Australian Aboriginal Geomythology: Eyewitness Accounts of Cosmic Impacts?

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Abstract

Descriptions of cosmic impacts and meteorite falls are found throughout Australian Aboriginal oral traditions. In some cases, these texts describe the impact event in detail, suggesting that the events were witnessed, sometimes citing the location. We explore whether cosmic impacts and meteorite falls may have been witnessed by Aboriginal Australians and incorporated into their oral traditions. We discuss the complications and bias in recording and analyzing oral texts but suggest that these texts may be used both to locate new impact structures or meteorites and to model observed impact events. We find that, while detailed Aboriginal descriptions of cosmic impacts and meteorite falls are abundant in the literature, there is currently no physical evidence connecting any of these accounts to impact events currently known to Western science.

Resumen

En todas las tradiciones orales de los aborígenes australianos se encuentran descripciones de los impactos cósmicos y de las caídas de los meteoritos. En algunos de los casos, estos textos describen los impactos detalladamente, lo que sugiere que estos eventos fueron presenciados físicamente, incluso a veces se reportan los nombres de lugares. En el presente trabajo se explora la posibilidad de que los choques cósmicos y las caídas de los meteoritos fueron realmente vistos por los aborígenes australianos e incorporados en su tradición oral. Se discuten las complicaciones y la parcialidad de juicio que hubo en el registro y el análisis de los textos orales y no obstante se sugiere que los textos mencionados se pueden usar para localizar nuevas estructuras de choque y para modelar los eventos de impacto observados. Notamos que, mientras en la literatura son muy frecuentes las descripciones detalladas de los aborígenes sobre los choques cósmicos y las caídas de los meteoritos, en la actualidad no hay ninguna evidencia física que pudiera conectar alguno de estos relatos con los fenómenos de choque conocidos por la ciencia occidental.

Notice to Aboriginal Readers

This article gives the names of or references to Aboriginal people that have passed away and information that may be considered sacred to some groups. It

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also contains information published in *Nomads of the Australian Desert* by Charles P. Mountford (1976). This book was banned from sale in the Northern Territory in 1976 as it contained sacred/secret knowledge of the Pitjantjatjara (see Brown 2004:33–35; Neate 1982). No information about the Pitjantjatjara from Mountford's book is presented in this article.

Introduction

Australia is home to hundreds of Aboriginal groups (Walsh 1991), each with a distinct language and culture, stretching back more than 40,000 years (O'Connell and Allen 2004). Many Australian Aboriginal cultures possess strong oral traditions and complex social systems (e.g., Maddock 1982; Ross 1986:232), including narratives and oral texts that have been handed down over many generations (Ross 1986). Threaded through these texts are accounts of geological events such as volcanic eruptions, earthquakes, and tsunamis as well as descriptions of the origins of mountains and islands. In some cases, the description indicates that these events were witnessed, resulting in a significant impact on that community, as suggested by Norman Tindale, who stated that "Aboriginal myths may occasionally refer to some half-remembered cataclysm of nature, or an eclipse, or a meteoric shower" (1946:76; Stanner 1975:5). The study of how geological events or geographical features and materials are incorporated into oral traditions is referred to as *geomythology* (see Piccardi and Masse 2007). This article focuses on oral texts relating to meteorite falls and cosmic impacts. Using the hypothesis that oral texts can serve as historical records of past geological events (Masse, Barber, Piccardi, and Barber 2007), we examine these records for information that could be used to locate new meteoritic sites, model meteoritic events, or measure the antiquity of dreaming stories. Scientific data from these events, including the age, location, and impact effects, can assist in understanding the nature and evolution of oral traditions over time.

Aboriginal Australia: Prehistory and Orality

From a scientific perspective, the arrival of humans in Australia is a matter of contentious debate. From approximately 15,000 to 70,000 years ago, the sea level was much lower than it is today (Voris 2001). During this period, Tasmania, Australia, and New Guinea were a single landmass, called Sahul. It is believed that humans migrated to Sahul in multiple waves from Southeast Asia, though it seems Aboriginal Australians share a common genetic thread with people from southern India as opposed to Indonesia or Malaysia (Redd and Stoneking 1999). The exact date of human arrival to Sahul is uncertain, but solid archaeological evidence suggests that Australia has been inhabited for at least the last 45,000 years (O'Connell and Allen 2004). Some archaeological sites suggest an earlier arrival date, such as 60,000 to 70,000 years at Lake Mungo in New South Wales (Adcock et al. 2001; Thorne et al. 1999) and 60,000 years at Nauwalabila I in the Northern Territory (Roberts et al. 1999). However, further analyses of these sites have constrained the age to between 40,000 and 50,000 years (Bird et al. 2002; Bowler et al. 2003; Gillespie and Roberts 2000). It is generally accepted by mainstream archaeologists that the age of human habitation of Australia is *at least* 40,000 years.

From the perspective of many Aboriginal communities, Aboriginal Australians have *always* been in Australia, and their cosmologies describe the origins of their ancestors and traditions in various forms. These cosmologies are recorded in the oral tradition, which itself is passed down subsequent generations, evolving as new events are incorporated into art, song, and story line. These oral texts preserve the knowledge, moral codes, laws, and traditions necessary for the survival, cohesion, and social structure of the community. "It is very difficult, as things stand, for anyone, scholar or layman, to gain an overall impression of the nature and extent of Aboriginal oral tradition" (Ross 1986:260).

Australian Aboriginal oral traditions are typically considered components of the "Dreaming," a term coined by anthropologist Francis James Gillen in 1896 to refer to the period in the religious mythologies of northern Arunta people of the Northern Territory (Dean 1996). The Dreaming is a highly complex concept that exhibits substantial diversity in meaning and purpose between different Aboriginal communities and cannot be simply regarded or dismissed as mythology or fables. We acknowledge that the

Indigenous Australian and the Western scientific methods and approach to acquiring knowledge and explaining the natural world are vastly different. We seek only to apply information from oral traditions to the discipline of geomythology. This work is in no way meant to "legitimize" or "marginalize" Aboriginal oral traditions or cultures. For a better understanding of the Dreaming, we refer the interested reader to Stanner (1958, 1965, 1975), Meggitt (1972), Charlesworth et al. (1984), Ross (1986), Rumsey (1994), Beckett (1994), Dean (1996), Bates (1996), and Rose (1996, 2000).

Given the substantial diversity of Aboriginal communities, customs, laws, and traditions may vary between Aboriginal communities, even those of the same language group. While some common themes exist across many Aboriginal communities, such as the concept of the Rainbow Serpent (Radcliffe-Brown 1926), each group has a different variation of these themes. For this reason, each reference to a particular Aboriginal story, ethnography, or word in this article will include the name and location of that particular Aboriginal group. A full list of the Aboriginal groups discussed in this article, including their location, can be found in the appendix.

In many Aboriginal communities, certain ceremonies and oral traditions are considered sacred and secret and thus are not shared with Westerners or even uninitiated members of that community. For example, Barker (1964:109–110) tells how a group of Aboriginal people knew of a meteorite in the desert and described how it fell to the earth from the sky, leaving little doubt in his mind that his Aboriginal informants had witnessed the fall. But since the meteorite was used as a source for sacred stories, the informants would not reveal its location to Barker or the other colonists. It is possible that some of the conclusions reached in this article, particularly regarding the lack of stories about known impact craters, may be affected by this need for secrecy.

Australian Impact Craters

Australia is home to 27 confirmed terrestrial impact structures and numerous suspected terrestrial and submarine structures (e.g., Abbott et al. 2005; Becker et al. 2004; Earth Impact Database 2009; Gibbons 1977; Green 2008; Martos et al. 2006). These structures range in size from the 20-m Dalgaranga crater to the 90-km Acraman crater and vary in age from billions of years to a few thousand years. Table 1a lists all confirmed Australian craters, while Table 1b lists all probable or suspected craters, shown in Figure 1. The vast majority (21 out of 27) of impact structures are found in the Northern Territory and Western Australia. There are only two confirmed in Queensland, one suspected crater in Tasmania, and no confirmed craters in New South Wales or Victoria. The recent discovery of a possible impact structure in northwestern New South Wales (Green 2008) may be that state's first known crater.

Of the confirmed craters in Australia, the constrained dates of only three occur within well-established human habitation of the continent (<40,000 years). These are the Henbury crater field and Boxhole crater in the Central Desert and the Veevers crater in Western Australia. O'Connell mentions a handful of crater candidates in Australia that are not listed above, including a crater "seen on an Aboriginal reserve on Koolatong River near Blue Mud Bay" (13°10'S, 135°40'E; 1965:16), the Lake Hamilton craters on the west coast of Eyre Peninsula, South Australia (33°55'S, 135°16'E; 1965:70), and the Weepra Park Depressions 30 km east of Elliston, Eyre Peninsula, South Australia (33°26'S, 134°16'E; 1965:125), which are both estimated to be <9,000 years old and are probably solution-collapsed domes. O'Connell also includes the Mount Doreen crater, Northern Territory, at the general coordinates of 23°S, 133°E, which is estimated to have formed ~100 years ago (1965:88).

Geomythology

The study of geological phenomena (including astronomical events such as comets, eclipses, and supernovae) inspiring aspects of oral traditions is referred to as *geomythology*, a term coined in 1968 by Dorothy Vitaliano, a geologist at Indiana University. The word *mythology* is derived from the Greek *mythos*, "story" (or in some cases "word"), and *logos*, "word" in the form of speech. Thus, mythology can be considered "spoken stories." There is a long-standing debate regarding the nature and purpose of myth,

Table 1a. Confirmed Terrestrial Impact Craters in Australia

N[a]	Name	Latitude	Longitude	State[b]	Age (Ma)	Distance (km)
1	Woodleigh	26°03'S	114°39'E	WA	364 ± 8	40
2	Dalgaranga	27°38'S	117°17'E	WA	~0.27	0.02
3	Yarrabubba	27°10'S	118°50'E	WA	~2,000	30
4	Shoemaker (Teague)	25°52'S	120°53'E	WA	1,630 ± 5	30
5	Glikson	23°59'S	121°34'E	WA	<508	~19
6	Connolly Basin	23°32'S	124°45'E	WA	<60	9
7	Veevers[c]	22°58'S	125°22'E	WA	<0.02	0.08
8	Wolfe Creek	19°10'S	127°48'E	WA	<0.3	0.87
9	Goat Paddock	18°20'S	126°40'E	WA	<50	5.1
10	Spider	16°44'S	126°05'E	WA	>570	13
11	Piccaninny	17°32'S	128°25'E	WA	<360	7
12	Matt Wilson[d]	15°27'S	130°28'E	NT	unknown	7.5
13	Liverpool	12°24'S	134°03'E	NT	150 ± 70	1.6
14	Goyder	13°28'S	135°02'E	NT	<1,400	3
15	Strangeways	15°12'S	133°35'E	NT	646 ± 42	25
16	Foelsche	16°40'S	136°47'E	NT	>545	6
17	Lawn Hill	18°40'S	138°39'E	QLD	>515	18
18	Kelly West	19°56'S	133°57'E	NT	>550	10
19	Amelia Creek	20°55'S	134°50'E	NT	600–1,640	90
20	Boxhole[c]	22°37'S	135°12'E	NT	0.0054 ± 0.0015	0.17
21	Gosses Bluff	23°49'S	132°19'E	NT	142.5 ± 0.8	22
22	Henbury[c, e]	24°34'S	133°08'E	NT	0.0042 ± 0.0019	0.15
23	Tookoonooka	27°07'S	142°50'E	QLD	128 ± 5	55
24	Mount Toondina	27°57'S	135°22'E	SA	<110	4
25	Acraman	32°01'S	135°27'E	SA	~590	90
26	Flaxman	34°37'S	139°04'E	SA	>35	10
27	Crawford	34°43'S	139°02'E	SA	>35	8.5

Source: Data from Earth Impact Database (2009).

[a] Numbered as in Figure 1a.

[b] States are abbreviated as follows: Western Australia = WA, Northern Territory = NT, South Australia = SA, Queensland = QLD, New South Wales = NSW (including the Australian Capital Territory), Victoria = VIC, and Tasmania = TAS.

[c] Craters with an established age consistent with human habitation of Australia.

[d] Kenkmann and Poelchau (2008).

[e] The Henbury crater field comprises 13 craters, resulting from the breakup of a nickel-iron meteoroid in the atmosphere before impact The diameter given here is of the largest crater, which is actually a cluster of three craters superimposed.

and associated theories of myth vary significantly between academic disciplines. Here, we draw from Masse, Barber, Piccardi, and Barber (2007) that myths can serve as oral records of natural events and that these records can be elicited by modern science to understand or model historic natural events—in this case, cosmic impact events.[1] During the twentieth century, the use of myth to explain geological events was viewed with skepticism by the scientific community, as there was little physical evidence to support the hypothesis. However, in the twenty-first century, physical evidence is helping geomythology gain new ground as a legitimate discipline. The first major peer-reviewed work on geomythology is *Myth*

Table 1b. Probable or Suspected Terrestrial Impact Structures in Australia

N[a]	Name	Latitude	Longitude	State	Reference
1	Hickman	23°02’S	119°40’E	WA	Glikson et al. (2008)
2	Wulinggi	13°02’S	131°06’E	NT	Murgatroyd (2001)
3	Maningrida	11°53’S	134°12’E	NT	Haines (2005)
4	Gulpuliyul	13°19’S	134°06’E	NT	Sweet et al. (1999)
5	Renehan	18°18’S	132°39’E	NT	Haines (2005)
6	Spear Creek	17°16’S	135°50’E	NT	Kruse et al. (2010:59)
7	Calvert Hills	17°22’S	137°28’E	SA	Macdonald and Mitchell (2004)
8	Wessel	20°36’S	135°05’E	NT	Macdonald and Mitchell (2004)
9	White Cliffs	30°47’S	143°08’E	NSW	Green (2008)
10	Darwin	42°18’S	145°39’E	TAS	Howard and Haines (2007)

[a] Numbered as in Figure 1b. Wulinggi is the local Aboriginal name for Crater Lake near Batchelor, considered a sacred site of the Kungarakany and Warai people (Murgatroyd 2001:13).

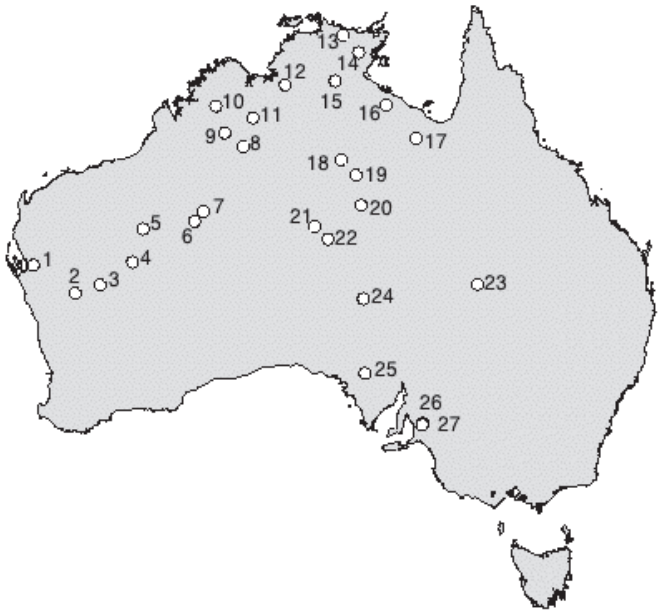

FIGURE 1A. Geographic locations of known terrestrial impact craters in Australia. Craters are numbered from Table 1a. The Flaxman and Crawford craters near Adelaide, South Australia (26 and 27), are very close in proximity and appear almost completely superimposed on this map.

FIGURE 1B. Geographic locations of probable or suspected terrestrial impact craters in Australia. Craters are numbered from Table 1b.

and Geology (Piccardi and Masse 2007), which provides the theoretical foundation of the discipline and serves as the methodological basis of this work. Given the generally negative connotations of the word *mythology*, we instead use the more accurate term *oral tradition*.

While Piccardi and Masse (2007) provide a plethora of examples of geomythology from around the world, they represent only the tip of the iceberg. Many stories use natural events or landforms to illustrate a moral point, sometimes including warnings to future generations. On December 26, 2004, such an example was witnessed by the world as an earthquake off the western coast of Sumatra induced a tsunami that swept across the Indian Ocean, killing thousands. Some Indigenous peoples of the Indian Ocean survived the tsunami because of information contained in their mythology. These groups, including the Moken people of Thailand and Indigenous Andaman Islanders, possessed stories that told of great waves that would "eat men" and that this wave would come when the sea receded rapidly. Their stories told them that to survive they must immediately run to high ground. Their adherence to these stories saved their lives (Arunotai 2006; Masse, Barber, Piccardi, and Barber 2007:18). This suggests that such events probably occurred in the past (see Jankaew et al. 2008) and were significant enough to be incorporated into story lines that lasted long periods of time. These stories contained information and warnings about natural catastrophes that were crucial to the survival of the community.

One of the most well documented examples of geomythology in Australia are the stories describing the volcanic eruptions that formed the Eacham, Barrine, and Euramo crater lakes in Queensland, which formed over 10,000 years ago (Dixon 1972:29; Rainforest Conservation Society of Queensland 1986:39). The stories describe the region as covered in eucalyptus scrub as opposed to the current rain forest. This was later confirmed by the analysis of fossil pollen found in the silt of these craters, which showed the current rain forest to be 7,600 years old (Haberle 2005; Kershaw 1970). The Australian Heritage Commission includes these stories on the Register of the National Estate and within Australia's World Heritage nomination of the wet tropical forests as an "unparalleled human record of events dating back to the Pleistocene era" (Pannell 2006:11; Rainforest Conservation Society of Queensland 1986:40).

Similarly, Native American stories describe the eruption of Mount Mazama, which formed Crater Lake in Oregon. Sandals excavated under Mazama ash have been radiocarbon dated at 6,500 years old (Vitaliano 2007), showing the area was inhabited and affected at the time of eruption. Not only do stories from South America suggest that Indigenous cultures witnessed volcanic eruptions, but the descriptions of these events remained in the oral tradition for hundreds, perhaps thousands, of years (Masse and Masse 2007).

Another example of geomythology from Australia and New Zealand is given by Bryant (2001; Bryant et al. 2007), who suggests that the southeastern coast of Australia was struck by a tsunami within the last 600 years. Bryant proposes that the tsunami was induced by a cosmic impact in the Tasman Sea and cites various Aboriginal and Maori stories describing tsunamis or cosmic impacts followed by a deluge to support his claim, including the Maori story "The Fires of Tamatea." This view was challenged by Goff et al. (2003), who argued that the Maori place-names were mistranslated and that no "smoking gun" (crater) existed. However, a submarine structure, named Mahuika after the Maori god of fire, was discovered in the Tasman Sea south of New Zealand by Abbott et al. (2003) and may be an impact crater 20 ± 2 km in diameter with an estimated impact date of ~1443 C.E. (Abbott et al. 2005), supporting Bryant's hypothesis. However, the dating of this structure and its origins are still the topic of contentious debate.

Known Australian Impact Craters

Gosse's Bluff

Gosse's Bluff, approximately 200 km west of Alice Springs, is an eroded impact crater with a diameter of ~22 km and a remnant circular uplift forming a mountain range ~5 km in diameter and ~150 m in height with an age of 142.5 ± 0.8 Ma (Milton et al. 1996). Scientists first proposed impact origins of the structure in the 1960s based on the abundance of

shatter cones (Dietz 1967). To the Western Arrernte people, Gosse's Bluff is known as Tnorala and is considered a sacred place.[2] An Arrernte story regarding its origins closely parallels the scientific explanation. During the Dreaming, a group of sky-women were dancing as stars in the Milky Way. One of the women grew tired and placed her baby in a wooden basket, called a *turna*. As the women continued dancing, the turna fell and plunged into the earth. The baby fell and was covered by the turna, which forced the rocks upward, forming the circular mountain range. The baby's mother, the Evening Star, and father, the Morning Star, continue to search for their baby to this day (Cauchi 2003; Malbunka 2009; Parks and Wildlife Commission of the Northern Territory 1997:1; Williams 2004).

Wolfe Creek

Wolfe Creek crater, located in northeastern Western Australia, is 850 x 900 m in diameter with an estimated age of ~300,000 years (Shoemaker et al. 1990; Shoemaker et al. 2005). The area is home to the Djaru, who call the structure Kandimalal (Tindale 2005:376). According to Cassidy, Kandimalal has "no particular meaning in their language, and no legend exists to give a hint of its origin" (1954:198). However, the literature reveals multiple stories associated with the crater, some of which describe cosmic origins (see Sanday 2007). One of the earliest Djaru accounts tells how a pair of subterranean Rainbow Serpents created the nearby Wolfe and Sturt creeks. One serpent emerged from the ground, creating the circular structure (Bevan and McNamara 1993:6; Goldsmith 2000). Another story tells how one night, the Moon and the Evening Star passed very close to each other. The Evening Star became very hot and fell to the earth, causing a brilliant, deafening explosion. This greatly frightened the Djaru, and it was a long time before they ventured near the site, only to discover it was the spot where the Evening Star had fallen (Goldsmith 2000). Goldsmith reports that the Aboriginal elder told him this story came from his grandfather's grandfather, indicating it was handed down in its present form before the scientific discovery of the crater. A Djaru elder named Jack Jugarie (1927–1999) gave his account of the Wolfe Creek crater: "A star bin fall down. It was a small star, not so big. It fell straight down and hit the ground. It fell straight down and made that hole round, a very deep hole. The earth shook when that star fell down" (Sanday 2007:26). Speiler Sturt, a Djaru elder from Billiluna, Western Australia, also illustrates the cosmic origins of Wolfe Creek crater (see Figure 2):

> That star is a Rainbow Serpent
> This is the Aboriginal Way
> We call that snake Warnayarra
> That snake travels like stars travel in the sky
> It came down at Kandimalal (Wolfe Creek)
> I been there, I still look for that crater
> I gottem Ngurriny—that one, Walmajarri/
> Djaru wild man [Sanday 2007:26].

Henbury Crater

With an age of 4,200 ± 1,900 years, the Henbury impact event was probably witnessed firsthand, since people have inhabited the Central Desert for more than 20,000 years (see Smith 1987; Smith et al. 2001). However, Alderman (1931:28) concludes that the local Aboriginal people seemed to have "no interest" in the Henbury craters or ideas as to their origins. An addendum by L. J. Spencer in Alderman (1931:31), however, suggests that Aboriginal people viewed the Henbury impacts with apprehension. A local prospector named J. M. Mitchell noted to Spencer that older Aboriginal people would not camp within a couple of miles of the Henbury craters and referred to them as *chindu china waru chingi yabu*, roughly translating to "sun walk fire devil rock" (Alderman 1931:31). Fitzgerald (1979) claims that Aboriginal people would not drink the water from the craters

for fear that the "fire devil" would fill them with iron. These views and the name suggest recognition of the site as different from the surrounding landscape, highlighting the iron fragments that litter the area and the site's unusual nature. However, not all Aboriginal people of the area shared this apprehension. Brown (1975:190–191) notes that the Henbury craters were an important water source to the local Aboriginal people, as the craters collected and retained rainwater for long periods of time. Although a story was recorded by Mountford (1976:259–260) describing the crater's origins, it did not attribute the structure's formation to a cosmic impact. According to the Parks and Wildlife Commission of the Northern Territory, the Arrernte name for the crater field is Tatyeye Kepmwere (Tatjakapara), and "some of the mythologies [*sic*] for the area are known but will only be used for interpretation purposes after agreement by the Aboriginal custodians of the site" (2002:15).

Veevers Crater

In the center of Western Australia lies the small, 70-m-wide Veevers crater, considered one of the best-preserved small-impact craters in the world and one of a minority that is associated with meteorite fragments (Shoemaker et al. 2005). Using cosmogenic nuclide exposure of the crater walls, the estimated age of Veevers crater is <20,000 years old. However, the well-preserved ejecta suggest it may be <4,000 years old (Shoemaker et al. 2005). In either case, the Veevers impact may have been witnessed by humans, but no Aboriginal stories about it are recorded in the literature.

Boxhole Crater

Boxhole crater is a 170-m-wide impact structure located ~170 km northeast of Alice Springs (see map in Figure 1). The age of this structure is contentious, as Kohman and Goel (1963) report an age of 5,400 ± 1,500 years using ^{14}C exposure, while Shoemaker et al. (1990; Shoemaker et al. 2005) report an age of ~30,000 years using 10Be/26Al exposure (see Haines 2005:484–485). In either case, the impact may have been witnessed, depending on the precise date of human arrival to the Boxhole region. Madigan (1937:190) claimed that the local Aboriginal people seemed to have "no interest" in the crater, and nothing else is reported in the literature.

Other Craters

A search for stories associated with other confirmed impact craters revealed a story about Liverpool crater in Arnhem Land (Haines 2005), which is described as the nest of a giant catfish. This story is supported by pictographs of giant catfish on the walls of a rock shelter located within the crater (Shoemaker and MacDonald 2005). The crater is ~1.6 km wide and dates to ~150 Ma.

Except for Gosse's Bluff, Wolfe Creek, Liverpool, and Henbury, we were unable to locate associated stories relating to other confirmed impact craters.

Summary of the Evidence from Known Impact Craters

Two Australian impact craters, Gosse's Bluff and Wolfe Creek, have associated stories that attribute extraterrestrial origins to the structures' formation, even though the craters were formed long before human habitation of Australia. It is unclear if (1) the stories describing Gosse's Bluff and Wolfe Creek as cosmic impacts incorporated the modern scientific explanation, (2) the Aboriginal people had deduced, without the influence of Western science, that these structures were formed by cosmic impacts, (3) parallels between scientific and Aboriginal views are simply coincidence, or (4) the information the Aboriginal elders provided to the researchers was misleading.

Misleading information can be caused by a poorly worded question (e.g., Researcher: "Do you have any stories about that meteorite crater we call — —?"), in which case the Aboriginal informant may tell the researcher what he or she "wants to hear" out of courtesy or respect (e.g., Clarkson 1999). The first argument could be falsified by showing, conclusively, that the cosmic impact stories predate the scientific discovery of the craters. Addressing the second, third, and fourth arguments requires a more detailed understanding of Aboriginal knowledge systems, Dreamings, and Aboriginal customs.

Three craters, Henbury, Boxhole, and Veevers, were formed during human habitation of Australia and would undoubtedly have caused widespread

destruction extending from several kilometers from the impact site. Although there are some stories related to the Henbury craters (although some of them are not in the public domain), it is curious that no story exists regarding Veevers or Boxhole. Possible explanations are that (1) humans did not inhabit that area at that time, (2) stories do exist but are too secret to be revealed to an uninitiated researcher, or (3) stories did once exist but have been lost in time, perhaps through cultural discontinuity. We do not currently have the information necessary to discriminate between these explanations.

Other Impact Sites

A survey of the available literature revealed a plethora of stories and accounts that describe stars falling from the sky and crashing to the earth. These stories, which do not correspond to impact structures or meteorite finds known to Western science, could be used to model possible impact catastrophes (e.g., Masse and Masse 2007) or to assist in locating new impact sites. Some stories are somewhat vague and do not cite a specific location, such as that from the Wolmeri of the Kimberleys, who tell how Venus came to Earth and left a stone in one of the "horde countries" (Kaberry 1939:12); a Wawilak (Yolngu) place in Arnhem Land called Katatanga, meaning the "falling meteor place" (Warner 1937:251); or the Indjabinda story about Mangela, who came to Earth with a fleeting appearance at a place denoted by a sacred mound called Kumana Kira (Cowan 1992:28). Other stories, however, cite the specific location of the event. Here, we sort the stories by state, citing locations where available. The coordinates of all locations followed by a dagger in the text are given in Table 2; their locations are shown in Figure 3. To facilitate later discussion, those events that may correspond to a historical event are assigned an event number.

Table 2. Coordinates of the Sites of Cosmic Impact Stories or Meteorite Falls/Finds

Name[a]	Latitude	Longitude	State
Augustus Island	15°20'S	124°34'E	WA
Bickerton Island	13°46'S	136°12'E	NT
Bodena	29°25'S	146°40'E	NSW
Caledon Bay	12°46'S	136°28'E	NT
Cranbourne	38°06'S	145°16'E	VIC
Entrance Island	16°16'S	124°37'E	WA
Eucla	31°42'S	128°50'E	WA
Forrest	30°51'S	128°06'E	WA
Girilambone	31°14'S	146°53'E	NSW
Hermannsburg	23°56'S	132°46'E	NT
Huckitta	22°22'S	135°46'E	NT
Jupiter Well	22°52'S	126°35'E	WA
Kurra Kurran	33°02'S	151°38'E	NSW
Lake Labyrinth	30°20'S	134°45'E	SA
Lake Mackay	22°35'S	128°41'E	WA
Louisa Bay	43°29'S	146°14'E	TAS
Mabuiag Island	09°56'S	142°10'E	QLD
Marabibi	12°37'S	131°40'E	NT
McGrath Flat	35°52'S	139°24'E	SA
Meteor Island[b]	15°19'S	124°37'E	WA
Millbillillie	26°27'S	120°22'E	WA
Mount Doreen	22°06'S	131°26'E	NT
Oyster Bay	42°09'S	148°06'E	TAS
Port George	15°22'S	124°42'E	WA
Puka (Palm Valley)	24°03'S	132°43'E	NT
Tenham	25°44'S	142°57'E	QLD
Wilcannia	31°33'S	143°30'E	NSW
Walcott Inlet	16°25'S	124°34'E	WA
Yurntumu	22°15'S	131°47'E	NT

[a] Sites are listed alphabetically and shown in Figure 3.
[b] Coordinates are of the area between Entrance and Augustus Islands.

New South Wales

Several oral traditions from New South Wales (NSW) describe cosmic impacts, especially in the northwestern region of the state. A story from the Muruwari of north-central NSW describes a catastrophic event that Mathews (1994:60) interprets to be a meteorite impact, citing a large circular area near the village of Bodena[†], where Mathews indicates the event took place (event 1). The story, recorded between 1968 and 1972, involves fire falling from the sky to the earth, causing death and destruction. Gien, the man responsible for the catastrophe, fled to the sky and became the Moon. Mathews recounts a nearly identical story from the nearby Ngemba peoples, who tell of a fireball that landed on the camp, killing everyone. A similar

FIGURE 3. Sites of cosmic impact stories or meteorite falls/finds described in this article. The coordinates of these sites are given in Table 2.

story from the nearby Kula peoples (recorded in 1804; Mathews 1994:60) describes a giant piece of burning wood that fell upon the camp, with the responsible party, Giwa, becoming the Moon. The similar stories probably represent variations of a single account that has been incorporated into the story lines of adjacent Aboriginal communities, with each group reciting its own interpretation of the story. While Mathews suggests the event took place near Bodena, the Kula story cites the location as Multaguna Run near the Warrego River, approximately 90 km west of Bodena. It is uncertain where the story originated, but the earliest record in the literature is the Kula account. No geophysical survey of the site confirming or rejecting this hypothesis is reported in the available literature.

A Weilan story (McKay et al. 2001:112–114) tells of a female shape-shifter who would lure men away from their camps and carry them away. A man cunningly led her to a water hole, where he tied a cord around her (made of human hair) while she slept. She awoke and fought to get him off her back, jumping into the water and turning it a dull color. He speared her in the back, but she would not die. She flew up to the sky with him still clinging on until they were in the path of falling stars. A falling star knocked the man off, and he fell with some stars to the ground (event 2) at a site known today as the town of Girilambone†. The Weilan (McKay et al. 2001:112–114) also tell of a large star that fell to Earth, lighting up all of the surrounding land—so brightly, in fact, that several different Aboriginal groups saw it (e.g., Murrawarri, Barkinji, Weilan, Ngemba, Narran, Kamilaroi, and Wongaibon). A nearly identical story from the Oongyee people of the Kimberleys in Western Australia is given in Sawtell (1955:21–22). The Sawtell account was published 46 years prior to the NSW account, though the story's origins are unclear. The Weilan story was published in a magazine "for the Aboriginal people of New South Wales," suggesting the story may have been adopted later by the Weilan. Given the nearly identical wording and theme of the text, we do not consider these to be independently contrived stories. There are no known impact craters in New South Wales, except for the newly discovered, albeit unconfirmed, structure near the town of White Cliffs, which is estimated to be more than two million years old (Macey 2008; see Figure 1b, Table 1b).

According to Threlkeld (1834:51), recounted in Turbet (1989:126), among the scattered rocks at a place called Kurra Kurran†, on Fennell Bay at the northwestern extremity of Lake Macquarie, between Sydney and Newcastle, lies an area of petrified wood. According to the local Awabakal people, the fragments are remnants of a large rock that was cast from the sky by a giant *goanna*, killing many people (event 3). Jones (1989) recounts a story of a large fiery star that rumbled and smoked as it fell from the sky, crashing into the ground near Wilcannia† (event 4). The impact was followed by a deluge, which Jones suggests is represented in rock paintings on Mount Grenfell, northwest of Cobar. The paintings show people climbing the mountain, supposedly to escape the rising water levels. Jones noted the presence of unusual black stones in the riverbed, indirectly suggesting they were meteorites. The story gives the impact location as the Darling riverbed northeast of Wilcannia at a place called Purli Ngaangkalitji. A survey of the area by Scottish-Australian astronomer Robert McNaught found no evidence of an impact crater or meteoritic material (Steel and Snow 1992:572).

Bevan and Bindon (1996:95) suggest that the story was recounted at this spot on the Darling River, but that was not where the event actually took place. If the story describes a real event, the location of the original site is currently unknown to Westerners.

Stories from the Shoalhaven region near Nowra describe an impacting meteor shower and airburst (event 5):

> The sky moved, heaved and billowed. The stars tumbled and clattered and fell against one another. The Milky Way split and great star groups were scattered. Many stars fell to the earth, flashing in the sky. A large red glowing mass burst in the air, giving a deafening roar, as it scattered millions of molten pieces on the ground. This occurred all night. The ground was covered in burned holes and great mounds, formed from the falling pieces [Peck 1933:192–193].

A similar story is recounted in Peck (1925:152–160). During a battle between two groups, a bright, burning blue light came hissing toward the earth from the sky. Surprised by this sight, the people thought it must have been an unknown great sorcerer. The earth trembled as the star crashed into the ground, sending rock and debris into the air. The noise of the explosion was deafening and reverberated around the surrounding hills. The men were filled with terror, and they all fell flat to the ground (event 6). Peck vaguely says this area is in "the belt of basalt country where the waratah does not grow" (1925:152).

Northern Territory

Two stories of falling stars in Arnhem Land describe fire resulting from the impact. A Gurudara story describes a bright star named Nyimibili falling from the sky onto the Marabibi† camp near the Wildman River, which burned all of the grass and trees, causing death and destruction (Berndt and Berndt 1989:25–27; event 7).[3] The Yolngu tell of Goorda, a fire-spirit from the Southern Cross, who came to the earth as a falling star to bring fire to people of the Gainmaui River, near Caledon Bay†. Once he touched the ground (event 8), he set the grass ablaze. The fire spread, causing death and chaos (Allen 1975:109).[4]

Many Aboriginal communities believe natural disasters are punishment for breaking laws and traditions. The Wardaman people warn of a fiery star named Utdjungon that will fall from the sky to destroy the earth if laws and traditions are not followed. The falling star will cause the earth to shudder, the hills and trees to topple and turn, and everything to go black, with night descending (Harney and Elkin 1949:29–31). A nearly identical story from the nearby Ngarinman tells of "a large black stone, thrown from the sky by Utdjungon—a killer who lives in the Milky Way and flings a fiery ball to slay" (Harney and Elkin 1949:72–74; event 9). No specific locations are cited in these stories, but presumably they take place within Wardaman or Ngarinman country.

Some stories of falling stars have Western religious overtones. In the town of Hermannsburg† (Ntaria), ~110 km west of Alice Springs, an Arrernte woman told of a star that fell to Earth (event 10), creating two holes on the site of the old Hermannsburg church prior to settlement of the area by Lutheran missionaries (Austin-Broos 1994:142, 2009:39). The story was heavily laced with Christian influence and symbolism, resulting from the close association between the Aboriginal community and the missionaries. Austin-Broos (1994:149, 2009:37–38) believes this account may relate to the story of a star that fell to Earth in a water hole in nearby Palm Valley called Puka†. Róheim (1945:183) provides an earlier record of this story, citing Western and Eastern Aranda folklore about a star that fell into a water hole where the serpent Kulaia lived, making a great noise like thunder. In the story, a thirsty boy who had only recently been circumcised (initiated) peered into Puka and saw the serpent, which rose and swallowed him whole. The boy's death caused much grief and mourning among his community, who promptly burned the food they had collected for the boy's initiation and left the camp.

In some cases, the progenitors of knowledge or humankind were brought to earth via falling stars. The Western Arunta say the first human couple originated from a pair of stones that were thrown from the sky by the spirit Arbmaburinga (Róheim 1971:370). Yarrungkanyi and Warlpiri of the Northern Territory tell how celestial Dreaming men fell

to the earth as falling stars, bringing the Dreaming to the people. The Dreaming men, armed with weapons, traveled through the sky and landed at a place called Purrparlarla (Warlukurlangu Artists 1987:127), southwest of Yuendumu (aka Yurntumu[†]; Warlukurlangu Artists 1987:4). Another description of a "sky man" falling to the earth is from Bickerton Island[†], between Groote Eylandt and the mainland. Connie Bush (Pascoe 1990:31–32) recounts a story (event 11) about a circular spot in the sand that was formed when a "terrific explosion in the sky" toward the west dropped a smoking white object to the earth early in the morning. At the supposed impact site, two Aboriginal men saw a white man "standing in the sand up to his knees" about an hour after the impact. The man lived with the community for many years, marrying one of the women and having a child, until he finally died. The story notes that the white man's son died as a young man during a measles epidemic that spread to the island from Groote Eylandt before the arrival of missionaries in 1921. This may be related to a measles epidemic on Bathurst Island in 1913, but it is not clear. This implies that the event occurred at the end of the nineteenth century, ruling out a plane crash as the cause. According to Bush, the circle is still void of vegetation, and shells are placed around the perimeter to remind people where the sky man fell. However, the discovery of the man and the bolide event may be purely coincidental, or perhaps the two events were incorporated into a single story line.

Western and South Australia

In Western Australia, Wirrimanu artists tell a story of a star (event 12) that fell from the sky to Lake Mackay[†], explaining that the "Rainbow snake came to this place and ate up a lot of people" (Bevan and Bindon 1996:96). No meteorite finds or impact sites are currently known in or near Lake Mackay. Another Dreaming tells of a hunter named Mangowa and how his actions led to a group of stars falling to the earth (event 13), forming the circular lagoons that line the coast of the Nullarbor (e.g., Reed 1993:237–239; Roberts and Mountford 1965:52; Smith 1970:24). A Wirangu story describes a meteorite impact (event 14) near the coastal town of Eucla[†], close to the border of South and Western Australia:

> A long, long time ago, a huge meteorite hurtled towards the earth from the northward sky, and smashed into the ground near Eucla. Because it was so big, a dent appeared in the crust of the earth and the meteorite bounced high into the air and out into the Great Australian Bight where it landed with an enormous sizzling splash. It was hot from its trip through space so it gave off a great deal of steam and gas as it sank through the waves. But this was no ordinary meteorite. It fact, it was the spirit Tjugud. In the deep water near by, the spirit woman Tjuguda lay asleep. All the noise around her woke her up and she was very angry. She bellowed and the elements roared with her. The wind blew, the rain pelted from the sky and the dust swirled [Education Department of South Australia 1992:32–33, retold by M. Miller and W. J. Miller].

Because of the generous use of Western scientific terms in the story ("meteorite," "crust of the earth," etc.), it is uncertain how close the story is to its original form, assuming it is precolonization. There are no known impact craters on the Nullarbor, but Gibbons (1977:265) and Bevan and Binns (1989) describe numerous meteorites that have been found in area, including those found near the town of Forrest[†], ~100 km northwest of Eucla.

A story (event 15) associating a fiery catastrophe with a large circular depression on the McGrath Flat[†] (aka Magrath Flat) homestead in South Australia prompted Tindale (1938:18; Stanner 1975:14) to conclude that the story described a meteorite impact. To date, no meteoritic material has been found in or near the structure, but it is uncertain if the structure has been properly surveyed for evidence of an impact.

When Ngalia men shared sacred information about the Walanari—celestial deities who were seen as protectors of good men and punishers of bad men that lived in the Magellanic Clouds—with the anthropologist Charles P. Mountford (1976:457), the Walanari became very angry and threw glowing stones onto the Ngalia camp later that night. Ngalia informants claim that men have been killed by falling stars thrown by the Walanari (event 16). They said that when totemic ceremonies were being performed at Mount Doreen[†], the Walanari threw meteorites to the earth to express

their pleasure (see Mountford 1976:Plate 584). O'Connell mentions a crater candidate near Mount Doreen with general coordinates of 23°S, 133°E that may have impacted ~100 years ago and states that a "local legend of fiery snake may refer to meteorite fall" (1965:88), but she gives no references to the legend. Meteors are often associated with serpents (see Hamacher and Norris 2010a).

The Kimberleys are rich in stories of objects falling from the sky as well as floods that indicate tsunamis. Bryant (2001; Bryant et al. 2007) proposes a link between these stories, hypothesizing that cosmic debris impacted the Indian Ocean, creating tsunamis that devastated the coastline. For example, Bryant (2001; Bryant et al. 2007) cites published evidence of a megatsunami on the northwest coast of Western Australia that he speculates was induced by a bolide impact. As evidence, he cites a rock painting on a rock called Comet Rock near Kalumburu that depicts a cometlike motif and lies 5 km from the ocean on a plain covered in a layer of beach sand. Aboriginal oral traditions provide descriptions of a deluge around Walcott Inlet (e.g., Mowaljarlai and Malnic 1993:180–181), covering mesas up to 500 m high (Bryant et al. 2007). One such account (Lucich 1969:52–57) describes a Jauidjabaija woman leaving Montgomery Island (Yawajaba Island) and canoeing to an island near the "fountain of the sea" (presumably near the mouth of Walcott Inlet†, as it lies ~25 km south of Yawajaba Island). The story tells that the woman was on the coast of the island when the ocean rapidly receded, leaving many sea animals beached. A rushing noise followed some time later, and the ocean tide came rushing back, covering the land, including mountains. The flood lasted a day before returning to the sea. Bryant et al. (2007) argues that such megatsunamis are probably caused by a cosmic impact in the Indian Ocean. Tides in the Kimberleys can vary by as much as 10 m, but such a substantial flood, preceded by a rapid recession of the ocean, indicates a genuine tsunami and not merely a higher-than-normal tide.

An Aboriginal elder from the Kimberleys tells that when a man dies, his spirit is carried to Meteor Island†, where he sits upon a long, chimneylike rock regarded as a meteorite (Mowaljarlai and Malnic 1993:159–161). He turns away from his former life, placing his foot on the rock, causing it to overturn and crash into the sea, shaking the earth, while his family chants "Kaaaa-o." He then shoots like a rocket into the spirit world. Mowaljarlai and Malnic claim that Meteor Island and Entrance Island† are so prone to meteorite falls that one can simply go out and collect meteorites on the ground and in the sea with minimal effort. No coordinates were given for Meteor Island, but the text states that it "lies near Augustus Island† (~90 km northeast of Yawajaba Island) further out from Port George†" (Mowaljarlai and Malnic 1993:159).

A Dreaming story of the Karajaree in the Kimberleys tells how the culture hero Miriny, while wandering with his wives, Wade and Gololo, heard the noise of a bullroarer (*bolewana*) in the sky and saw churingas (*gaellgoro*, sacred stones) falling down from heaven (Worms 1943–1944:297), which may describe a meteorite fall (event 17).[5] The Worora, just north of Derby, have a children's story about the Moon falling to Earth onto two children as punishment for staring at the Moon (it was taboo for children to stare at the Moon). At the site are two stone pillars representing the children (Lucich 1969:33–34).

Tasmania

A story from Bruny Island in southeastern Tasmania tells how two star-spirits fought each other and fell to earth in Louisa Bay†, where one turned into a large stone that can still be seen today (Coon 1972:288; event 18). A similar account from the nearby Needwonee is given in Haynes (2000:57). A story from Oyster Bay† tells how fire was brought to the earth by two men who stood on a mountaintop and "threw fire, like a star" that "fell among the blackmen" (Robinson 1966:95). The two men live in the clouds and can be seen in the night sky as the stars Castor and Pollux (the Gemini twins). The concept of fire being brought to Earth by sky spirits in the form of a falling star is also found among the Yolngu of Arnhem Land, as described previously. Although a direct comparison is made between fire and stars, the story states that fire was thrown *like* a star, not *as* a star.

Queensland and Victoria

While Queensland and Victoria are both rich in stories and descriptions of comets and meteors (see

Hamacher and Norris 2010a, 2010b), there were no Aboriginal stories or descriptions of meteorite falls or cosmic impacts in the reviewed literature for either state, except for brief colonist accounts of the Tenham meteorite in Queensland and the Cranbourne meteorites in Victoria, as described below. To date, only two impact craters are known in Queensland, and both are considerably large and old (see Table 1a). Victoria has no confirmed impact craters.

However, there is an account from the Torres Strait Islands, which are administered by Queensland, of a stone that fell from the heavens (event 19). The story tells of people camping on the tiny islet of Pulu (near Mabuiag Island[†]).[6] A "great stone" called Menguzi kula fell from the sky, crushing everyone except two lovers, who then became the progenitors of the current population (see Haddon 1904:22; McNiven et al. 2009:311–313; Róheim 1971:370–371). Torres Strait Islanders are distinctly different from Aboriginal Australians, as they are of Melanesian extraction, having a close cultural and genetic link with Papuans.

Meteorites Falls and Finds

A meteorite fall may be a source of fear or fascination for the peoples who witness the event. Poirier (2005:237–238) cites an example of a meteorite fall near Jupiter Well[†], Western Australia, that was incorporated into a new story line, while Madigan and Alderman (1939:355–356) tell how Aboriginal people would steer clear of the Huckitta meteorite and suggested that they were in awe of the stone, perhaps considering it sacred.[7] In 1879 a shower of meteorites fell near Tenham[†] station in South Gregory, western Queensland (Hellyer 1971). It was reported in 1900 that Aboriginal people were "deadly afraid" of the Warbreccan masses of the Tenham meteorite: "They cover them in the bush with kangaroo grass, a twisted gidga bark and mud, and then by boughs over the top. Their idea is if the sun sees them, more stones will be shaken down to kill them," suggesting that they had witnessed the fall (event 20).[8]

According to Spencer (1937), the Warbreccan stones were taken by an opal dealer named T. C. Wollaston and sold to the British Museum. Wollaston invented a story to explain the origins of the stones and how he acquired them. The Aboriginal account is taken from files in the British Museum, so this account is considered dubious (although we do not know if the account is fictitious). However, a news article describes an eyewitness account of the Tenham fall on Monday, April 25, 1880, that involved Aboriginal policemen and their reaction to the event:

> A few minutes after six o'clock . . . a very large and brilliant meteor shot from overhead and descended in a southerly direction. The meteor appeared to be the size of a six-quart billycan, and was one splendid ball of fire; it left no streak of light after it, and was the largest one I have ever seen. When the meteor had descended about three parts the distance from where I first saw it to the earth, I lost sight of it, as it was passing behind a large dark cloud. I stood looking in the direction the meteor was traveling, when a loud explosion took place in the same direction which slightly shook the ground for miles around; then a loud rushing noise could be heard as though a great blast of air was rushing through a large tube suspended in mid-air. This sound must have lasted for nearly two minutes when it died away. Next morning, when I rode up to Jundah, everyone there wanted to know what the explosion was, and the only conclusion we could arrive at was that when the meteor struck the ground it must have exploded, but we have not been able to account for the rushing sound afterwards. Inspector Sharp of the black troopers [an Aboriginal police force] said that when the explosion took place, the house he was in shook very much, and that when he ran out to see what was taking place he saw all the troopers running into the barracks with fright depicted on each countenance. From what I could learn I was the only white man at Jundah who saw the transit of the meteor. It is my opinion that it struck the earth a few miles above Galway Downs, and close to the Barcoo River, or we could not have felt the earth shake when it exploded [*Western Champion* 1880].

There were conflicting accounts and dates of the fall recorded in the media (see Spencer 1937). Although the account states that the Aboriginal policemen were struck with fright, this is an expected reaction for anyone who witnesses such an event.

The Yintjingga people of Stewart River in the Kimberleys perceive a meteor as a spirit (*mipi*) and a portent that someone has died. Sometimes the mipi "brings his light" and crashes to the earth, creating noise. At the same moment, a "big devil" (named Wo'odi Mükkän) that sits in a tree drops a "great stone" to the ground (Thompson 1933:499). This provides direct links between the meteor, the noise made upon impact, and the presence of a stone at that spot, presumably a meteorite. Thompson notes that the Aboriginal ideas of the stone being dropped from the sky "can be easily understood, for meteorites must at times have been seen actually to fall and bury themselves in the earth" (1933:499). The Mycoolon of northwestern Queensland believe that death resulting from a stone falling from the clouds is a penalty for children eating forbidden food (Palmer 1884:294).

However, not all meteorites were viewed negatively. The Mycoolon believe that falling stars strike and penetrate certain acacia trees, transforming into gum (sap) that is a well-liked food source (Palmer 1884:294). Bevan and de Laeter mention how a group of Aboriginal people would dance around a larger fragment of the Cranbourne† meteorite fall (southeast of Melbourne) while hitting it with stone axes, apparently "pleased by the metallic sound it made" (2002:18). The meteorite may have been part of a ritual or ceremony of some kind that was either unknown or unacknowledged by the colonists. It may also be that the Aboriginal people interacting with the Cranbourne meteorite did not see it fall and had no reason to fear it, as opposed to the Jupiter Well and Tenham meteorites. Meteorites have been found in deserted Aboriginal camps (e.g., Alderman 1936:542; Johnson and McColl 1967), but there is little hard evidence to determine whether the stones had any special significance or practical use.

Aboriginal Discovery of Meteorites and Impact Craters

Over the last century, Aboriginal people made significant contributions to the discovery of meteorites and impact craters in Australia. A lunar meteorite was found by an Aboriginal meteorite hunter in the Millbillillie† strewnfield in the Nullarbor near Calcalong Creek in Western Australia (Hill et al. 1991; Wlotzka 1991). According to Hill et al., the creek derives its name from an Aboriginal word meaning "seven sisters (Pleiades) [who] went up into the sky, chased by the Moon" (1991:614), although this is not sufficient evidence that the meteorite has anything to do with the name of the creek. Dalgaranga Crater, located 75 km west of Mount Magnet in Western Australia, was discovered in 1923 by an Aboriginal man named G. E. P. Wellard (McCall and de Laeter 1965:28, 60) but was not identified as an impact crater until 1938 (Simpson 1938).[9] An Aboriginal man named Billy Austin witnessed a bright meteor around February 5, 1924, and later discovered a crater in the central South Australian desert near Lake Labyrinth† approximately 4 m in diameter, with the impacting meteorite 33 m to the west (Spencer 1937:353–354). Numerous additional meteorite discoveries have been made by Aboriginal people and are well recorded in the literature (see Barker 1964:109–110; Hodge-Smith 1939; McCall and de Laeter 1965:28, 33, 38, 39, 41, 52; Madigan and Alderman 1939:353).

Aboriginal Use of Meteoritic Material

Bevan and Bindon (1996) published a comprehensive work on the Aboriginal use of meteoritic material, showing that there was no evidence that Aboriginal people worked meteoritic iron, despite some accounts of Aboriginal people using meteoritic iron for weapons (e.g., Peck 1925:152). There is evidence to support the transport of meteoritic material by Aboriginal peoples (Peck 1925:152) but little physical evidence to explain the use of meteorites or their significance to Aboriginal cultures.

However, the use and role of tektites (glasslike terrestrial rocks formed by meteor impacts) among Aboriginal peoples was studied extensively by Baker (1957) and Edwards (1966), who showed that many Aboriginal groups had a number of uses for tektites, including surgical tools and implements used in ritual and ceremony. Some Aboriginal groups in Western Australia and the Nullarbor Plains believed tektites to be magic "sky stones" and associated them with meteors and cosmic impacts (Bates 1924:11d).

Gibbons (1977) presents a comprehensive (albeit

dated) list of meteorites, impact structures, and meteorite fall/find locations (as of the late 1970s), which can be used, in conjunction with current databases, to correlate associated Dreamings with known meteorite finds or cosmic impacts.

Statistics of Meteorite Falls and Cosmic Impacts

We now attempt to quantify the meteorite influx rate in Australia, the probability of a person seeing a meteorite-producing meteor from any location in Australia, and the probability of a person being hit or killed by a meteorite or airburst (exploding meteor).

Meteorite Influx Rate

It is difficult to quantify the rate of meteorite falls on Earth's surface given the number of variables and uncertain statistics. However, general estimates can be made using different techniques. One technique is to observe the number of bright meteors over a given area combined with the meteorite recovery rate (see Halliday et al. 1984). The technique used by Halliday et al. derives an annual fall rate, per million km^2, of 39 for a minimum mass m >0.1 kg, 7.9 for m >1 kg, and 1.6 for m >10 kg. Another technique is to derive a fall rate based on recovered meteorites within a surveyed area (see Zolensky et al. 1990). Using a sample of recovered meteorites within an 11-km^2 area in New Mexico, Zolensky et al. provide a fall rate of ~940 meteorites per million km^2 per year with a mass exceeding 10 g. Table 3 lists the expected meteorite fall rates over Australia and each of its states and territories, given these estimates.

During known human habitation of Australia (a lower limit of 40,000 years), an estimated 286 million meteorites with mass >10 g have fallen. During periods of lower sea levels, this number is higher because of the larger continent size. While Aboriginal language groups are not spread evenly in size and population density across the continent, a rough approximation of 300 distinct Aboriginal language groups (Walsh 1991) of equal size gives a land area of ~25,300 km^2 per group, showing that each group would expect approximately 23 meteorite falls per year within their land area, each assumed to be accompanied by a visible meteor.[10]

Table 3. The Expected Meteorite Fall Rate

State	Area	N_{yr} per Minimum Mass (kg) 0.01	0.1	1.0	10.0
	10^6	940	39	7.9	1.6
AU	7.617	7,144	296	60	12
WA	2.529	2,378	99	20	4
QLD	1.730	1,626	67	14	3
NT	1.349	1,268	53	11	2
SA	0.983	921	38	8	2
NSW	0.800	752	31	6	1
VIC	0.227	213	9	2	0
TAS	0.068	64	3	1	0

Source: Estimates given by Halliday et al. (1984) and Zolensky et al. (1990).
Note: Land areas are given in 10^6 km^2, sorted by minimum mass (kg). N_{yr} is the fall rate per year. State abbreviations are the same as in Table 1, while Australia is abbreviated as AU. Fall values are rounded to the nearest whole number.

Probability of Casualty Due to Meteorite Falls and Cosmic Impacts

Historic accounts of meteorites striking or killing people are recorded in the literature (e.g., Gritzner 1997; Lewis 1999:14–25; Yau et al. 1994). Accounts from Aboriginal sources include Mountford (1976:457), who noted that men in Western Australia had been killed by fiery stones thrown to the earth by the Walanari. However, meteorite falls are a relatively rare occurrence at any given location, so what is the probability that a person has been struck by a meteorite since humans first arrived in Australia?

Given the number of meteorites that fall per annum as described in the previous section over the land area of Australia (N_m = 7,144 for m >10 g, from Table 3) and assuming an evenly distributed constant population of 250,000 people (N_p) over the course of human history in Australia (T_A = 40,000 years), we estimate the number of people who have been struck by a meteorite in Australia (N_s) as

$$N_s = [(A_H) / (A_A)]\, N_m\, N_p\, T_A, \qquad (1)$$

where A_H is the surface area of a person (from a "bird's-eye view," estimated at 0.3 m^2) and A_A is the area of Australia (7.6 x 10^{12} m^2). For the values given, the number of human beings struck during the course of Australian human history is about three. Because this happens so infrequently, it is extremely unlikely that the literature would have records of such an event in Australian human history, yet there are several Aboriginal accounts of people being killed by meteorites. Of course, populations are not spread evenly across the continent, and populations fluctuate in number, so this and all subsequent estimates in this article serve only as first-order approximations.

To estimate the probability of being within the destruction area of an airburst or impact in Australia, we first determine the area A_D (km^2) of devastation caused by an impactor of energy E (megatons) using the relationship given by Steel (1995):

$$A_D(E) = 400\ E^{0.67}. \qquad (2)$$

Thus an impact energy equivalent to the Hiroshima bomb (13 kt) would destroy an area of ~22 km^2. Impactors with energies of 1 megaton will devastate an area of 400 km^2, equivalent to the area of a large city. To estimate the frequency of impacts by impact energy, we estimate the time interval between impacts t (years) of a given impact energy E (megatons), using Collins et al. (2005:Equation 3):

$$t_i(E) = 109\ E^{0.78}. \qquad (3)$$

The 1908 Tunguska airburst in Siberia was estimated to have an energy of 10 megatons from a height of 8.5 km and destroyed ~2,000 km^2 of Siberian forest, in agreement with Equation 2 (Napier and Asher 2009). Using Equation 3, Tunguska-like events are expected about every 650 years. However, other large bolide explosions have occurred within the last century, including the burst over the Curuçá River, Brazil, in 1930 (Bailey et al. 1995; Huyghe 1996), with an estimated energy of 1 megaton (Chown 1995), and a Tunguska-like blast over Guyana in 1935 (Steel 1996). None of these airbursts left a known impact crater or meteorite debris, which is consistent with a cometary origin (since comets are composed of low-density ice and dust). Additionally, all three airbursts occurred when the earth passed through major meteor streams (Napier and Asher 2009) caused by the earth passing through the dust tail of a comet.

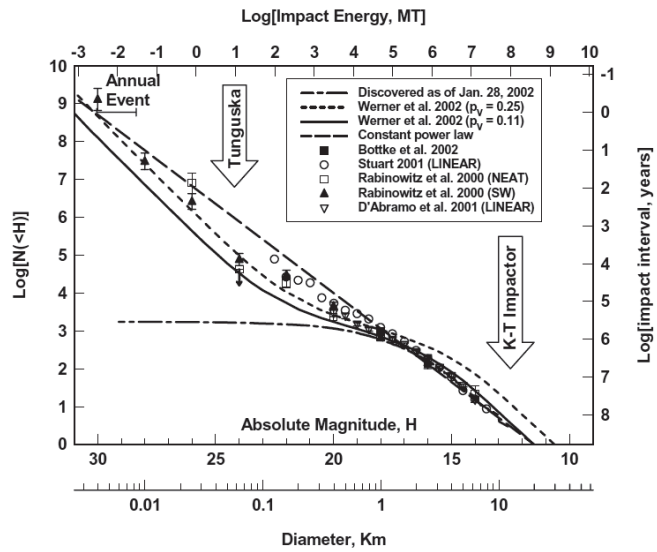

FIGURE 4. The impact frequency and energy of Near Earth Objects from several surveys (taken from Morrison et al. 2003, with corrected publication dates). The horizontal axis shows the impact energy and also the meteoroid diameter and absolute magnitude (luminosity) of the NEO. The vertical axis shows the time interval between such impacts and also the expected number of NEOs that are brighter than a given magnitude (H). A review of this subject can be found in Ivanov (2008).

However, the atmospheric dynamics of meteors are still poorly understood, and recent research indicates that the Tunguska blast had much lower impact energy than previously estimated (3–5 megatons; see Boslough and Crawford 2008). Estimates of the time interval of Tunguska-like impacts range from once every 1,000 years (Brown et al. 2002) to once every 250 years (Equation 3). Networks scanning the global atmosphere for explosions were not incorporated until the latter twentieth century, so other airbursts could have occurred over the ocean unnoticed. Rocky meteoroids, corresponding to impact energies of up to 1 megaton, often explode high in the atmosphere, having little effect on the earth (Collins et al. 2005). Figure 4 shows the estimates of the impact frequency and impact energy of impactors based on several

Table 4. Number of Meteor Events Predicted by the Meteor Literature Throughout Human Habitation of Australia (Last 40,000 Years) Compared with Those Indicated by Australian Aboriginal Tradition

Phenomenon	Meteoritic/Geological Evidence	Oral Tradition	Event Number	Notes
Known impact craters in Australia formed within span of human habitation.	Three craters known (Boxhole, Henbury, and Veevers).	No oral tradition of being caused by a cosmic impact, except perhaps Henbury, where the stories are secret.		Two other craters (Gosse's Bluff and Wolfe Creek) have impact stories but were formed before human habitation.
Meteorite strikes and kills a human.	About three fatalities expected.	One or two fatalities in oral tradition.	16? and 19.	
Meteorite impacts causing human fatality.	About five events expected.	Seven oral accounts of fatal events.	1, 3, 7, 8, 12, 16, and 19.	
Meteorite impacts causing destruction or crater but not necessarily human fatality.	Expect about five language groups to have witnessed such an event.	Seventeen events (including those involving fatalities) are recorded in the oral tradition.	Those above, plus 4, 5, 6, 9, 10, 11, 13, and 15.	
Notable bright meteorite impacts but not causing destruction.	Many expected—difficult to quantify.		2, 14, 17, 18, and 20.	

Near Earth Object (NEO) surveys. The assumptions and equations used in this article provide a reasonable first-order approximation for estimating impact probabilities.

The time between impacts within Australia, using a modified version of Equation 3, is given as

$$t_{iA}(E) = 109\ E^{0.78}\ [(A_E) / (A_A)], \quad (4)$$

where A_E is the area of earth (5.1×10^8 km^2) and A_A is the area of Australia (7.6×10^6 km^2). Equation 4 tells us that a 1-megaton event occurs about every 7,300 years. This means that approximately 5.5 such events have occurred in Australia over the last 40,000 years.

The total number of people killed by any single 1-megaton event in Australia is

$$N_{Ki} = [(A_D \times E) / A_A]\ N_P, \quad (5)$$

where $A_D(E) = 400$ km^2 (from Equation 2), A_A is the area of Australia, and N_P is the total average population of Australia (250,000). Equation 5 shows that ~13 people are killed by any single 1-megaton event.

Since ~5.5 such events have occurred during the human habitation of Australia, each killing 13 people,

the total number of people killed by all combined impact events is about ~72.

Of course, such events would have had an influence (perhaps distress or surprise) on the people in the region who witnessed the event but were not killed. For a 1-megaton event, the radius of destruction (Equation 2) is ~11.3 km. If we assume that people within a 25-km radius heard or saw the event, then the "area of influence" would be ~2,000 km^2. This would mean that only about 360 people have been "influenced" by such an event during the course of human history in Australia. However, this number should be taken as no more than a rough estimate, since it will depend on how the population is distributed.

Another approach is to estimate the number of language groups that would have witnessed an impact. If we assume 300 evenly spread language groups and estimate that five impact events (with $E = 1$ megaton, using Equation 4) have occurred during the human history of Australia, then only five language groups would have witnessed an impact over the last 40,000 years. Over the last 10,000 years that number drops to only one. If oral traditions can survive for 10,000 years, we would statistically expect to find only one story. Since many Aboriginal cultures, including their oral traditions, were damaged or lost because of colonization, it would be surprising if any group now had an oral tradition based on a witnessed cosmic impact.

Discussion

We now compare the impact rates predicted by the meteor literature with those indicated by Australian Aboriginal tradition. The results are summarized in Table 4. We emphasize that extreme caution is needed when evaluating such subjective material quantitatively and that the following discussion should be treated as a guide to further research rather than as a definitive statement.

Table 4 shows that the number of events expected from meteoritic knowledge is comparable to that recorded in oral tradition, with the exception of witnessed destructive events, where the number of stories is about three times higher than that expected. However, the oral traditions sampled here are only a small fraction of those that have originated over the 40,000 years of Australian human history. While the longevity of oral traditions is not known (and remains the topic of debate), we have examples that suggest these records can last thousands of years, including those of the erupting crater lakes in Queensland (Dixon 1972:29), the eruption of Mount Gambier in South Australia (*Sydney Morning Herald* 1870), and the traditions associated with the Henbury impacts (Parks and Wildlife Commission of the Northern Territory 2002:15).[11] If we liberally estimate that Dreaming stories have a typical longevity of 10,000 years and that perhaps a quarter of precontact Aboriginal cultures have had their oral traditions recorded and published (many stories are considered sacred and secret and are not shared with outsiders), then the number of stories describing cosmic impacts exceeds the number expected by a factor of about 17, or, in the case of witnessed major impacts, by a factor of about 50.

The explanation of this discrepancy may include a combination of the following factors:

1. These stories were not based on witnessed events.
2. These stories have been influenced by Western science.
3. A single story was shared with many other Aboriginal groups.
4. Impact events were more frequent than estimated.
5. Some unacknowledged factor plays a role.

In the following paragraphs we address each topic separately.

In some cases, the description of an event is vague (see Bevan and Bindon 1996:96; Lucich 1969:33–34), but in other cases, the description closely parallels the scientific explanation (see Harney and Elkin 1949:29–31; Peck 1933:192–193). The account of a cosmic impact near Wilcannia described by Jones (1989) and cited above is an example of a story that claims the event was witnessed but currently lacks physical evidence to support it (see Steel and Snow 1992:572). It is possible that the event occurred elsewhere at a location yet to be identified by Westerners (Bevan and Bindon 1996:95). While this explanation may be the case for some stories, other descriptions of impact events so

closely parallel the scientific explanation (e.g., Peck 1925, 1933) that it seems unlikely that the story has been fabricated. However, because Peck, a Westerner, recorded the stories, it is unknown how much his bias affected his writings.

It is also possible that the impact stories derived from logical deductive reasoning. For example, dropping a rock into the sand may have helped people recognize that larger falling rocks may have created larger craters that are of a similar shape. A smaller impact, such as the one witnessed at Lake Labyrinth, could have prompted elders to create a story about a similar event.

Another possibility is that these accounts were influenced by Western science, with Western information about cosmic impact events being incorporated into oral tradition. This is certainly possible in some cases. For example, the literature records no accounts of the Wolfe Creek crater having cosmic origins before it was known as an impact crater (see Sanday 2007 versus Bevan and McNamara 1993:6). However, many of the Aboriginal informants interviewed by Sanday (2007) and Goldsmith (2000) maintain that their accounts of the cosmic origins of Wolfe Creek (Kandimalal) were handed down over many generations, before Westerners knew of its cosmic origins. This would be difficult to substantiate unless a written record of the story existed before the crater was identified by Westerners. Unfortunately, in the case of Gosse's Bluff and Wolfe Creek, no written records have been found describing these structures prior to their identification as impact craters by Western science.

Examples of a particular story that was shared by several distinct communities exist, two of which were described above: the Mathews (1994) account and the McKay et al. (2001:112–114) account. In these cases, a single group witnessed an event, and the story of that event spread to other communities. However, this suggests that *some* group must have witnessed the event. It is possible that many stories are based on a few much earlier stories that have spread to other communities and been placed in a local context (see also Michaels 1985). The oldest recorded story may identify the particular community from which it came.

If the Aboriginal accounts described in this article are records of witnessed events, despite the statistics describing meteorite falls and cosmic impacts discussed above, then the evidence suggests that we are underestimating the impact rate. This could be because either the literature on impact rates systematically underestimates rates or impact events are more frequent than previously thought.

The distribution of known impact structures is not uniform. For example, 25 craters are found in the Baltic countries and Scandinavia, while the rest of Western Europe contains only four. The remote, dry Australian continent contains 27 confirmed craters, while the much larger and wetter South American continent contains only eight. This indicates that many more impact craters remain to be discovered. In remote, moist areas such as the rain forests of the Amazon, Congo, and Southeast Asia, no confirmed craters have been found. On the ocean floor, which should account for ~70 percent of impact craters, the search for these structures is difficult.

The hypothesis that impacts are more frequent than currently estimated was proposed by members of the Holocene Impact Working Group, which claims that some historic catastrophes were caused by impact events (see Baillie 2007; Firestone et al. 2006; Masse, Weaver, Abbott, Gusiakov, and Bryant 2007; Rappenglück et al. 2009).[12] There are only 11 confirmed Holocene (i.e., within the last 12,000 years) impact sites out of 176 known craters to date (Earth Impact Database 2009; see Table 5). Figure 4 shows the estimated impact intervals based on impact energy and impactor diameter. Using the scaling equations of Collins et al. (2005), we expect large impact events (impactors exceeding 1 km in diameter) to occur at intervals >100,000 years.

However, proposed structures from the Australian–New Zealand region suggest that multiple large impacts have occurred over the last few thousand years. These include the Mahuika structure described above as well as two proposed submarine structures named Kanmare (Serpent) and Tabban (Rainbow) that were discovered on either side of Mornington Island in the southeast corner of the Gulf of Carpentaria (see Figure 5a, Table 6, and Appendix B). The latter two structures are approximately 18 km and 12 km in diameter, respectively, based on satellite altimetry, and they have a measured date (first-order

Table 5. Confirmed Holocene Impacts

Name	Country	Age (years)	Field	Associated Myths/Records
Sikhote Alin	Russia	63	No	Gallant (1996)
Wabar	Saudi Arabia	140	Yes	Bobrowsky and Rickman (2007:30)
Haviland	United States	<1,000	No	—
Sobolev	Russia	<1,000	No	—
Whitecourt	Canada	<1,100	No	—
Camp de Cielo	Argentina	<4,000	Yes	Bobrowsky and Rickman (2007:31)
Kaalijärv	Estonia	4,000 ± 1,000	Yes	Bobrowsky and Rickman (2007:29)
Henbury	Australia	4,200 ± 1,900	Yes	Bobrowsky and Rickman (2007:31)
Ilumetsä	Estonia	<6,600	No	Bobrowsky and Rickman (2007:29)
Macha	Russia	<7,000	Yes	—
Morasko	Poland	<10,000	Yes	—

Source: Earth Impact Database (2009). See also Baillie (2007).
Note: The names, locations, and ages are provided. Crater fields are noted, as well as any impact sites with related myths or records of the event.

Table 6. Submarine Crater Candidates from the Australia–New Zealand Region, Shown in Figure 5b

Name	Latitude	Longitude	D (km)	T (years)	Location
Kanmare	16°34'S	139°03'E	18	572 CE ± 86	Gulf of Carpentaria
Tabban	17°07'S	139°51'E	12	572 CE ± 86	Gulf of Carpentaria
Kangaroo	39°02'S	141°16'E	5	Unknown	Off coast of Victoria
Joey	39°09'S	141°11'E	4	Unknown	Off coast of Victoria
Mahuika	48°18'S	166°24'E	20	~1443 C.E.	Tasman Sea, south of NZ
Burckle[a]	30°51'S	61°21'E	30	<6,000	Southern Indian Ocean

Note: The location, estimated diameter (D), and proposed age (T) of each structure are provided.
[a] Not shown in Figure 5b.

approximation) of 572 C.E. ± 86 years (Abbott et al. 2007).[13] Numeric models of these impacts (using Collins et al. 2005) show that Mornington Island and the surrounding archipelago would have succumbed to devastating effects (including widespread fires, impact ejecta, tsunamis, and earthquakes), of which we should expect to find significant archaeological, geological, and environmental evidence. Another alleged submarine structure found in the southern Indian Ocean, Burckle, has a diameter of ~30 km and a proposed age of <6,000 years (Abbott et al. 2009).

In addition, there are several other large, alleged impact structures from the other regions of the world that have proposed dates within the last 6,000 years, for example, the Umm al Binni structure (see Master and Woldai 2004) and the Chiemgau crater field (see Rappenglück et al. 2009).[14] To account for this discrepancy, Baillie (2007) suggests that these impacts may have originated from fragmented comets or "dark" comets, which have a very low albedo and are difficult to detect (Napier et al. 2004), and that current impact estimates represent very conservative

FIGURE 5A. The Kanmare and Tabban submarine crater candidates, located on either side of Mornington Island in the southern section of the Gulf of Carpentaria.

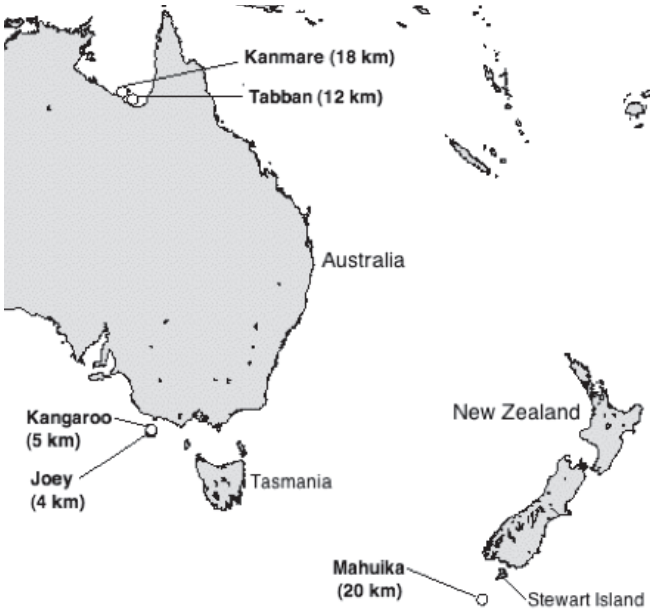

FIGURE 5B. Proposed Holocene submarine impact craters near Australia and New Zealand, including the estimated crater diameter.

minima. This hypothesis has been met with criticism and controversy and continues to be heavily debated (e.g., Abbott et al. 2010; Baillie 2007; Bourgeois and Weiss 2009; Bunch et al. 2008; Firestone and West 2008; Gusiakov et al. 2008; Pinter and Ishman 2008; Rappenglück et al. 2009).

Conclusion

None of the events described in Aboriginal oral traditions correspond to currently known impact events that occurred during the human history of Australia. Furthermore, although some impact events caused craters during Australian human history (e.g., Boxhole, Veevers, Henbury), there is no (publicly available) oral tradition of witnesses to these events.

On the other hand, we find that the number of stories describing eyewitness impact events in the oral traditions greatly exceeds the number expected from current estimates of meteorite influx rates and impact intervals. We conclude that either the current meteor literature severely underestimates the impact rate (and there are hotly contested arguments supporting this) or else the stories are not based on witnessed events.

We examine three possible explanations for why the stories may not be based on witnessed events: (1) the stories are postcontact and have incorporated information from Western science, (2) the Aboriginal people independently deduced that impact craters were formed from a cosmic impact, and (3) a single or small number of events were incorporated into oral traditions and spread to other communities across the continent. While we cite evidence supporting each explanation, we are unable to conclude with any certainty which explanation best explains the discrepancy.

We suggest that oral traditions may be used to identify impact structures and meteorites unknown to Western science. Besides the plethora of useful scientific information that would benefit various scientific fields, the information gathered from an impact structure described in Aboriginal oral tradition, including its age and impact effects, could show how some oral traditions evolve over long periods of time. Such studies may also be useful in modeling alleged submarine Holocene impact events, such as Mahuika, Tabban, and Kanmare. For this reason, we encourage investigations and surveys of the areas where cosmic

impact stories were recorded, which may shed light on this elusive problem.

Acknowledgments

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Appendix A

Table A. Aboriginal Groups Discussed in This Paper, Including the Group Name (Language, Clan, Dialect, or Community Name) and General Area of That Group, Including the State(s)

Group	General Region	State
Alyawarre	Southeastern region	NT
Amangu[a]	Region 200–350 km northwest of Perth	WA
Anula[b]	Carpentaria Gulf region	NT
Andedja	Kimberleys	WA
Anguthimri[a]	Near Mappon, far northwest of Cape York	QLD
Arrernte[c]	Central Australia, area of Alice Springs	NT
Awabakal[a]	Lake Macquarie/Newcastle Region	NSW
Badaya	Region east of Darwin	NT
Barkinji	Northwestern region	NSW
Binbinga	Borroloola area, near Gulf of Carpentaria	NT
Bindal[a]	Townsville, Cleveland Bay	QLD
Birria	Southwestern region	QLD
Bogan	North-central region	NSW
Boorong	Northwestern region	VIC
Boonwurrung[a]	Area southeast of Melbourne	VIC
Bundjalung[a]	Richmond-Tweed region	NSW
Darkinung[a]	Cessnock-Wollombi region	NSW
Dhauwurd[d]	Portland/southwest region	VIC
Dieri[a]	Northeast region	SA
Djaru (Jaru)	Northeast region, southeast of Kimberleys	WA
Djirbalngan[a]	Tully River region	QLD
Euahlayi	North-central region	NSW
Giya[a]	Proserpine area	QLD
Goreng[a]	Near Bremer Bay	WA
Gundidjmara	Southwestern region	VIC
Gunwinggu	Arnhem Land	NT
Gurudara	Region east of Darwin	NT
Indjabinda	Pilbara	WA

Table A. (cont.)

Jajaurung[e]	Northeastern region	VIC
Jauidjabaija	Yawajaba Island, Kimberleys	WA
Jindjiparndi[f]	Chichester region, Pilbara	WA
Jiwarli	Henry River, northwestern region	WA
Jupagalk	Northwestern region	VIC
Kaitish	Barrow Creek, north of Alice Springs	NT
Kamilaroi	North-central region	NSW
Karadjeri[g]	Lagrange Bay, Kimberleys	WA
Kaurna	Adelaide Plains	SA
Koko Ya'o[h]	Eastern Cape York	QLD
Kukata	South-central region	SA
Kukatja	Balgo, Lake Gregory, South Halls Creek	WA
Kuku-Yalangi[a]	Bloomfield River region	QLD
Kula	North-central NSW, south-central QLD	NSW/QLD
Kungarakany	Northwestern region, south of Darwin	NT
Kunwinjku	Arnhem Land	NT
Kurnai	Gippsland Region	VIC/NSW
Kurulk	Arnhem Land	NT
Kwadji	Eastern Cape York	QLD
Lardil	Mornington Island, Gulf of Carpentaria	QLD
Luritja[i]	Southeast of Alice Springs	NT
Mal Mal	Cleveland Bay near Townsville	QLD
Mara	Limmen Region, Arnhem Land	NT
Marduthunira	Cape Preston, Dampier, Pilbara Region	WA
Meru	Lower Murray River District	SA
Moporr	Between Leigh and Glenelg rivers	VIC
Mukjarawaint	North-central region	VIC
Muruwari	North-central NSW, south-central QLD	NSW/QLD
Mycoolon	Saxby River region	QLD
Nawu	Port Lincoln area	SA
Narangga	Yorke Peninsula	SA
Narran	North-central region	NSW
Needwonee	Southwestern region	TAS
Ngalia	Leonora, central region	WA
Ngarigo	South-central NSW, southeast of Canberra	ACT/NSW
Ngemba	North-central NSW, south-central QLD	NSW/QLD
Ngarinman	Jasper Creek, Gregory National Park	NT
Ngarinyin	Kimberleys	WA
Ngarrindjeri	Lower Murray River District	SA
Noongahburrah[j]	Narran River, north-central NSW	NSW
Nuenonne	Bruny Island, south-central region	TAS
Nungubuyu[k]	SE Arnhem Land, bordering Gulf of Carpentaria	NT
Plangermairrener	Ben Lomond District	TAS
Ramindjeri	Encounter Bay	SA
Ritarungo	Arnhem Land	NT
Tangani[l]	Lower Murray River District	SA
Tanganekald	Banks of the lower Murray River	SA

Table A. (cont.)

Group	General Region	State
Tiwi	Bathurst and Melville Islands	NT
Turrbal[m]	Brisbane area	QLD
Walangeri	(see Yarralin)	NT
Warai	Northwestern region, south of Darwin	NT
Wardaman	Upper Daly River District	NT
Warkawarka	Lake Tyrell region	VIC
Warlpiri	Tanami Desert	NT
Wathi-Wathi	Murray River region	VIC
Wawilak[n]	Arnhem Land	NT
Weilan	North-central region	NSW
Wheelman	Near Bremer Bay	WA
Wik-Munkan	Cape York Peninsula	QLD
Wiradjuri	Central region	NSW
Wirangu	West coast	SA
Wolmeri	Kimberleys	WA
Wongaibon	North-central region	NSW
Worora	North of Derby, Kimberleys	WA
Wotjobaluk	Lake Albacutya region	VIC
Wunambal	Kimberleys	WA
Yarralin	Victoria River District	NT
Yarripilangu	Area northeast of Alice Springs	NT
Yarrungkanyi	Area northeast of Alice Springs	NT
Yerrunthully	Central region	QLD
Yiiji[a]	Forrest River region, Kimberleys	WA
Yintjingga	Stewart River area	WA
Yugerra[a]	Brisbane region	QLD

[a] Not identified in the text by group name but rather by geographic location or identifying landmark, such as a river or town. The group given is taken from the Australian Institute for Aboriginal and Torres Strait Islander Studies map of Aboriginal Languages.
[b] Also known as Yanyuwa.
[c] Also known as Arunndata, Aranda, and Arunta.
[d] Dhauwurd Wurrung language, part of the Gundidjmara people.
[e] Also known as Jaara, a subgroup of the Djadjawrung.
[f] Also known as Yindjibarndi.
[g] Also known as Karajarri.
[h] Subgroup of the Kwadji.
[i] Also known as Jumu.
[j] Subgroup of the Narran.
[k] This is the language of the Numbulwar of Arnhem Land.
[l] Subgroup of the Ngarrindjeri.
[m] Also known as Jagara, of the Yugerra Language group.
[n] A clan of the Ritarungo people.

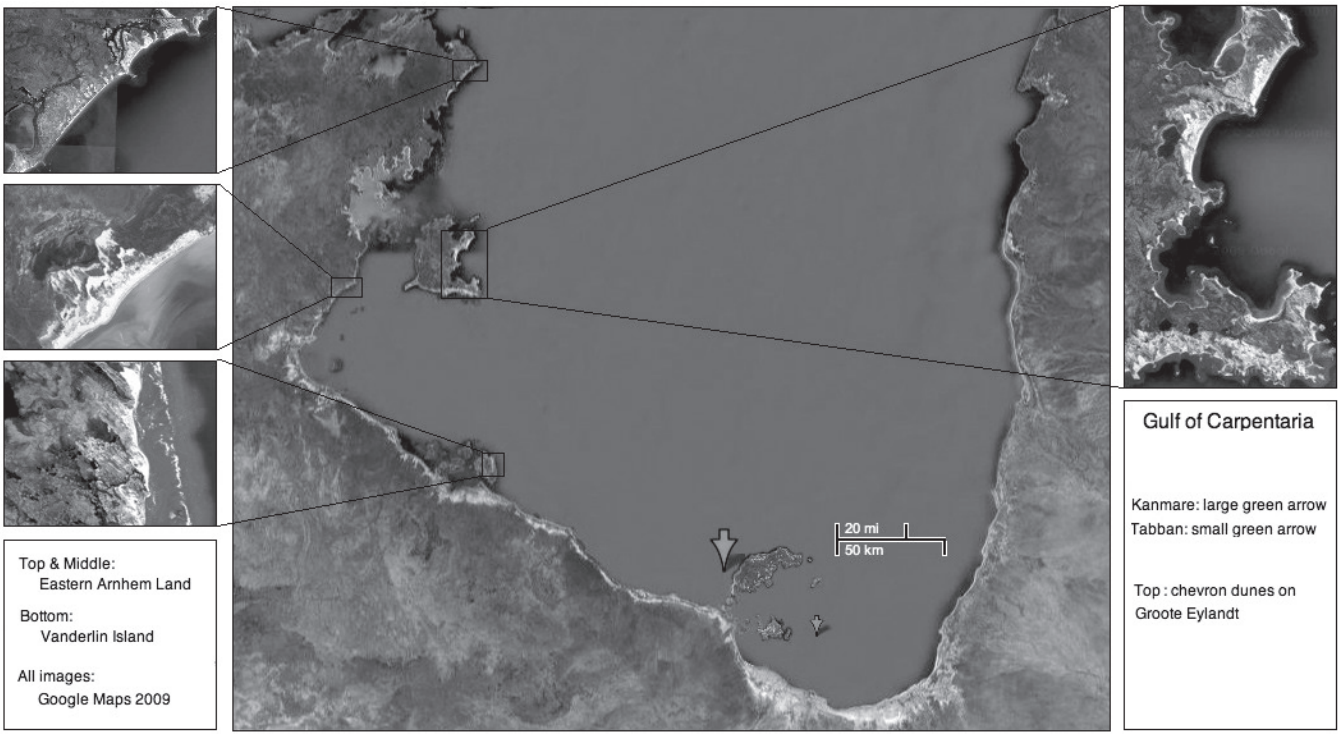

FIGURE 6. Chevron dunes on the coastal regions of the Gulf of Carpentaria, including the southeast coast of Groote Eylandt, the eastern coast of Arnhem Land, and Vanderlin Island, which strike from the southeast, toward the Kanmare structure. A debate regarding the origins of these chevrons is ongoing.

Appendix B: Evidence for a Tsunami in the Gulf of Carpentaria

Evidence that tsunamis struck the coastal regions of the Gulf of Carpentaria, including Groote Eylandt, Vanderlin Island, and parts of the eastern Northern Territory coast, has been proposed in the form of "chevron dunes," which Abbott et al. (2007) and Tester and Abbott (2007) argue were formed when submarine sediment and coastal debris were washed inland by the tsunami. The chevrons all appear to "strike" (radiate) from the southeast, in the direction of Kanmare structure (see Figure 6).

Notes

1. For a similar study applied to South America, see Masse and Masse (2007).

2. Arrernte, Aranda, and Arunta are all different spellings of the same Aboriginal language group of Central Australia. Different spellings are used in this article according to the spelling given in the source from which the account was taken.

3. The fiery star Nyimibili was described as having a large eye as bright as the Moon, burning alight during the day and night. This description closely relates to other malevolent, one-eyed meteor beings found in the oral traditions of Aboriginal people of the upper Northern Territory such as Namorrodor and Papinjuwari.

4. There is some debate as to whether meteorite impacts can trigger fires (e.g., Durda and Kring 2004; Jones and Lim 2000). Masse and Masse (2007:196) cite several examples from South America describing fires that were caused by fiery objects falling from the sky. Collins et al. (2005) cite the heat-energy levels required to ignite grass and trees, among other materials, based on nuclear tests by Glasstone and Dolan (1977).

5. We were unable to obtain the original text from Worms (1940).

6. Pulu has an area of <0.5 km^2 and is considered a sacred place (see McNiven et al. 2009).

7. The Huckitta meteorite was discovered by an Aboriginal worker named Mick Laughton.

8. See the meteorite files under "Jhung" and "Tenham" in the British Museum of Natural History.

9. Wellard was also instrumental in the identification of other

meteorites, including the 33.6-kg Gnowangerup meteorite (de Laeter 1982), a Mellenbye/Yalgoo meteorite fragment (McCall and de Laeter 1965:38).

10. However, not all visible meteors produce recoverable meteorites, as many burn up in the atmosphere.

11. See Blong (1982) for examples from Papua New Guinea and Masse and Masse (2007) for examples from South America.

12. See http://tsun.sscc.ru/hiwg/hiwg.htm. A full list of publications by the group can be found at http://tsun.sscc.ru/hiwg/publ.htm.

13. Tester and Abbott (2007) describe the craters as elliptical in shape, indicative of a low-angle impact (<15°).

14. Another close pair of submarine crater candidates consist of the 5-km-wide Kangaroo and 4-km-wide Joey structures (Abbott et al. 2006), located south of Portland, Victoria (see Figure 5b, Table 6). Geophysical surveys of these structures are in progress (e.g., Abbott et al. 2006; Elkinton et al. 2006; Martos et al. 2006), although no age estimates have been published. A news account (*Sydney Morning Herald* 1870) of an Aboriginal story describing a massive tsunami that destroyed the region between Portland and Mount Eckersley, Victoria, suggests a potential link to the Kangaroo and Joey craters but includes references to volcanic activity on Mount Gambier, suggesting either a volcanic event or two separate events incorporated into the same story. Any connection between the craters and the Aboriginal account is speculative.

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