suggested physical causes and as well as the timing of this event (Peiser 2003).

More recent microstratigraphic examination of this dust layer and its context now suggest an impact origin together with a significant revision of chronology (Courty 1998). As reconstructed by Courty at Tell Leilan (Syria), the dust layer sits on top of an occupational surface possibly deformed by a shock wave. This surface exhibits evidence of the rapid propagation of wildfire, synchronous with the fallout of distinct black carbon associated with major forest fires in other nearby regions. The dust layer contains tiny rock fragments from various contexts (sandstones, basalts, marine limestone, gabbros), along with numerous glassy microspherules of varying mineralogical compositions and glassy grains derived from vaporized rocks. The shocked and burned occupational layer and overlying dust layer are themselves sealed with mud from a heavy rainfall. Thus what had been originally considered a tephra fall now appears to be impact ejecta. Courty notes that the occupation surface and dust layer are quite variable throughout the site as are the radiocarbon dates associated with those layers. Courty (2001) has also examined soils at Tell Brak (Syria), and has modeled a similar sequence that took place very rapidly. Although, most scholars remain sceptical of Courty's impact interpretation, her model fits well with data from surrounding regions (Masse 1998).

A problem when dealing with the study of microspherules (Raukas 2000) is that many different sources exist for such material including terrestrial (diagenic, biogenic, industrial, volcanic), extraterrestrial (interstellar and interplanetary dust, meteoritic airbursts) and melt from cosmic impacts. Thus key components of research into the origin of specific microspherules are the depositional environment and stratigraphic context as defined by the use of microstratigraphic methodologies.

The messages from this study and from the two examples in Sect. 2.2.3 are: (*1*) Airbursts and tektite strewn fields are poorly known and documented in terms of the Quaternary paleoenvironmental and cultural record; (*2*) few people, including those in the Quaternary geosciences, are trained to recognize and deal with potential tektites, impact glass melts, and microspherules – archaeologists are woefully lacking in this regard; and (*3*) the use of microstratigraphic methods and distributional studies are vital for determining the nature and context of impact glasses and other impact products.

2.2.4.2
Umm al Binni, Iraq

Umm al Binni lake is situated in the Al' Amarah marshes in southern Iraq near the junction of the Tigris and Euphrates rivers. This has been proposed by Master (2001, 2002; Master and Woldai 2004; this volume) as a 3.4 km-diameter candidate impact structure based on aerial photographic images that revealed Umm al Binni to be distinct in shape from all other marsh lakes in the region. Umm al Binni is nearly circular whereas the latter are quite irregular in shape. The sediments of this region are thought to be less that 5 000 years in age, thus suggesting that if it is an impact structure Umm al Binni could date to the Bronze Age. As such and if validated, the impact could account for some but not all of the striking devastation layers noted in the Bronze Age archaeology of Mesopotamia. Using impact modeling such as that by Marcus et al. (2005), the size of the hypothesized crater indicates a moderately small impactor, perhaps around 300 m in diameter for a stony asteroid, that would have had substantive effects only a few hundred kilometers from the impact site. Regrettably, regional politics and war have conspired to prevent the detailed physical examination of the structure, and the recent attempted draining of marshes has potentially imperilled aspects of the information value of the structure itself.

2.2.4.3
Sirente, Italy

A case was recently made for the impact origin for small depressions in a mountain plain in central Italy (Ormö et al. 2002). A single large crater, 130 m in diameter, was identified along with between 17 to 30 smaller craters. Radiocarbon samples underneath the rim of the large crater indicate a date in the 5^{th} century AD. A correlation was made between the presumed impact and local mythology about "… a new star, brighter than the other ones came nearer and nearer, appeared and disappeared behind the top of the eastern mountain" (Santilli et al. 2003). The authors suggest that the presumed impact, which occurred during a pagan festival, inspired the observers to convert to Christianity as suggested in other documentary sources. Speranza et al. (2004) conversely claim that the larger "crater" is of anthropogenic origin, being constructed for use during historic seasonal migrations of sheep and shepherds, and the smaller "craters" are natural karstic basins. They further claim that the radiocarbon dates associated with one of the smaller "craters" are more than 2 000 years earlier than the alleged main "crater."

2.2.4.4
Iturralde, Boliva

Scientists from NASA Goddard have attempted to prove the impact origin of an 8 km wide circular depression located in an alluvial basin of the Amazonian rain forest of northern Bolivia. Based on geological context, it is likely to date between 30 000 and 11 000 years ago (Wasilewski et al. 2003), the latter date would put it coeval with humans in South America. Formal expeditions in 1987 and 1998 met with insurmountable logistical obstacles and the site was not reached and studied until 2002. Even this expedition was fraught with logistical difficulties and did not achieve all of its objectives. Definitive confirmation of the structure as an impact crater has not yet been achieved, nor has it been subjected to absolute dating techniques.

2.2.4.5
The Bavarian Crater Field, Chiemgau-Burghausen, Germany

Within the past few years, preliminary and conflicting information has appeared from two competing research groups regarding a probable impact crater field located just north of the Alps in south-eastern Germany. One group (Fehr et al. 2005) has described an area directly north of the town of Burghausen containing 12 documented and several suspected craters distributed in a south to north pattern in an area 7 km × 12 km. The craters range between 5 to 18 m in diameter and were emplaced in glacial gravels and pebbles. No meteoritic material was observed in or surrounding the observed craters. Impact breccias, shocked quartz, glass melts, and other such impact signatures were not observed, which is consonant with the small size of the craters. The main impact effect other than the cratering itself was that of the breakage and crushing of the pebbles and gravels in the bottom of the craters. Iron silicide alloys were found in the vicinity but not within the craters, and an industrial origin was suggested for their occurrence. No oral historical information was obtained regarding the craters, and radiocarbon-dated charcoal from the base of a lime kiln within one crater suggests formation of the crater before the 2nd century AD.

The second research group has offered a radically different interpretation of this crater field (Chiemgau Impact Research Group 2004; Rappenglück et al. 2004). They note the presence of 81 impact craters ranging between 3 and 370 m in diameter, encompassing an area 27 km wide and 58 km long from the southwest to the northeast. The major difference between the two crater field models is the presence of several larger craters defined by the Chiemgau Group near Lake Chiemsee – the far northeastern end of their crater field matches the previously discussed area of small craters defined by Fehr et al. (2005).

The larger craters defined by the Chiemgau group are associated with a variety of glass melts, shattered sandstone, and widespread evidence for the unusual iron-silica alloys gupeiite and xifengite stated as having been documented through microprobe analysis, polarization microscopy and X-ray diffractometry. In addition, titanium carbide is similarly present based on optical and analytical scanning electron microscopy. A date for the impact of around 200 BC has been suggested by the Chiemgau Group based on the association of cultural artifacts with the glass melts, however, an argument can be made that the impact is several hundred years more recent than modeled. A potential association between the hypothesized Chiemgau event and the AD 536–545 climatic event (e.g., Baillie 1999, 2007 [Chapter 5 of this volume]) has not been ruled out (Ernstson 2005), although a first millennium BC date is more likely. Indeed, the most intriguing aspect of the Chiemgau Group model is their hypothesis that a fragmenting comet whose original size was around 1.1 km in diameter created the crater field.

The strongly interdisciplinary nature of both research groups is noted, but the hypothesized impact cannot be fully assessed until the findings are corroborated by additional study and more fully published. In this regard, I found it curious that the Chiemgau Group chose to utilize semi-popular media (the Internet and *Astronomy* Magazine) for their initial publication. This choice allegedly (Ernstson 2005) was due to the reluctance of reputable journals to consider their submitted material and the refusal by potential reviewers to personally inspect the hypothesized impact site and its associated recovered materials. Ernstson (2005) suggests that such response to their work stems in part due to the prevalent assumption in the NEO community that a recent catastrophic comet impact on the Earth is highly unlikely based on the current modeling of hazard and impact rates. Several scientists working on other potential recent impacts have related similar experiences, thus lending credence for a claim of possible scientific bias. The Chiemgau Group has collected additional recent physical and oral tradition data supporting the impact and its cometary origin and has plans for future peer-reviewed publication.

2.2.5 Oceanic Impacts

There has been growing recognition of the importance of the study of oceanic cosmic impacts and a concerted effort to document and model such impacts (e.g. Gersonde et al. 2002; Dypvik and Jansa 2003; Dypvik et al. 2004). However, work on oceanic impacts generally has lagged far behind that of terrestrial impact studies and virtually all work to date has been performed on craters formed in water less than approximately 800 m in depth. In addition to the two oceanic impacts noted in this section, Eltanin and Mahuika, I present modeling for a hypothesized mid-Holocene globally catastrophic oceanic impact in Sect. 2.3.3, along with the physical evidence for a candidate abyssal crater in Sect. 2.4.1.

2.2.5.1 *Eltanin*

The best documented abyssal cosmic impact to date, but not listed in the Earth Impact Database due to lack of a detailed published and confirmed crater, is that of the early Quaternary Eltanin asteroid impact in the Bellinghausen Sea in the southeast Pacific about 1 400 km west of Cape Horn (Kyte et al. 1988; Gersonde et al. 1997). Eltanin was first recognized as a tektite-strewn field on the seabed covering several hundred square kilometers, associated with high iridium counts. Initial dating placed it at around 2.15 Ma, but this has since been revised to 2.511 Ma ± 70 ka (Frederichs et al. 2002). As such the date is remarkably close to the boundary of the Quaternary period. If new data on an apparent associated impact crater (discussed below) is correct, it could be reasonably argued that the Eltanin impact is a geological boundary event.

Until recently, modeling of the size and magnitude of the Eltanin impact had a maximum of 4 km diameter for the asteroid, but most calculations placed it around 1–2 km in diameter with an impact energy of around 10^5 to 10^6 MT, the threshold for globally catastrophic impact. Recent research by Dallas Abbott and her colleagues (Glatz et al. 2002; Abbott et al. 2003a; Petreshock et al. 2004) has led to their conclusion that a putative crater 132 ± 5 km in diameter is the source crater for the tektite strewn field and iridium layer. Although not directly comparable with terrestrial craters, an abyssal oceanic crater of the size suggested by Abbott and her colleagues would rank Eltanin as the fourth largest in the current listing of the Earth Impact Database, only some 38 km smaller than the Chicxulub K-T boundary event. Although the present evidence by Abbott and her colleagues is currently poorly published, if eventually validated, the Eltanin impact not only may explain much about the erratic nature of Quaternary period warming and the abrupt cooling cycles, but also aspects of early hominid evolution.

2.2.5.2
Mahuika

At the younger end of the Quaternary period, Dallas Abbott and her colleagues have announced the discovery of an apparent sizeable oceanic impact crater on the continental shelf south of New Zealand (Abbott et al. 2003b, 2004), which they have most recently dated to around AD 1450. The crater, 20 ± 2 km in diameter, shows evidence of a widespread tektite field up to 220 km away from the crater itself (Matzen 2003). The impact is thought to be responsible for massive tsunami deposits in Australia and New Zealand, earlier documented by Bryant (2001). Assuming that the crater is real and that the impact did occur during the Maori occupancy of New Zealand, it should be possible to derive a near absolute date from myths associated with Maori royal chiefly genealogies, as dated by known astronomical events such as eclipses (see Sect. 2.3.1). In addition, it is of considerable interest to see how the impact may correlate with a period of rapid environmental degradation in New Zealand dated at around AD 1450–1550. This is seemingly part of a major Pacific-wide climatic event noted at around AD 1450 (Nunn 2000; Masse et al. 2006), thought to be associated with the onset of the Little Ice Age.

It should be noted that Steel and Snow (1992) earlier modeled an airburst in the Tapanui region of South Island as having caused the environmental degradation in New Zealand, whereas an airburst over water was originally suggested by Bryant (2001) as the source of the New Zealand mega-tsunami deposits. Goff et al. (2003) have raised a number of useful criticisms regarding the airburst model and Bryant's translations of Maori names, and most likely would have extended their argument to include the hypothesized Mahuika impact had it been available for their scrutiny. My own review of the Mahuika materials and the arguments of Goff and his colleagues indicates that not enough data have been yet marshalled to either validate or completely eliminate the claims for a cosmic impact in or near New Zealand in the 15th century. A much more detailed published treatment of Mahuika is necessary to evaluate this hypothesized impact event and putative crater. Additional research on both Eltanin and Mahuika is ongoing (Bryant et al., in press; Abbott 2005).

2.3
Oral Tradition, Myth, and Cosmic Impact

To say that science has not looked favorably upon attempts to glean meaningful historical information from oral history and mythology is to grossly understate the contempt that some physical scientists have for such endeavors. Indeed, physicists and astronomers who were active in the early 1960s understandably are still upset when confronted by anything bearing a resemblance to the infamous theories and claims of Immanuel Velikovsky (Grazia et al. 1966).

However, part of the blame for the sad state of myth as an explanatory tool must also rest on the shoulders of the ethnologists, folklorists and other scholars who most closely work with myth. The study of mythology during the last 100 years has been dominated by classical (e.g. Graves 1960), structural (e.g. Levi-Strauss 1969), and psychological (e.g. Campbell 1981) approaches. Although these approaches have produced fascinating insights into the nature and meaning of myth and have helped to highlight the critical role that myth has played in non-western and early western culture and society, they have misled generations of scholars by their assumption that myth lacks a meaningful foundation in the processes and events of real history.

Recent studies are beginning to revise our thinking with respect to the relationship between myth and history (Vitaliano 1973; Baillie 1999; Mayor 2000; Barber and Barber 2005; Piccardi and Masse, in press). The work of geologist Russell Blong (1982) with a previously undocumented 17th century Plinian style volcanic eruption in Papua New Guinea is singled out as an exquisite example of the use of mythology to complement and enhance the findings from physical geology. By collecting and analyzing the environmental details in myths about the "time of darkness" from widespread villages and tribes in and around the tephra fall, Blong documented aspects of the nature and duration of the eruption that were otherwise enigmatic in the physical record. Blong demonstrated that no one set of myths from a given village or tribe contained all of the pertinent environmental details, but rather each set had just a few details, a situation likely representing individual local circumstances and a natural response for people reacting to major natural disaster.

2.3.1 The Nature and Principles of Myth and Oral Tradition

Throughout Polynesia, myths are attached to and embedded within royal chiefly genealogies, which in Hawaii stretch back more than 95 generations prior to the reign of Kamehameha I at the end of the late 18th century. The value of this association became evident while conducting rescue archaeology in 1989 at the site of Hawaii's legendary first human sacrificial temple complex, then being overrun by lava from the ongoing eruption of Kilauea Volcano (Masse et al. 1991). In the mythology surrounding Pele, the Hawaiian volcano goddess, historically known lava flows are believed to have been created by Pele during supernatural battles attributed to the reigns of specific chiefs listed in the genealogical records. When the genealogical dates of these chiefs (based on a heuristic 20-year generation period) were compared with radiocarbon dates collected by the staff of Hawaii Volcanoes Observatory from these same named lava flows (Holcomb 1987), the close correspondence between the two sets of dates were striking (Masse et al. 1991; Masse et al., in preparation).

Hawaiian mythology contains accurate details of transient celestial events such as great comets, meteor storms, supernovae and even auroral substorms that can be exactly matched with the historic record in Asia, Europe, and the Middle East (Masse 1995). More recently, reconstructions of Polynesian solar eclipses by Fred Espenak of NASA Goddard has led to demonstrable matches with genealogically-based Polynesian eclipse stories including Hawaiian eclipses in AD 1679, 1480, 1257, 1104, and 975, a Samoan eclipse in AD 761, and perhaps a Tuamotuan eclipse in AD 605 (Masse et al. in preparation). There are dozens of exactly dated matches between natural events and Polynesian myths for a period of more than 1 000 years.

Hawaiian oral tradition may support the validity of the hypothesized lunar impact witnessed on June 18, 1178 by monks in Canterbury, England, which may relate to the formation of the 20 km diameter Giordano Bruno crater on the Moon (e.g. Lewis 1996, p 50). Several Hawaiian genealogical chiefs dating to this time period (by birth or rule) have unique literal names seemingly evocative of the dusty aftermath of the lunar impact, such as *Hina-ka-i-ma-uli-awa* "Having discolored the Moon with a dark mist" and *pôʻele-i-ke-kihio-ka-Malama* "darkened in the corner of the Moon" (Masse 1995; Masse et al., in prep.). Hawaiian myth even alludes to a major meteor storm at about this time. Despite considerable scepticism from the NEO community for the lunar impact hypothesis, the Hawaiian data suggest that it may be premature to rule out the AD 1178 impact scenario for Giordano Bruno crater.

The analysis of Hawaiian myths, and similar studies in the American Southwest (Masse and Soklow 2005; Masse and Espenak 2006) and South America (Masse and Masse, in press), provide a unique window on the general nature and structure of myth that substantially differs from current anthropological characterizations. A myth is an analogical story created by highly skilled and trained cultural knowledge specialists (such as priests or historians) using supernatural images in order explain otherwise inexplicable natural events or processes. The more unusual or striking the event, the more likely the knowledge specialist will resort to using supernatural elements, such as the creation of demigods. Natural events leading to considerable loss of life for a given cultural group – such as devastating regional floods, large-scale mass fire, and massive Plinian volcanic eruptions – become part of the sacred cosmogony or creation mythology for that group. Each cataclysm typically leads to a new creation of the world and humankind and is sequenced in relative order of occurrence.

Vansina (1985) and other scholars have demonstrated that oral tradition is a particularly robust form of history, in some situations nearly matching the written word in terms of the long-term conservation of the most important details of a myth storyline. Most cultures had strict institutional mechanisms by which orally transmitted sacred knowledge could be preserved largely intact for hundreds or even thousands of years as demonstrated in Polynesia. These mechanisms included the use of highly skilled and trained narrators, typically chiefs, priests or shamans whose livelihood and sometimes their lives depended on the ability to perform their duties well as oral historians. In cultures such as China, Mesopotamia, Egypt, Mexico, Peru and Polynesia, natural events, especially great comets, meteor storms, supernovae and solar eclipses, were closely tied into the power and lineage of hereditary rulers. Typically, they were considered the property and even the euhemeristic persona of the chiefs (Masse 1995, 1998) and as such became embedded in naming chants and birthing stories attached to those chiefs.

Traditional narration of myths involved annual cycles of myth told during solstice ceremonies and other prescribed seasonal settings in which dance, chant and story repetition ensured that key details were faithfully transmitted through many generations of narrators. The unsavoury reputation currently given to oral history is largely the fault of anthropologists and historians who not only fail to understand the historical basis of the myths they collect, but who also typically record the myths in sterile settings in which the narrator has been removed from the normal highly structured and richly contextual environment of myth performance.

This is not to say that all myths and their English language translations are "literal truth." There are mechanisms that compress and distort myth storylines (Barber and Barber 2005). Adequate translations of historical documents depend on translators knowing the context of the time period in which the document was written, including cosmology and use of iconographic symbols. Few translators are trained to recognize and understand astronomical descriptions, much less cosmic impacts. Except in rare cases where myths are chronologically ordered (e.g. Polynesia), myths can only represent at best a model of past observations of the natural world. However, as defined below there are ways to systematically organize narrative data that not only strengthens the model but also provides the means by which to test and validate the encapsulated natural events (Masse et al., in press).

2.3.2
Using Myth to Identify and Model South American Cosmic Impacts

South America is both physically and culturally diverse. It was the last of the inhabited continents to be colonized, a process beginning sometime prior to 10 000 BC. Despite these recent cultural roots, there are at least 65 known language families with estimates of the numbers of individual languages ranging between 400 to as many as 3 000 (Bierhorst 1988, p 17). Prior to European contact early in the 16th century, a wide range of societies flourished throughout South America, ranging for the simple migratory hunter-gathers of Patagonia and Tierra del Fuego to well-known state-level societies of the central Andes and coastal plains of Chile and Peru. In between these two extremes were semi-sedentary and sedentary village horticulturalists occupying the tropical lowlands and highlands of Brazil and the Pampas regions of central Argentina and the Gran Chaco lying between these two areas.

South America has a rich legacy of oral traditions and mythology (c.f. Levi-Strauss 1969; Bierhorst 1988). Particularly valuable for our interests in cosmic impact are a set of 4 259 myths from 20 major cultural groups east of the Andes gathered by the University of California at Los Angeles (Wilbert and Simoneau 1992). 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 from widely distributed portions of South America: 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 now extinct) from Tierra del Fuego at the southern tip of the continent.

Masse and Masse (in press) analyzed these 4 259 myths, concentrating on those myths that describe various local, regional or "worldwide" natural catastrophes that led to the deaths of members of a given cultural group. Events that led to the deaths of small numbers of individuals include local floods, fire, lightning – and in the case of two myths from the Brazilian Highlands, the observed thunderous fall of a meteorite into a river that killed several youths then swimming in the river. Several other myths from the Brazilian Highlands, and the Northwest talk about meteorites as being capable of causing human death – including, poignantly, the overall eventual destruction of the world – but do not describe actual impact events themselves. A single exception, not in the UCLA collection, is an Inca myth that describes a sizeable airburst in a remote mountain range near modern Cusco, which apparently did not result in any deaths.

Of greater interest is a set of 284 myths that have as their primary motif a single major cataclysm stated as having led to the deaths of most or all members of one or more cultural groups – typically referred to as having led to new creations of humanity. While one might scoff at the rational basis of such "new creations," it should be remembered that these cultural groups typically were small, a few hundred or at most a couple thousand people, and that while their overall territorial ranges may have been large the cultural group only occupied a small portion at any given time. Therefore, rare large-scale cataclysms such as Plinian eruptions, mass fires and torrential monsoons of unusual duration could indeed decimate such groups.

Table 2.2 organizes these myths by cultural group and by five defined categories of cataclysm. The stories, particularly those from the Gran Chaco, appear to be divided into relative time within the overall set of 284 myths, with certain cataclysms being stated as having occurred before or after other cataclysms. Thus myths about a lengthy time of darkness and a similar set of myths combining darkness with the sky falling or collapsing on top of people, houses, and forests are said to have occurred most recently (but still in the distant past), whereas myths of a "great" or "worldwide fire" occur in the middle of the myth cycle, and myths about a "great flood" occur at the beginning of the myth cycle, the latter sometimes coupled with a period of "great cold" stated as having occurred immediately after the flood.

The details of the "sky fell" and "darkness" myths encode ash fall from Plinian eruptions, and closely match aspects of the myths collected by Blong (1982) in his study of the Papua New Guinea Plinian eruption. Three separate ash fall events are seemingly attested in the South American myths, including one in the Northwest, one in the Guiana Highlands and a particularly convincing case in the Gran Chaco. The Gran Chaco ash fall may relate to a largely unstudied and poorly dated (1000–2000 BP?) pre-European Plinian eruption of the easternmost Holocene-active volcano, Nuevo Mundo, located in Bolivia some 500 km west of the Gran Chaco.

"World fire" myths not surprisingly are distributed in those areas most subject to devastating droughts and large-scale fires – the Gran Chaco and the Brazilian Highlands. Tribal groups of the Gran Chaco, such as the Toba, are noted for their burning of grasslands and brush as a common hunting technique, eating on the spot the charred remains of game animals (Metraux 1946, p 13). In a similar vein, the Brazilian *cerrado* is a massive mosaic of mixed grassland, planted shrub and forest occupying much of the Brazilian Highland region. The *cerrado* has been termed "the natural epicenter for Brazilian fire" (Pyne et al. 1996, p 685), whose configuration has been maintained through deliberation annual burning by tribes such as the Gé.

Given the close relationship between people and fire in the Gran Chaco and Brazilian Highland *cerrado* and the likelihood of periodic mass fires as have occurred historically due to both natural (lightning) and anthropogenic causes, it is of interest that sets of myths describing what appear to be cases of a single devastating "world fire" exist for each region. What makes the world fire distinct from all other fires is the specific *meteoritic* reason given in several of the myths for the cause of the world fire. Even in culture areas where mass fire is not common, such as that of the Bororo, the

Table 2.2. Myths of cataclysm in South America east of the Andes Mountains (from Wilbert and Simoneau 1992)

Location and culture	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)
Northwest					
Cuiva	13	–	–	4	–
Guajiro	9	–	–	–	1
Sikuani	10	–	–	–	–
Warao	3	–	–	–	–
Yaruro	10	–	–	–	–
Guiana highlands					
Yanomani	17	–	–	11	2
Brazilian highlands					
Bororo	4	–	1	–	–
Ge	11	–	6	–	1
Gran Chaco					
Ayoreo	17	–	2	–	1
Caduevo	–	–	–	–	–
Chamacoco	10	–	1	1	–
Chorote	10	–	7	1	–
Makka	2	–	–	–	1
Mataco	12	–	5	–	1
Mocovi	7	–	3	–	–
Nikvale	6	1	6	9	–
Toba	24	5	27	–	12
Patagonia					
Tehuelche	2	–	–	–	–
Tierra Del Fuego					
Selknam	1	–	–	–	–
Yamana	3	1	2	–	1
Totals	*171*	*7*	*60*	*26*	*20*

people have an extraordinary fear of loud bolides (Masse and Masse, in press). In several stories it is pieces of the Moon or Sun breaking apart and falling, that causes the fire. This is evident in the following story from the Toba-Pilagrá of the Gran Chaco (Métraux 1946, p 33; Wilbert and Simoneau 1982, p 33):

> The people 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" *[a lunar eclipse]*. 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 … 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 places not covered with bulrushes died and there most of the people were burnt alive. After everything had been destroyed the fire stopped. Decayed corpses of children floated upon the water. A big wind and a rain storm broke out. The dead were changed into birds. The large birds came out from corpses of adults, and small ones from the bodies of children.

The meteoritic cause of the fire is 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."

There has been debate as to the capacity of impacts to start ignition fires (e.g. Jones and Lim 2000; Svetsov 2002; Jones 2002; Durda and Kring 2004). Although the discussion has been geared to large impactors, it would appear – in contrast to the conclusions of Jones and Lim – that eyewitness accounts of falls, the limited archaeological record of impact sites and the myths discussed here indicate that wildfires are a common product of at least some smaller impacts. 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 is not an issue.

The combination of ascribing the world fire to multiple meteoritic fragments (of the Moon or Sun) and that in a large percentage of stories the Toba were saved by going into "a hole many meters deep" arguably refer to the Campo del Cielo event and its multiple craters, some which would have resulted in tunnels several meters deep. The location of the majority of the Gran Chaco meteorite and mass fire stories in the general area directly north and east of the Campo del Cielo crater field is also suggestive. However, a direct link between the world fire and the Campo del Cielo impact event cannot be established without recourse to additional microstratigraphic archaeological and paleoenvironmental fieldwork in and around the Campo del Cielo impact site.

As previously noted, there also are stories of world fire in the Brazilian Highlands that appear to be linked with meteors or the fall of meteorites (Masse and Masse, in press). 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 feathers of Woodpecker. In some stories the ornament is described as a "wheel of fire." Finally, Sun agrees to drop the ornament down to Moon, but warns Moon not to lose his grip or it will cause something bad to happen on the Earth. Sun tosses the ornament, but along with it are hot coals that prevent the Moon from holding on to the ornament. The feathers touch the ground, creating a world fire. "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. I suggest that it reflects the observation (from a safe distance) of an airburst that resulted in the creation of impact glass melt. Schultz and his colleagues (Schultz et al. 2004) have noted that temperatures in excess of 1 700 °C created the glass melts formed from the Argentine Pampas loess. A similar situation would be expected for the Brazilian Highlands loess. The maximum temperatures that can be achieved by burning of wild-land fuels are thought to be between 1 900 and 2 200 °C, but this would be an extremely rare situation not achieved in most wildfires (Pyne et al. 1996, pp 21–23). Sustained temperatures in wildfires and in the purposeful burning of fields likely would not be much greater than 1 650 °C with normal temperatures being closer to 1 000 °C. Therefore to create a large area of "burning sand" would seemingly require a meteoritic airburst. This implies that a glass melt-producing airburst has occurred in the Brazilian Highlands during the Holocene.

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. (Masse and Masse, in press). This appears to be a somewhat confused rendering of the oceanic comet impact described in the next section. Unfortunately, since the Yamana are now extinct, there will be no future chance to clarify the details.

2.3.3 Modeling the Flood Comet Event – a Hypothesized Globally Catastrophic Mid-Holocene Abyssal Oceanic Comet Impact

The studies of myth in Polynesia, the American Southwest, and South America, coupled with Blong's (1982) work in Papua New Guinea, indicate the potential for the worldwide corpus of myth to have preserved the observation of Holocene period globally catastrophic cosmic impacts. Only one cosmogenic set of myths relate to a cataclysmic event that has universal distribution in virtually all cultures. This is the myth of the so-called "great flood."

2.3.3.1 *Stilling the Waters*

Two popular misconceptions exist within the scientific community regarding the flood myth. First is the belief that European missionaries and explorers diffused the myth across the world from its presumed origin in Mesopotamia or the Near East. Although there are examples of the Biblical flood having been diffused by Christian missionaries, the great majority of flood myths from more than 1 000 cultural groups worldwide demonstrate independent development of the myth within each culture (e.g. Frazer 1919; Dundes 1988). The universal nature of the great flood myth is evident in Table 2.2 where not only is this myth by far the most prevalent of all the South American catastrophe myths, but also it occurs earliest in the Gran Chaco myth cycle before the Plinian eruptions of AD 1 to AD 1000, and before the meteorite impacts at around 2700 to 2200 BC. The common claim that the myth is absent from the records of ancient Egypt and China, for example, is the result of not recognizing variant forms of the myth (Masse

1998), whereas the general lack of the myth in Sub-Saharan Africa (Dundes 1988, p 2) is possibly the product of the oceanic impact described in Sect. 2.4.1.

A second misconception is that each culture often had multiple myths of different floods, and that flood myths from each region are based on observations of local or regional floods, thus comparisons between flood events in each region would be of little consequence. In fact, in the vast majority of cultural traditions only a single worldwide flood is identified (although other more restricted local floods may also be mentioned), typically representing either the last in a cyclic sequence of global catastrophes or a unique watery disaster from which humans emerged. In either case, our modern world is seen as having evolved from a worldwide flood.

There have been a large number of attempts by reputable and well-meaning scientists to derive some kind of historical truth from the flood myth. Among the more recent are those by Ryan and Pitman (1998) regarding flooding of the Black Sea around 5600 BC and by Teller and his colleagues (Teller et al. 2000) regarding postglacial flooding of the Persian Gulf. These and similar studies invariably suffer from a biased sampling of the overall population of worldwide flood myths and by the deliberate exclusion of certain classes of environmental data – such as the presence of torrential rainfall – in those myths that they do use. To use an archaeological analogy, this is like attempting to date and interpret a stratigraphically complex archaeological site from which you have collected a total of 1000 radiocarbon samples, but limiting actual analysis to 50 samples from but a single stratum, and then discarding half of the resultant dates because they do not fit your preconceived model.

While on this topic, I am compelled to address the interesting work of Austrian geologists Alexander and Edith Tollmann (1994) whose independent long-term study of flood mythology and geophysical evidence has resulted in findings superficially similar to my own described here. They hypothesize a major comet impact at the beginning of the Younger Dryas climatic event (ca. 9600 BC), which they claim to have resulted in seven fragments each conveniently hitting separate oceans or parts of oceans, thus creating the universal myth of the great flood. The Tollmann's particularly drew upon mythology, but also physical geology, tektites, ice cores, and other related databases.

Shortly after publication of their Flood Impact paper, a team of 13 scientists took the Tollmanns and their hypothesis to task (Deutsch et al. 1994). Their brief acerbic review highlighted a number of flaws in the Tollmann Flood Impact model. However, I suggest that the biggest flaw in the model was the failure by the Tollmanns to treat mythology with the same contextual and methodological rigor required of any scientific body of data. For example, they uncritically mix the Biblical creation myth with flood myths and make generalizations not warranted by the myths they use. Likewise, their historical illustrations are of dubious relational context to the hypothesized impact event.

I cannot overemphasize the fact that the analysis of myth requires the same stringent and systematic standards applied to all other categories of scientific data. Although my data here are admittedly preliminary, in the following discussion I attempt to provide enough details about the nature of the flood myth data and my methods of analysis so that the logic of these data and my interpretations can be understood and evaluated. This groundwork is necessary in that my conclusions about the nature of the hazards and effects of the hypothesized Flood Comet impact differ substantially from other impact models presented at the ICSU workshop and in this volume. However, I fully realize that in order to allow colleagues to satisfactorily judge my methods and inferences, it will be necessary to follow up this preliminary treatment with a subsequent detailed published analysis of the larger corpus of English language flood myths.

2.3.3.2
Preliminary Analysis of Flood Myths

Reported here is a preliminary analysis of environmental information contained in a worldwide sample of flood myths from 175 different cultural groups. The primary source for the myths is the 127 distinct myths and 46 variants contained in Frazer (1919), whereas the remaining 48 myths are from various other published sources in the initial attempt to better even out the regional distributions of the studied myths (see Masse 1998 for an earlier treatment of the Frazer myths). The myths are from the following regions: Artic Circle (5); North America (49); Central America and Mexico (11); South America (18); Africa (4); Europe (5); Middle and Near East (5); Russia (3); China/Tibet (11); Southeast Asia (31); Australia and New Guinea (22); and island Oceania (11). These 175 myths likely represent about 15% of all "great flood" myths printed in the English Language.

The premise of my comparative analysis is simple and straightforward. I hypothesize that if the universal great flood myth is based on a single worldwide natural catastrophe occurring sometime during the Holocene period, then there must be a single natural phenomenon that can logically account for the suite of all environmental information encoded in the totality of all great flood myths (Masse 1998, Table 2.1). Furthermore, these data and findings can be weighed and tested against the Holocene archaeological, geomorphological and paleoenvironmental record.

The brief analysis that follows suggests that *only* a globally catastrophic deep-water oceanic comet impact could account for all environmental information encoded in the corpus of worldwide flood myths and that my defined impact is consonant with the archaeological and paleoenvironmental record.

I identify 12 environmental variables within the corpus of great flood myths. These include: (*1*) Source and nature of the flood waters, vis-à-vis torrential rain and tsunami; (*2*) the nature of the storm, if any, associated with the flood; (*3*) earthquakes in conjunction with the flood; (*4*) time of day when the flood (or flood storm) began; (*5*) direction from which the flood storm originated; (*6*) duration of the flood storm; (*7*) unusual occurrence of light and/or darkness during the flood; (*8*) methods how survivors escaped the flood; (*9*) a rough estimate of the percentage of deaths caused by the flood; (*10*) advanced warning prior to the event that something was going to happen; (*11*) seasonal, astronomical or archaeological indicators that help to date the flood; and (*12*) descriptions of supernatural creatures associated with the flood.

Space precludes full citations and discussion of each variable and a complete distributional analysis of these preliminary data, but there are several highlights that likely speak directly to the effects of cosmic impact on human society (see also Masse 1998 for additional citations):

- *Source of floodwaters.* Some 76 (43%) of the myths do not define the nature of the "deluge" or "flood," but of the remaining 99 myths, 50 (51%) indicate the presence of torrential rainfall, 35 (35%) indicate tsunami, whereas 14 (14%) describe both rainfall and tsunami. Four of the 14 myths describing both elements indicate that the tsunami occurred before the rainfall, the others being equivocal. Nearly two-thirds of the 99 defined myths indicate the presence of torrential rainfall. Of these, 24 also indicate the presence of hurricane force winds and 23 indicate unusual darkness during the flood storm. The distribution of these elements is worldwide.
- *Duration of flood storm.* Thirty-three of the 175 myths provide a specific number of days for the flood storm. Nine are obvious outliers, several of which conflict with other myths from the same cultural group or region, including the confused dual rendering in Biblical tradition that the flood storm lasted either 40 days or 150 days (Habel 1988). The remaining 24 (73%) myths form a rough bell-shaped curve ranging between 4 and 10 days for the flood storm duration (Fig. 2.1). Intriguingly, the combined mean – 6.5 days – of these 24 worldwide myths matches exactly the duration provided in the two earliest written versions of the flood myth from Mesopotamia, the Gilgamesh (Kovacs 1989) and related Atrahasis (Lambert and Millard 1969) epics. Clay text fragments of these myths date to the 2nd and early 3rd millennium BC, and place the duration of the flood storm as six days and seven nights, and seven days, respectively. Torrential rainfall in historic hurricanes can occur at a rate of more than 10 cm per hour. In 1969, rainfall from Hurricane Camille during one six-hour period averaged more than 7.5 cm per hour throughout all of Nelson County, Virginia, leading to widespread devastating flooding and death (Clark 1982, pp 100–103). Even at the modest rate of 5.0 cm of

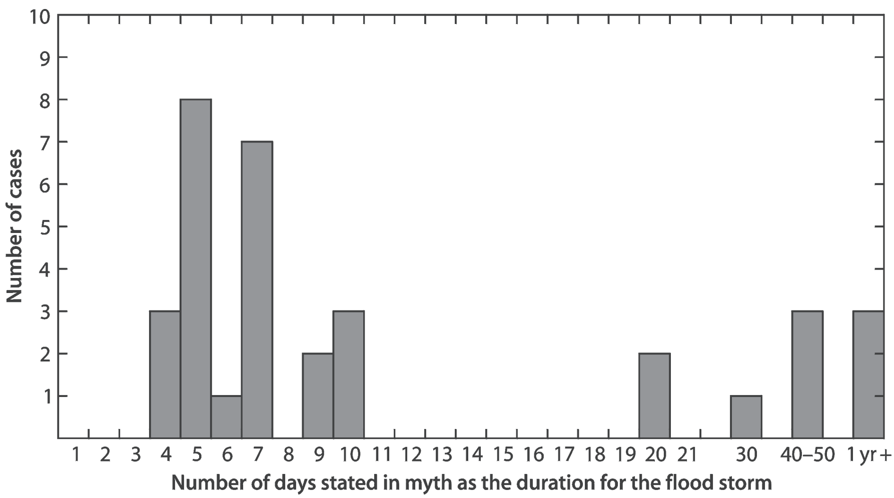

Fig. 2.1. Bar graph depicting the duration of the flood storm in days, based on 33 myths with explicit numbers out of a total sample of 175 analyzed English language flood myths. The nine cases on the right side of the graph – from 20 to more than 365 days – are considered to be non-representative outliers that encode culturally symbolic aspects of the flood event rather than the actual duration of the flood storm

rainfall per hour, the mid-Holocene flood storm, stated as being a continuous deluge throughout its duration, would yield a staggering total of 7.8 meters of water if constant for 6.5 days.

To appreciate the violence and overall duration of the flood storm, we again turn to Gilgamesh (Kovacs 1989, pp 100–101):

> Just as dawn began to glow there arose from the horizon a black cloud. Adad *[god of storms]* rumbled inside of it, before him went Shullat and Hanish *[minor storm gods]*, heralds going over mountain and land. Erragal *[Nergal – underworld god associated with forest fires and plagues]* pulled out the mooring poles, forth went Ninurta *[a warrior and farming god]* and made the dikes overflow. The Anunnaki *[Anunnakku – assistants to the sky god Anu]* lifted up the torches, setting the land ablaze with their flare. Stunned shock over Adad's deeds overtook the heavens, and turned to blackness all that had been light. The … land shattered like a … pot. All day long the South Wind blew …, blowing fast, submerging the mountains in water, overwhelming the people like an attack. No one could see his fellow, they could not recognize each other in the torrent The gods were frightened by the Flood, and retreated, ascending to the heaven of Anu … Six days and seven nights came the wind and flood, the storm flattening the land. When the seventh day arrived, the storm was pounding, the flood was a war – struggling with itself like a woman writhing (in labor). The sea calmed, fell still, the whirlwind (and) flood stopped up. I looked around all day long – quiet had set in and all the human beings had turned to clay!

- *Tsunami and storm surges.* Although a relatively small number (< 10%) of myths note that flood survivors saved themselves on the tops of high mountains such Mount Ararat (Turkey) and Mount Parnassus (Greece), most stories present more logical scenarios for surviving tsunami and cyclonic storm-induced storm surges. These tsunami locations (e.g. California; Brazil; Tierra del Fuego; Indonesia; India) are in quite believable situations, between to 15 to 100 km inland, and the hillsides or hilltops where people were stated as saving themselves typically range between 150 to 300 m above sea level. For example, near the town of Bonsall directly north of San Diego, California, the Luiseño Indians relate that the flood surrounded but did not cover the top of modern Morro (Mora) Hill (Frazer 1919, pp 288–289), a cluster of small rounded peaks that lie 16 km inland. I have visited this location. The highest elevation of Morro Hill is 280 m above mean sea level, but more pertinent is the fact that a roughly one square kilometer parcel (247 acres) lies at an elevation of more than 200 m, and is significantly higher than the directly adjacent countryside, much of which is < 100 m in elevation. That the Spanish were aware of the local flood legend for this hill is likely in their choice of the name *mora* (since corrupted to Morro), a colloquialism that means "unwatered."
- S*upernatural entities associated with the flood.* Half of the 175 myths describe supernatural entities associated with the flood, typically as undefined creators or nature deities, human-like deities, or helpful animals lacking descriptive detail. The 38 detailed descriptions include: Giant snake or water serpent (6 examples); giant bird (3); giant catfish (3); giant horned snake (3); elongated fish (3); and single examples of a giant fish with long snout; sperm whale; giant crocodile with cassowary feathers; giant horned earth dragon; monsters who grew up into the sky (perhaps a description of a debris plume); lizard thrown into the fire; battle between giant saw-fish and crocodile; dragon churning the water; battle between Sun and Moon; kite; fallen angels; blazing brand; star with fiery tail; flood begins when "dusty star-baby" is pulled apart; deity described as low-flying meteor; tongue of fire turned into flood; great light like the Sun followed by

great heat and then the flood; rain of fire associated with a serpent; battle in the sky of fiery and dark forces; and a man in a garment of lightning.

The typical elongated and celestial nature of these giant supernatural creatures, the presence of horns, their association with fire or brightness, and their presence for several days prior to the flood event are strongly suggestive of the observation of a near-Earth comet. Particularly fascinating is a composite description of a flood myth from several well-known Indian texts (*Satapatha Brahmana,* the *Mahabharata* and the *Puranas*): The progenitor of humankind, Manu, finds a tiny fish "bright as a moonbeam" in a puddle. He compassionately rescues it by putting it in a jar of water. The fish grows larger, and Manu in turn places it in a large pond, the Ganges River, and finally the ocean. By this time the fish is huge and "lotus-eyed." The fish reveals himself as a god, telling Manu that he will disappear for a period of time but will return later that year at the onset of the dissolution of the universe. The fish tells Manu that he, the fish, will be recognizable by a horn on his head. The fish later reappears, golden in color and as big as a mountain with a large single horn on his head. Manu uses a serpent rope to attach his boat to the fish and is pulled to safety across the turbulent flood-disturbed sea.

It is noted that in Indian tradition the lotus is situated in cosmic waters and is golden and radiant as the Sun (Zimmer 1946, p 90). The described characteristics of the fish well match the naked-eye visible orbital behavior of a comet observed during both the pre-perihelion and post-perihelion stages. Solar wind has the energetic velocity to blow cometary dust and ion tails away from the Sun even during the post-perihelion stage, thus creating an image visualized by naked eye observers as a headdress or horn attached to the head of the comet (Masse 1995, 1998).

- *Fire or hot water (rainfall and ocean swells) associated with the flood.* Notable is the presence of hot water, or fire/fiery rain in conjunction with the flood. At least seven myths from various parts of the world state that devastating fire or flames or rain of fiery particles occurred at some point immediately before the arrival of the flood storm. These include Arizona and Idaho in North America, the Congo in Africa, central and northern India and New Guinea. A likely related story from Egypt is the famous myth of the destruction of mankind (Pritchard 1975, pp 10–11; Ions 1968, p 106). In this myth the sky-goddess Hathor transforms into an enraged lion-headed goddess Sekmet – as the Eye of the Sun god Ra, representing the scorching, destructive power of the Sun, spitting flames at the enemies of Ra – and humankind is only saved when the land is flooded to a depth of 3 palms (ca. 25 cm) above the fields by 7 000 vats of blood-red mash brewed by the other gods and Sekmet pauses to reflect on her beauty.

  In addition are myths from Chile, Bolivia, Brazil in South America, Iraq, India and New Guinea describing hot water falling out of the sky, whereas myths in Tierra del Fuego, Taiwan and New Guinea describe hot ocean water washing up on their shores. A story about hot water bubbling out of the ground from near the Ural Mountains in Russia likely represents traditions that originated with people who migrated from India. Although not being described as "hot," the Maya Indians of Mexico describe the beginning of the flood as that of a thick resin falling out of the sky.
- *Seasonal and calendrical dating of the flood.* The seasonal and lunar data within the myths are remarkably consistent. Sixteen of the 175 myths describe seasonal indicators or name an exact month. Of these, 14 are in the northern hemisphere spring (late April –

May – early June), whereas one from the southern hemisphere is situated in the fall (equivalent to the northern hemisphere spring). In terms of described lunar phase, six of seven worldwide stories indicate that the flood began at the time of the full Moon, whereas the other story indicates a time two days later, the 17th day of the lunar cycle. In addition, there are stories in Africa and South America that place the flood at the time of a partial lunar eclipse, a phenomenon that only takes place at the time of a full Moon. The 4th century BC Babylonian historian, Berossos provides an exact day and month of the 15th of Daisios, which translates to the day of the full Moon in late April or early May (Verbrugghe and Wickersham 1996, p 49).

Equally striking are specific calendrical markers associated with these myths (Masse 1998, pp 64–65) from Chinese annals, and from well-dated archaeological contexts in Mesopotamia, Egypt, and elsewhere in the ancient Near East. China's Han Dynasty chronologists provide the date of 2810 BC for the end of the reign of first empress Nu Wa (Walters 1992). Nu Wa was a supernatural woman who at the end of her reign repaired the cosmic damage and flooding caused by the red-haired horned cosmic monster Gong Gong who knocked over a pillar of heaven, upsetting the universe. It is of some interest that Nu Wa mended the sky with melted stones of many different colors, thus matching the Biblical rainbow, as do in their own way a substantive number of traditions elsewhere in the world.

The 3rd century BC Egyptian historian, Manetho, noted that during the reign of Semerkhet, 7th of the 8 kings in Egypt's First Dynasty, "*there were many extraordinary events, and there was an immense disaster*" (Verbrugghe and Wickesham 1996, p 132). Although the nature of these events (also stated as "portents" in other renditions of Manetho) and disaster are not specified, there are several reasons to link them with the hypothesized Flood Comet impact. Semerkhet's reign is around 2800 BC, based the most recent dating of the First Dynasty between ~2920 to 2770 BC (Kitchen 1991). Not only does Semerkhet have the shortest reign of the First Dynasty kings, but he is the only one to lack an elite tomb at Saqqara (Wilkinson 1999, p 80).

Semerkhet's successor, Qa'a, the final king of the dynasty, is of interest in two respects. One is the translation of a variant of his name as "*abundance*" *in the sense of "flood*" (Weigall 1925, p 49). The other consists of unusual aspects of his tomb at Abydos noted by its excavator, Sir Flinders Petrie. Petrie (1900, pp 14–16) documented serious wall collapse in the lesser chambers due to insufficiently dried mud bricks; wooden timbers were unusually decayed as compared with earlier tombs; the entrance passage turned at an odd angle and was closed by rough bricks; and clean white sand was placed in and around the coffins of retainers. Re-excavation in 1992 indicated that the structure apparently was built in two or more stages over a long period of time (Wilkinson 1999, p 237). These data together suggest that the tomb of Qa'a was under construction at the time of the Flood Comet impact, suffered extensive water damage, and after a lengthy period of time was repaired and completed. This interpretation is also consonant with the fact that the succeeding kings of the 2nd dynasty abruptly shifted the location of their royal tombs at Abydos from the upper floodplain of the Nile to the nearby mesa tops, but returned to the original upper floodplain location at the end of the 2nd dynasty.

The ancient Near East exhibits a number of paleoflood deposits of various ages, typical for any region prone to flooding. Of particular interest are deposits at the ancient Mesopotamian cities of Shuruppak (modern Tell Farah), home of the legendary flood survivor, Atrahasis (Lambert and Millard 1969), and that of Kish (modern Tell Oheimer). These cities are mentioned in the famous Sumerian King list, created around 2300 BC by Enheduana, priestess of the Moon-god at Ur and daughter of King Sargon of Akkad (Postgate 1992, pp 27–28). The document lists five antediluvian cities, the last of which was Shuruppak, and then goes on to state: "*After the Flood had swept over (the earth) (and) when kingship was lowered (again) from heaven, kingship was (first) in Kish*" (Pritchard 1969, p 265). Sir Max Mallowan (1964) defined specific paleoflood deposits at both cities that he equated with Noah's Flood. The current date for these flood deposits and the establishment of Kish as a major city is estimated to be around 2800 BC (Porada et al. 1992).

This is also the time of abrupt movement of at least half of the people in Palestine from valley floors to the hill country of Galilee, Samria, and Judah, only to return to the valley floor a few generations later (Mazar 1990, pp 111–113). This unique settlement pattern is accompanied throughout much of the ancient Near East by the construction or enhancement of massive walls around most settlements, suggesting unsettled times. Many curious things from an archaeological perspective occur at around 2800 BC, including the marked dispersal and migration of five major language groups in five different parts of the world, Bantu (Africa), Indo-Aryan (Near East and Europe), Uto-Aztecan (North America), Austronesian (Southeast Asia), and Gé-Pano-Carib (South America). Significantly, this date also is roughly the boundary between the middle and late Holocene climate regimes, moving from warmer and dryer to cooler and wetter conditions.

Astrological aspects of the flood are mentioned in a number of myths. For example, Peruvian and Hindu myths mention a conjunction of planets immediately prior to the flood, whereas Hopi traditions (e.g., Mails and Evehama 1995, pp 506–509) note that the previous world ended several thousand years ago when there were violent signs in the sky and when certain "stars" (presumably planets) came together in a row. The Roman philosopher, Seneca, indicated that the 4th century BC Babylonian historian, Berossus, could date the end of the world by fire and flood by calculating when all the planets would again be positioned in a row (Verbugghe and Wickersham 1996, p 66).

Aquarius, "Water Bearer," is almost universally noted in Old World zodiacal mythology as being a source of water, with myths from China, Greece, Mesopotamia, and Egypt all specifically linking the constellation to the flood or at least some form of watery deluge (Motz and Nathanson 1988). In Greek mythology as well as in Babylonian symbolism, the asterism representing the urn carried by the Water Bear, which is located at approximately Zeta Aquarii, was the location from which the floodwaters came forth.

Pisces is of special interest due to the widespread historical astrological belief that conjunctions of planets within this sign, in particular Jupiter and Saturn, portend spectacular events and occasionally dire consequences. For example, in Biblical astrology it was predicted that another deluge would occur in the year AD 1524 when Jupiter, Saturn and Venus were in conjunction with Pisces (Allen 1963, p 341; North 1989, pp 63–68). The beginning of the modern Hindu age (*yuga*) of Kali after the flood, is stated by the 5th century AD Hindu astronomer, Âryabhata, as beginning at dawn on February 18, 3102 BC at a time when the naked-eye visible planets were in conjunction at 0° Aries, near the star Zeta Piscium (Pingree 1972; Gleadow 1968, pp 138, 147). A similar concept was expressed by the 9th century Arab astrologer, Albumasur, who predicted the destruction of the world when the five planets, Sun and Moon were in conjunction in the last degree of Pisces (Allen 1963, p 77). However, astronomy software demonstrates that such a conjunction of the five visible planets did not occur in 3102 BC or any year near that date.

This cluster of astrological details can be subjected to systematic analysis similar to that done for the environmental details in the flood myths described above to see if there is a logical explanation for these diverse statements. As reconstructed by astronomy software programs (*RedShift Multimedia Astronomy* 3.0©, *TheSky, version* 5©), it turns out that the year 2807 BC was highlighted by an extremely rare quadruple conjunction of Saturn and Jupiter at the boundary between Pisces and Aquarius (22 January, 26 April, 2 August, 10 November) with another such conjunction (including Venus) occurring on January 11, 2806 BC. On February 7, 2807 BC, the five planets were situated evenly in a row within Aquarius and Capricornus spaced about 10° apart from one another just before sunrise as seen in India, while on February 25 they were similarly situated in Aquarius in a row along with the Moon, spaced about 5° apart. During the middle of March at dawn, Venus and Mars were conjoined for several days with Saturn and Jupiter adjacent to Zeta Piscium. On April 25, 2807 BC there was a total eclipse of the Sun, and on May 10, 2807 BC there was a partial lunar eclipse.

The seasonal, calendrical and archaeological data form a compelling and logical story that well complements the rest of the environmental information in our sample of 175 flood myths. The principle of Occam's razor suggests that an oceanic comet impact on or about May 10, 2807 BC more simply and better explains the combined mythology, archaeology, paleoenvironmental record and documentary history surrounding the boundary between the middle and late Holocene (ca. 2800 BC) than do our current diverse models and theories of Holocene cultural evolution and climate change.

2.3.3.3
Modeling the Flood Comet Impact Event

Based on a reading of the preliminary set of flood myths summarized above, there are several aspects of the hypothesized impactor that can be logically elicited from these details, particularly in reference to the modeling of Toon and his colleagues (Toon et al. 1994, 1997) and the web-based impact modeling programs of Melosh and Beyer (2005) and Marcus et al. (2005).

In order to model likely impact effects, it is useful to first briefly discuss the Earth's atmosphere (Salby 1996). The atmosphere is dominated in volume by a mixture of molecular nitrogen (78%) and molecular oxygen (21%), with water vapor, carbon dioxide, ozone and other trace species comprising the remaining 1%. Although water vapor is a trace species, it plays a significant role in cloud formation, radiative processes and in energy exchanges with the oceans. About 60% of the overall water vapor is situated in the trophosphere, and then steady decreases in percentage at higher elevations. Gravity stratifies the atmosphere vertically, whereas the Earth's rotation creates meridional stratification and the development of large-scale circulation such as airflow around centers of high and low pressure. Atmospheric pressure and density decrease exponentially with increased elevation above the Earth's surface, but temperature varies in pronounced ways giving rise to the designations troposphere (lower atmosphere) from 0–10 km, the stratosphere (10–50 km) and mesosphere (50–85 km) of the middle atmosphere, and the thermosphere of the upper atmosphere (above 85 km). Upper troposphere circulation is characterized by subtropical jet streams, while the polar-night jet operates in the lower mesosphere. Collectively, the temperature-related layers below 100 km are termed the homosphere. In the heterosphere (100–500 km), molecular diffusion suppresses turbulent air motions and airflow is nearly laminar. The highest layer of the atmosphere is the exosphere, in which molecular collisions are rare and in which some molecules can achieve velocities that enable them to escape the Earth's gravity and enter deep space.

Toon et al. (1997) have noted that only limited modeling has been accomplished thus far of the potential atmospheric effects of water injection by the plume of a large abyssal oceanic impact. This was evident at the ICSU workshop in that virtually none of the presentations and papers addressed the effects and hazards of such a massive water injection.

The review and modeling of the effects of water injections in Toon et al. (1994, pp 817–821) is directly pertinent to defined effects of the hypothesized Flood Comet impact. A large comet hitting the abyssal ocean would loft an amount of water equal to about 10 times the mass of the comet into and through the middle and upper atmosphere. The latent heat of the water would cause the vapor cloud to adiabatically expand. High-altitude portions of the vapor cloud will form ice crystals that will fall downward, evaporate and humidify the lower atmosphere. Toon et al. (1994, pp 818–819) note: "Condensation after a 10^4 megaton impact may occur over several days, during which time the water will have been transported great distances from the impact site." They go on to note "a water-rich atmosphere is unstable with respect to vertical motions because any descending air parcels will have a water vapor partial pressure exceeding the vapor pressure, leading to rainout of the water, latent heat release and convective mixing." In simple terms, this means that there will be a lot of rain and very unstable atmospheric conditions. Toon et al. (1994, p 805) also note that submicron dust loading of the atmosphere caused by large terrestrial impacts may be countered by the water vapor in a large oceanic impact, and that "ice clouds formed by oceanic impacts have the potential to sweep some or all of the dust from the sky."

The environmental data in the flood myths fit remarkably well with the above modeling for a large oceanic comet impact above the threshold for global catastrophe at or greater than 10^6 MT (100 gigatons). The hypothesized Flood Comet impact is associated with six or seven days of intense atmospheric rainout, accompanied by hurricane-force winds for the duration of the period of rainout. Presumably the winds and a sizeable percentage of the rainfall are part of a system of ocean-fed worldwide cyclonic storms generated and sustained by the air pressure blast wave, the impact plume, the spread of water vapor, and its subsequent rainout. The intense darkness accompanying the flood storm is an indication of the amount of submicron and larger dust grains that accompany the water injection into the atmosphere, which is then seemingly effectively removed during the process of rainout. Intriguingly, the current myth sample suggest that torrential rainfall may have been limited to mid and low latitudes between about 55° N and 55° S. The few myths outside this range do not specifically mention rainfall.

Regardless of interpretation, the impacting comet was large enough to result in a seabed crater. Myths from Greece, Mesopotamia, India and Taiwan all indicate that the flood storm originated somewhere to their south, suggesting a possible impact location in the abyssal depths of the Atlantic-Indian Basin. Prior to the ICSU workshop, I originally modeled the impact in the general vicinity of 38° east longitude and 58° south latitude, a location reasonably close to recently discovered Burckle Crater (Sect. 2.4.1). The putative diameter of abyssal Burckle Crater at around 29 km can be modeled as the impact of a comet slightly larger than 5 km in diameter and a speed of 51 km s^{-1} entering the ocean at an act angle of 45° (Marcus et al. 2005). The energy produced by such an impact is approximately 2×10^7 MT. Of interest is the fact that such an impact would eject rocky debris to a distance of approximately 9000 km from the impact site, which is the approximate distance in which myths mention hot or fiery water falling from the sky (Fig. 2.2).

The common motif about rainbows and other similar phenomena immediately after the flood as described in a number of our sampled myths is fully consistent with

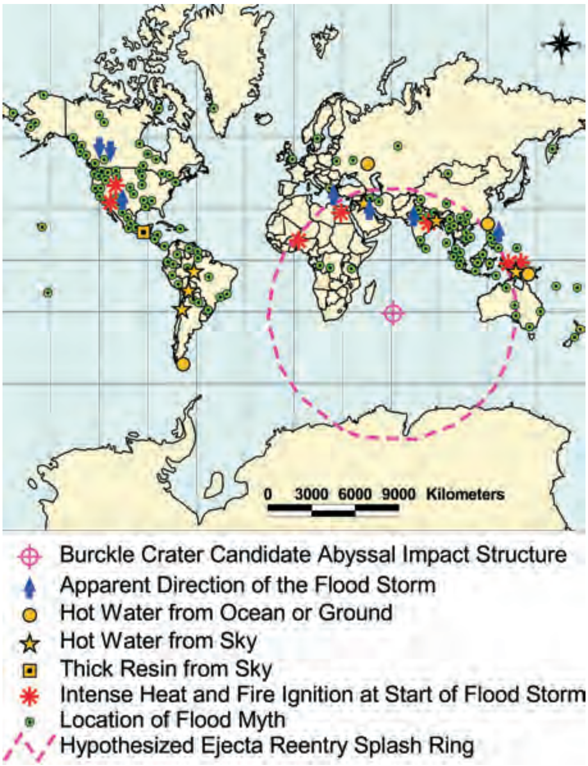

Fig. 2.2. Map depicting the location of Burckle Crater candidate abyssal impact structure in relation to selected environmental variables as stated in a sample of 175 "Great Flood" myths. In addition to depicting the approximate locations of the sampled flood myths themselves, the variables include the apparent direction traveled by the flood storm; hot water noted as coming from the ocean; hot water and "thick resin" noted as coming from the sky; and intense heat and ignition fires at the start of the flood storm (the latter includes a story from Egypt not in the sample of 175 myths). The figure also depicts a "hypothesized ejecta re-entry splash ring" modeled as the approximate boundary between the limits of rocky ejecta and condensed water vapor from the hypothesized Burckle Crater impact

the atmospheric physics of injecting a large column of water into and through the upper atmosphere. This would have led to the formation of high altitude ice clouds, that would become visible once the atmosphere had sufficiently rained out and stabilized, including the removal of obscuring dust particles. This rainbow effect, a greatly enlarged version of the common winter halo effect around the Sun and Moon, would dissipate as the ice volatilizes.

What does not fit the model of a single large Indian Ocean impact is the presence of a number of mega-tsunami myths from Brazil, the western coast of North America, the Arctic Ocean and in other locations outside the Indian Ocean basin. Likewise, the presence of hot or fiery water falling from the sky in several North and South American myths cannot have been caused by atmospheric re-entry ejecta from the Burckle Crater event. Myths from north-western North American describe the flood storm as coming from the north. And as noted in Sect. 2.4.1, Burckle Crater by itself cannot explain the large volume of rainfall indicated by worldwide mythology.

Not only was the Flood Comet likely composed of several fragments (Abbott et al. 2005), one may have considerably lagged behind the others. There are several stories from New Guinea and Australia about a flame or bright light witnessed oddly enough during the middle of the flood storm. One such Aboriginal Dreamtime story from Australia is as follows (Smith 1930):

> An old goanna *[lizard]* stuck his head out *[from the protective cave]*, but quickly withdrew it … "I have seen a wonderful sight, an awful monster with an eye as big and bright as the Moon. But wait a moment, his eye is brighter than the Moon, and nearly as bright as the Sun" … They all gathered together to discuss what they had seen, and each had a different account to give their new *Intelligence* that had arrived with the rain, the thunder, and the lightning. There was one thing, however, regarding which they were all agreed, and that was the brightness that shone from this formless being. Strange to say, whenever rays of light appeared to the vision of the watcher they were stamped upon his memory and also upon his body, and were plainly visible to those round about.

Also of interest along with these particular myths are descriptions of a second tsunami along the coast of New Guinea three days after the onset of the flood storm.

The internal consistency of these sets of myths from Australia and New Guinea are suggestive of a second smaller impact two or three days after the first, therefore indicating that the comet had calved into several separate fragments, perhaps in a prior perihelion passage of the Sun. Such a situation may help to explain the imagery of giant supernatural twins or companions that is prevalent in Mesopotamian, Egyptian and even Mesoamerican myth and iconography between the period of about 3200 BC to around 2650 BC (Masse 1998).

2.3.3.4
The "Invisible" Mid-Holocene Globally Catastrophic Comet Impact

One obvious question jumps out for anyone considering these data: How did we miss it – how did we (science) fail to recognize the signature of a globally catastrophic impact dating to less than 5000 years ago … or even more specifically in 2807 BC? This is a disturbing question that, if the impact is real and correctly modeled, must give us great pause. There are at least four circumstances that together may extract us from this dilemma.

The first involves our current reliance on radiocarbon dating for dealing with issues of mid-Holocene archaeology and climate change. Ironically, the modeled date of 2807 BC falls into the middle of one of the largest bursts of natural radiocarbon production evident in the past 5 000 years of the calibrated radiocarbon production curve (Taylor 1997, Table 3.1). Radiocarbon production occurs in the upper atmosphere as the product of neutrons in cosmic rays interacting with nitrogen atoms to produce radiocarbon. A burst of newly formed radiocarbon has the effect of creating a "shingle" or period of a couple hundred years during which radiocarbon dating itself cannot well separate the dates for one given year from any other within that specific period. Due to such secular variation, carbon samples formed during the year of the hypothesized comet impact could be represented by radiocarbon ages anywhere between 4300 and 4080 BP.

Or perhaps it is not so ironic. We need to evaluate the possibility that the Flood Comet impact itself contributed to this radiocarbon dating shingle. The introduction of vast amounts of nitrogen into the atmosphere by the impact plume, coupled with the possibility that the plume blew off part of the atmosphere and thus would have allowed cosmic rays to more deeply penetrate and react with the nitrogen, is an ideal setting for enhanced radiocarbon production (a possibility also raised by Tollmann and Tollman 1994).

Reliance upon radiocarbon dating also masks changes in regional population size. Widespread mammalian populations such as deer typically recover rapidly from mass mortality. Even if there had been a loss of two-thirds (67%) of all people due to the Flood Comet and its aftermath, it would take the survivors only 80 years to fully recover to the previous population level, assuming a very modest average population increase of 2% per year beginning in the sixth year after the impact. Given that radiocarbon dating typically has a standard deviation of 40 to 50 years, and given that for any time period during the middle Holocene we have likely documented far fewer than 1% of all habitation sites, and given that archaeologists tend to lump population estimates into 100 or even 500-year periods for ease of data manipulation, the catastrophic loss of 67% of humanity would be hard to define in the archaeological record. Having said that, there is some indication of population decline around 3000 BC give or take a few hundred years (Masse 1998, Fig. 2.3), including the interesting extirpation of humans from sizeable Flinders Island near Australia.

The second circumstance is related to the potential environment transforming complexities of oceanic impacts. Our present models of effects for oceanic impacts at the threshold for global catastrophe (e.g. Toon et al. 1997; Marcus et al. 2004), particularly in those cases where the impact location is far from continental margins and major islands, tend to focus on tsunami rather than other effects. Based on the assumption that the hypothesized Flood Comet impact is a real event and that my preliminary modeling of magnitude is relatively accurate, I would argue that the most devastating effects on human life and infrastructure would stem from the "flood storm," that is, from the combination of atmospheric rainout and concomitant cyclonic storms.

With a globally catastrophic oceanic comet impact, there occurs – in addition to the air pressure blast wave, splash ejecta re-entry, and variable fires from ablation and ballistic re-entry of larger particulates – massive tsunamis and storm surges along coastal margins followed by even more massive water movements across the entire landscape from the flood storm. This would result in the cutting and filling of drainage systems, landslides, along with the stripping of forests and the variable destruction of vegetation communities caused by the atmospheric rainout and cyclonic storms. Ironically, the tsunamis signatures may be obscured by the surface water and sediment flows from the atmospheric rainout and cyclonic storms. Unlike the KT-boundary impact, there likely is nothing equivalent to the KT boundary iridium layer – there is no one single uniform archaeological, geomorphological or paleoenvironmental signature for the Flood Comet impact itself.

The third circumstance, related closely to the first two, is that our present field methods for studying past environmental change are ill suited for the study of abrupt large-scale catastrophe and particularly for the identification and explication of oceanic cosmic impacts. There is a need for better dating of stratigraphic columns including the securing of larger numbers of chronometric dating samples and the use of a larger range of both chronometric and relative dating techniques, including the use of microspherules as suggested by Raukas (2000) and others. There is also a need for systematic local and regional stratigraphic sampling strategies that go beyond our present research designs for looking at environmental change.

I am intrigued by the coincidence of the Flood Comet impact date with the boundary between the middle and late Holocene climatic regimes. We still have much to learn about the coupling between the atmosphere and the oceans of our world. If the Flood Comet impact were to be validated and if it could be demonstrably linked to this perceived minor climate boundary change, then what if the comet had instead crashed elsewhere into the world's oceans such as the north Pacific? Would this have created different climatic effects? Do we need to think about and to model the effects of different magnitudes and locations of oceanic impacts in relation to the El Niño-Southern Oscillation (ENSO) or some of our other climatic cycles? And what might validation of the Flood Comet impact tell us about past climate change? For example, the dramatic beginning of the Younger Dryas period at around 9600 BC, mirrors the physical signatures of the hypothesized Flood Comet impact, but is marked by an even larger burst of radiocarbon production and even greater shifts in climate and in ocean circulation, along with the destructive flooding of contemporaneous archaeological sites and the extirpation and eventual extinction of several large mammal species. Tollmann and Tollman (1994) may have been right about a hugely catastrophic comet impact at 9600 BC … even if for the wrong reasons.

The fourth circumstance is that we are dealing with the "Flood Comet" and not the "Flood Asteroid." Not only do we lack some of the telltale clues of asteroid impact such as recognizable meteoritic fragments and possibly elevated iridium concentrations, but we also do not yet know the full range of variation in comet composition, therefore even our modeling of potential impact products for which to search becomes suspect.

2.3.3.5
Surviving the Flood Comet Impact

Settlement patterns 48 centuries ago as today favored the use of coastal margins and valley bottoms due to access to farmlands, transportation corridors, marine fisheries and river resources. Ironically, these are the areas most vulnerable to a globally catastrophic oceanic impact given the “1-2-3 punch” of tsunamis, massive flooding from storm surges and extended atmospheric rainout, as well as accompanying hurricane-force winds. In addition to the staggering loss of human life, these combined forces would destroy homes, crops, animals and plant resources, with large areas being stripped of its forest leaf cover and in many cases of the trees and shrubs themselves.

The great majority of the 175 flood myths describe in fair detail the numbers of people who survived and how they survived. Collectively, the flood myths suggest that between 50–75% of humanity died during the Flood Comet impact and its aftermath. Only about 15% of the myths indicate that more than half of a given cultural group survived, while about 35% of the myths indicate survivorship by multiple couples, families, and portions of villages. Thus half the myths indicate few or “no survivors,” with the modern world being replenished by a new creation of humanity. Regions of seeming higher survivorship include Tibet, north-eastern India, portion of New Guinea and southern Australia, New Mexico in the United States, and especially portions of Alaska, northern Canada, and the North American Pacific Northwest.

About half of the myths indicate that people saved themselves on boats, canoes, makeshift rafts, or by floating on or in a log or other buoyant debris, which then typically became grounded on mountainsides or other high spots. In more than a third of the myths, survivors sought refuge by climbing tall mountains or hills near their village, in some cases occupying known caves. A few survivors found refuge at the tops of tall trees. Many refugees are stated as dying due to exposure and famine following the flood storm. The previously mentioned language dispersals around 2800 BC are an expected response to widespread destruction of habitat and the fragmentation of many societies.

The most sobering way to measure the effects on human society of the Flood Comet impact is to use the voices of the survivors and their descendents. While there are hundreds of poignant stories, I here quote two. The first is from *Metamorphoses* by Roman poet Ovid (Melville 1986):

> And out on soaking wings the south wind flew, his ghastly features veiled in deepest gloom … and when in giant hands he crushed the hanging clouds, the thunder crashed and storms of blinding rain poured down from heaven … The streams returned and freed their fountains’ flow and rolled in course unbridled to the sea. Then with his trident Neptune struck the earth, which quaked and moved to give the waters way. In vast expanse across the open plains the rivers spread and swept away together crops, orchards, vineyards, cattle, houses, men, temples and shrines with all their holy things … over the whole earth all things were sea, a sea without a shore. Some gained the hilltops, others took to boats and rowed where late they ploughed … The world was drowned; those few the deluge spared for dearth of food in lingering famine died.

The second story is a composite sense of how Australian Aborigines view the coming of the powerful deity Rainbow Serpent and his role in the flood (Berndt and Berndt 1994):

> As for appearance, there is basic agreement that a great snake is involved, but other features vary. In western Arnhem Land, for instance, reference is often made to ‘horns’, one at each side of the snake’s head, to ‘whiskers’ (when it is male), and to the dazzling light from the snake’s eyes. But most it is the sound of the snake’s approach, rather than the sight, that is mentioned in stories. The victims are so overcome by what is happening to them that they have only a vague vision of ‘who’ might be doing it. Apart from the sight and the feel of rising waters, trees falling and their belongings being washed

away, they hear the noise of rushing flood-streams or tides, and the roar of the wind like the combined 'voices' of many bees, or like a huge bush-fire speeding toward them. That noise is sometimes contrasted, in myths, with the stillness and quietness later on when all is over, when the bones have turned to rock. At some sites a pool of clear water reveals, deep down and unmoving, rocks that were once the domestic belongings of the people who had lived there.

2.4 Epilog and Conclusions

2.4.1 Candidate Abyssal Impact Structure

Shortly after the conclusion of the ICSU workshop, I discussed my project with geophysicist Dallas Abbott, who volunteered to perform a preliminary search for young abyssal craters in the Indian Ocean. This search resulted in the discovery of a candidate abyssal impact structure (Burckle Crater) about 1 500 km southeast of Madagascar, centered at 30.87° S and 61.36° E (Fig. 2.3). The structure is approximately 29 ± 1 km in diameter, and is discernable on bathymetric topographic maps as a nearly circular feature on the edge of a fracture zone along the southeast Indian ridge at an abyssal depth of about 3 800 m (Abbott et al. 2005). The rim is not continuous but rather is broken by a series of low points that likely represent resurge gulleys formed in the crater walls by water movement during the collapse of the impact water cavity. A study of pertinent seismic lines reveals that the only areas with any sediment cover are all topographic lows near Burckle Crater, while away from the crater the basement is completely bare of sediment including topographic lows.

The examination of three cores from the vicinity of Burckle Crater, but away from the ridge itself, revealed the presence of a likely ejecta layer (Abbott et al. 2005). This is represented by high levels of magnetic susceptibility in the uppermost portion of the column, along with grains of freshly broken plagioclase feldspar and other displaced mantle and fracture-related rocks such as a spinel peridotite, chrysotile asbestos and manganese-rich pyroxene. Of particular interest is a 200 micron wide grain of pure native nickel that exhibits oxidation droplets along one margin. Because pure nickel melts at 1 453 °C, a higher temperature than ever occurs in mid-ocean ridge magmas, this is assumed to be evidence of impact alteration. It is presently uncertain if the nickel is extraterrestrial in origin or from the mantle. Pleistocene bedrock at the base of one of the cores and the location of the magnetic susceptibility layer at the top of each core strongly suggests a Holocene age less than 6 000 years for the putative impact event.

Modeling of the injection of water vapor into the upper atmosphere from the Burckle Crater event yields a maximum rainout worldwide of around 9.2 cm (Abbott et al. 2005). As previously noted this figure is far too small to account for worldwide flood mythology rainfall. However, even with several similar-sized fragments impacting other oceanic locations as part of the overall Flood Comet impact event, this would still not produce the volume of water necessary for 6 to 7 days of worldwide torrential rainfall. I suggest that the majority of the rainfall was due to ocean-fed prolonged cyclonic storm activity stimulated by atmospheric rainout and blockage of sunlight. The termination of the cyclonic storms coincided with the return to pre-impact levels of water vapor in the atmosphere.

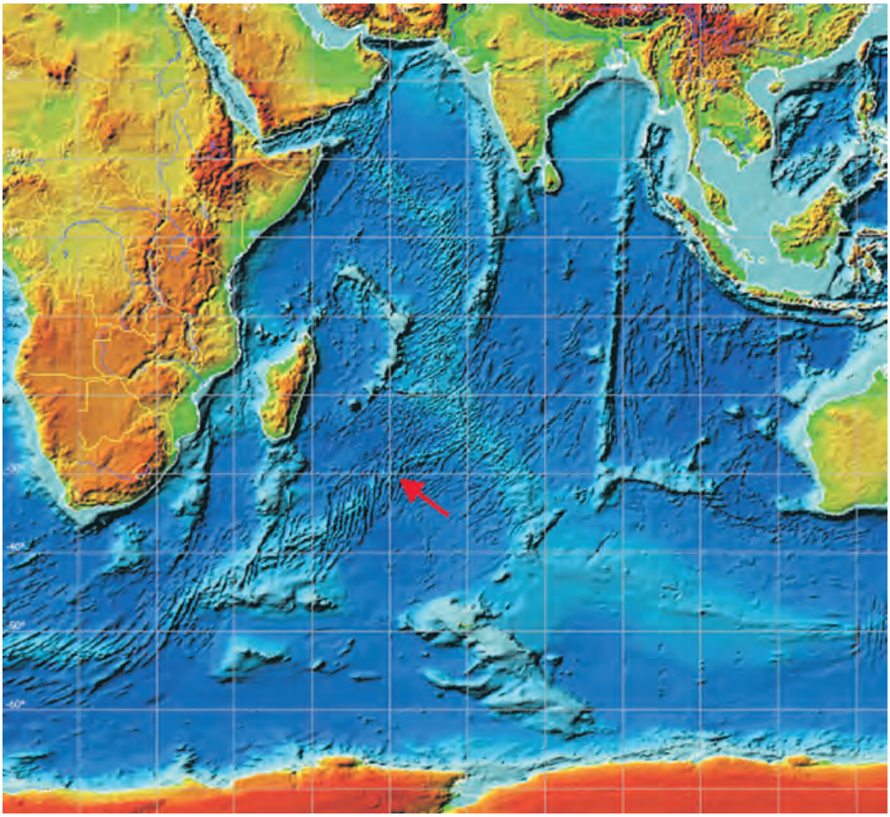

Fig. 2.3. Map of the approximate location of Burckle Crater candidate abyssal impact structure (*red arrow*) along the southeast Indian Ridge. The map is adapted from the ETOP-5 topography coverage on the *Integated Tsunami DataBase for the Pacific* compact disc (ITDB 2004)

The location of Burckle Crater is well situated to be the source for likely Holocene mega-tsunami chevron deposits documented along the western coast of Australia (Kelletat and Scheffers 2003; Abbott et al. 2005) and for Tamil myths in which a tsunami at the time of the great flood ran inland for nearly 100 km and an elevation of 100 m only to stop at the edge of the city of Madurai in southern India (Shulman 1988). But even more compelling is the language and imagery from the Sanskrit Puranas that tell of the destruction of the world at the end of the present Kali age, but which also is paraphrased in the previously mentioned great flood myths about Manu (Dimmitt and van Buitenen 1978):

> So when Janardana in Rudra's form *[the god Visnu in the form of Siva, the destroyer god]* has consumed all creation *[with fire]*, he produces clouds from the breath of his mouth that look like a herd of elephants, emitting lightning, roaring loudly. Thus do dreadful clouds arise in the sky. Some are dark like the blossom of the blue lotus; some looking like the white water-lily; some are the color of smoke; and others are yellow. Some resemble a donkey's hue; others are like red lacquer; some have the appearance of a cat's-eye gem; and some are like sapphire. Still others are white as a conch shell

> or jasmine, or similar to collyrium *[an eye lotion]*; some are like fireflies, while others resemble peacocks. Huge clouds arise resembling red or yellow arsenic, and others look like a blue-jay's wing. Some of these clouds are like fine towns, and some like mountains; others resemble houses, and still others, mounds of earth. These dense, elephantine clouds fill up the surface of the sky, roaring loudly. Pouring down rain they completely extinguish this dreadful fire which has overtaken the three worlds. And when the fire is thoroughly quenched, the clouds raining day and night overwhelm the entire world with water.

Such a description could not have been written from pure imagination. Rather, this can only be conceived as an eyewitness account of the debris plume of a cataclysmic explosion. The Sanskrit Puranas were originally written about 1000 BC, and revised during the 4^{th} through 6^{th} centuries AD. The contextual relation of this description to the flood and specifically to the previously noted myth of Manu and the horned, golden-colored fish suggests that the description is of the debris plume associated with the impacting Flood Comet.

2.4.2
Post-Workshop Final Thoughts

The archaeology and anthropology of cosmic impact during the Quaternary period has proven fascinating to compile and to research, but also extraordinarily complex and problematic. For example, it is clear that during the past 5 000 years – the period of recorded human history – cosmic impacts lead to significant human death and culture change. Although there can and will be debate about the scale of these effects – local, regional or global – what remains frustratingly unclear is what this record may ultimately mean toward understanding the ongoing risks of cosmic impact.

At one end of the spectrum, we have witnessed during the 20^{th} century substantive but still local impacts such as Tunguska (1908) and Sikhote Alin (1947), each in largely uninhabited areas. The Tunguska event is typically modeled as anomalous, happening only once every few hundred or even several thousand years based on the latest modeling trends (e.g. Stuart and Binzel 2004). Such modeling seemingly fails to consider the admittedly poorly studied but very real 1930 Brazil impact (Bailey et al. 1995) and 1935 Guyana impact (Steel 1996) that also apparently exceeded one megaton in magnitude and devastated several hundred square kilometers of forest and perhaps some of its human occupants. Also, it should be remembered that the Sikhote Alin meteorite swarm impacted an area at least 4×12 km, and resulted in thousands of individual impacts, nearly 200 of which were of such size to form small craters (Gallant 2002). Had any of these four events during the 40-year period of 1908 through 1947 occurred in an urban setting, there would have been considerable property destruction and loss of life – there also would be no current need to justify research on the topic of the risks and hazards of cosmic impact.

Moving back into archaeological and anthropological time, local Holocene populations unquestionably suffered greatly from the Kaali, Campo del Cielo, Rio Cuarto (airburst), and possibly the Henbury impacts with potential regional effects (social disruption) likely for each.

There are several potential impacts toward the other end of the magnitude scale during the past 20 000 years, but for which we unfortunately are faced with preliminary data requiring varying degrees of additional research and physical validation. These include the large potential Bronze Age airburst in the Near East and the hypothesized Umm al Binni impact (ca. 10^2 MT); Iturralde in Bolivia (ca. 10^3–10^4 MT); Mahuika in the waters near New Zealand (ca. 10^4 MT); Chiemgau-Burghausen in southern Germany (ca. 10^4–10^5 MT), which may (or may not) relate to Mike Baillie's (this volume) hypothesized cometary atmospheric dust loading in the 6^{th} century AD; Rio Cuarto, if the impact origin for the purported craters is validated (ca. 10^5–10^6 MT); the hypothesized Flood Comet impact (ca. 10^7 MT) of 2807 BC, and the putative impact associated with the Younger Dryas climate event of about 9600 BC (ca. 10^7 to 10^8 MT). There likely are other potential substantive Holocene impactor candidates that have not yet been satisfactorily identified for modeling and testing (Masse 1998). The good news is that all of these hypothesized impacts can and will be further researched and tested by all necessary physical means for eventual validation or dismissal. The length of time such research and testing will take depends partly on the degree to which the NEO community and funding agencies view this as a serious and worthwhile endeavor, and are willing to support such study.

As noted during the ICSU workshop, the validation of any one of these hypothesized larger magnitude ($> 10^3$ MT) recent events will strain existing astrophysical models of cosmic impact hazard and risk. The validation of two or more of these events, particularly if they involved comets, could not be reconciled with existing impact models. Given the nature of the information seemingly encoded in the documentary and oral historical record of humankind, and given the fact that there are several substantive widespread rapid changes in both climate and archaeological/historical culture during the past 20 000 years for which we do not yet have a satisfactory explanation, I anticipate that at least two and likely more of the hypothesized larger impacts will be validated. What this may mean in terms of the reality of assessments of the risks and hazards of cosmic impact remains to be addressed.

Virtually all past traditional knowledge keepers insisted that information about immense natural catastrophes preserved in oral traditions and myths were among the most valuable legacies that any cultural group could pass on to future generations. Perhaps they were right.

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