NATIVE AMERICAN TRADITIONS OF METEOR CRATER, ARIZONA: FACT, FICTION, OR APPROPRIATION?

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Abstract: Hopi and Navajo oral traditions describing the formation of Meteor 'Barringer' Crater in Arizona are reported in early twentieth century news media, but some scholars claim these traditions are deliberate fabrications or misidentified stories about more recent volcanic events. This paper critically analyses these accounts and examines explanations for the apparent traditions and the history of associated research at the crater. We show that Navajo communities *do* maintain oral traditions about the crater, and the evidence suggests an unknown person(s) appropriated and/or altered them to generate interest in the structure's impact hypothesis. A motivation may have been to use these traditions to boost interest by investors to mine meteoritic iron believed (at the time) to be buried under the crater floor.

Keywords: Meteor Crater, oral tradition, Native American, Navajo, Hopi, Indigenous Knowledge, meteorites, and history of science

1 INTRODUCTION

Indigenous oral traditions around the world describe geo-hazards, such as volcanic eruptions, tsunamis, earthquakes, and meteorite impacts. In 1968, Indiana University Professor Dorothy Vitaliano examined oral traditions for descriptions of geological events and features, such as volcanic eruptions, tsunamis, and fossils (Vitaliano, 1968). Her work, and that of scholars over the last several decades, shows that oral histories do include descriptions of known geological and geo-hazard events (e.g. Masse et al., 2007).

Meteorite craters around the world have associated oral traditions that describe their origin, including the Henbury, Gosse's Bluff, and Wolfe Creek craters in Australia (Hamacher and Goldsmith, 2013) and the Rio Cuarto and Campo de Cielo craters in Argentina (Barrientos and Masse, 2014; Giménez-Benítez et al., 2000). Some of these traditions describe the structure forming from the impact of a celestial body, suggesting either a witnessed event or knowledge the structure was formed from a similar event. It is plausible that accounts of witnessed events can remain in oral tradition for thousands of years (Henige, 2009; Mayor, 2005). Some traditions attribute impact origins to structures that are too old for humans to have witnessed (according to scientific evidence). This raises questions regarding the nature of these oral traditions: were they influenced by Western science? Are the impact-formation traditions simply coincidental to the formation of the crater, or did Indigenous peoples deliberately develop traditions that explain that the craters were formed from an impact?

Some Australian Aboriginal oral traditions of the Wolfe Creek crater (*Gandimalal*) describe it as a spot where a 'star fell'. Some local Jaru elders say that this was influenced by conversations with geologists, stating that the "… falling star story is whitefella's story." (Hamacher and Goldsmith, 2013: 306). Initially estimated to be 300,000 years-old (Shoemaker et al., 1990) recent research shows it is much younger at 120,000 ± 9,000 years old, with various dating techniques ranging from 86,000 to 137,000 years (Barrows et al., 2019). Although this date lies just outside the currently known habitation of Australia, recent archaeological evidence at the Moyjil site in Australia's south-west Victoria shows humans may have been in Australia when the impact occurred (see the entire issue of *Proceedings of the Royal Society of Victoria*, Volume 130, Issue 2, 2018).

Indigenous traditions will describe origins and natural processes in relation to their language, worldviews, and perceptions. This may or may not have alignments with Western science. The *assumption* that Indigenous traditions explaining the formation of geological features that coincide with the Western scientific version *must have been* the result of Indigenous people's contact with Western culture is problematic as it degrades the knowledge systems of Indigenous people and is inconsistent with current evidence.

For example, Luritja Aboriginal descriptions of the formation of the ~4,700 year-old Henbury craters (known as *Tatyeye Kepmwere* in the Arrernte language, Figure 1A) indicate a living memory of the event (Hamacher and Goldsmith, 2013). Western Arrernte traditions of the 142.5 million-year-old Gosse's Bluff crater (*Tnorala* in the Arrernte language, Figure 1B) attribute its formation to the impact

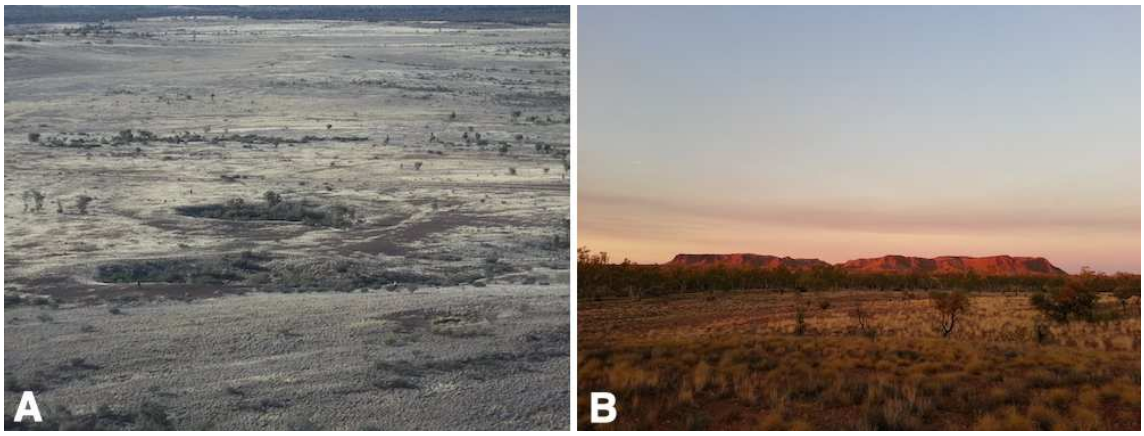

Figure 1: (A) The Henbury crater field (Tatyeye Kepmwere) and (B) Gosse's Bluff (Tnorala), both in Arrernte country in the Northern Territory. Images by the author.

of a celestial baby that fell from the Milky Way as a fiery star, striking the ground and creating the (highly eroded) ring-shaped mountain range we see today (*ibid*). There is no evidence that Western science influenced the Arrernte traditions about the formation of Tnorala. Mavis Malbunka, an Arrernte custodian of the site, says the story has been in Arrernte traditions for generations (Malbunka et al., 2007). During filming of a National Geographic documentary, Warren Williams (a relative of Malbunka and another Traditional Custodian) told the author that the Tnorala tradition has been in the family for generations and that it is not a recent fabrication.

Indigenous Knowledge is developed to explain the origins and connections between life, law, and culture with significance to the landscape and environment (see Agrawal, 1995; David and Hamacher, 2018; Elliott, 2008). Indigenous knowledge was developed over many generations through first-hand experience, experimentation, and empirical observation and is passed to successive generations through oral tradition and material culture (Clunies-Ross, 1986; Vansina, 1985). Indigenous Knowledge systems are dynamic and evolving, incorporating new information over time. Although one should not *assume* that traditions attributing the formation of meteorite craters to cosmic impacts are the result of Western scientific influence, we cannot always rule-out this explanation.

This paper examines alleged Native American traditions of Meteor 'Barringer' Crater in Arizona that were reported in news media. Some of these reported traditions describe the crater forming from a 'falling star'. Some scientists have dismissed these traditions as fabrications (e.g. Blackwelder, 1932: 559; Ley, 1966: 244), but the reasons cited are based primarily on the antiquity of the crater's accepted age of 50,000–61,100 years (Barrows et al., 2019; Roddy and Shoemaker, 1995) as compared with the contentious archaeological record of human presence in America (generally accepted to be <20,000 years). Pseudoscientists have exploited these traditions to promote fringe viewpoints related to Young-Earth Creationism (DeYoung, 1994) and 'Atlantis' hypotheses (Joseph, 1996). The latter views are based primarily on early (and since disproven) claims that the crater is only a few thousand years old and consistent with YEC claims of the Earth originating only 6,000–10,000 years ago (Wood, 1981).

2 NATIVE AMERICAN METEORITE TRADITIONS

Meteorites are variously viewed as objects of reverence or taboo to many Native American communities (Burke, 1991: 223–225; McBeath, 2010). For example, a large meteorite near Red River, Texas was believed to be a sacred object with healing properties by the local Pawnee and Hietan people (Nininger, 1933: 131). The 'Great Navajo Meteorite', weighing some 1,500 kg, was regarded as a revered object to which offerings were made (Nininger, 1933: 1). The Navajo believed the meteorite, which they called "*pish le gin e gin*" (black iron), was sacred and was kept hidden from Europeans and other tribes (Roy and Wyant, 1949: 114).

The famous Willamette Meteorite, now on display in the American Museum of Natural History in New York (Figure 2), is venerated as a sacred religious object, sent by the Sky People to the Clackamas people of Oregon, who called it *Tomanowos* (AMNH, n.d.). Meteorites were also collected by Hopewell people and found within their burial mounds (Prufer, 1961). The Camp Verde meteorite was reputedly 'found' (pillaged) by George Dawson,

who was searching for artefacts to sell for profit on a mesa above West Clear Creek in Arizona (Ayers, 2009).

Native American traditions from New Mexico were recorded by conquistadors in 1598. One of those stories (Lekson, 2008: 214) told of a large mass of people marching south from Pueblo country, led by two brothers. On the journey, they encountered a large "… mass of solid ore … so smooth and polished and free from rust as though it were the finest Capella silver." According to the story, a terrible old woman carried this huge rock and hurled it through the air "… with the speed of a lightning bolt …" before vanishing. When the object struck the ground, the Earth trembled. One of the brothers took this as a sign to found a city. As the Spaniards marched north from Chihuahua to New Mexico, they saw the city as "… ruins of a great capital."

A 1,500 kg meteorite was found by looters at Pacquimé (*aka* Casas Grandes, a prehistoric archaeological site in the northern Mexico) in the nineteenth century. Masse and Espenak (2006: 235–238) argue that this meteorite very likely represents the object described in the 1598 tradition. Currently housed at the Smithsonian Museum, the meteorite was initially found in an adobe sepulchre wrapped in a cotton burial shroud.

3 THE 'BARRINGER' METEOR CRATER

Meteor Crater (35° 01′ 38″ N, 111° 01′ 21″ W, Elevation: 1,740 m) is a simple impact structure (Figure 3) located near Canyon Diablo, near the town of Winslow, Arizona, USA. It was formed by the impact of a 50-meter wide nickel-iron meteorite and studies provided an age of the crater of approximately 50,000 years (Roddy and Shoemaker, 1995; Nishiizumi et al., 1991). Using new dating techniques, Barrows *et al.* (2019) pushed the age of the crater back to 61,100 ± 4,800 years. The crater is ~1.2 km in diameter and ~170 meters deep, with a rim rising 45 meters above the surrounding landscape (Shoemaker and Kieffer, 1979). A further 690–790 meters of breccia fill the crater floor (*ibid.*) for a total depth of ~960 meters.

It is estimated that half of the impactor's original mass vaporized on impact (Melosh and Collins, 2005; Schaber, 2005), with the remaining fragments scattered across the landscape—some individually weighing over 100 kg (Shoemaker and Kieffer, 1979). These fragments played an important role in the identifying the formation mechanism of the crater and contributed to its mysterious nature in the eyes of the local population.

According to the literature, the crater was long known the Hopi and Navajo. The Navajo call it *'Adah Hosh {ání,* meaning "many cacti descending from a height," possibly referring to desert plants on its slopes and floor (Zeigler *et al.,* 2013). Hopi refer to it as *Yuvugbu* (var. *yuvukpu*), meaning 'cave-in' or 'sink' (Hunter *et al.* 1999).[1] Hopi would regularly search for golden eagle nests on the rim (Page, 2003) and ruined dwellings have been found and excavated along the rim and walls of the crater (LaPaz, 1950). Flint tools were found around the crater (Barringer, 1905: 882) and the Hopi and Navajo gather finely ground white silica from the crater for use in ceremonies (Ley, 1966: 244). The term *yuvukna* is descriptive and not unique to Meteor Crater. For example, the term is attributed to a depression in the land near Pasture Canyon, 120 km north of Meteor Crater, near Tuba City (Hill et al., 1998: 796).

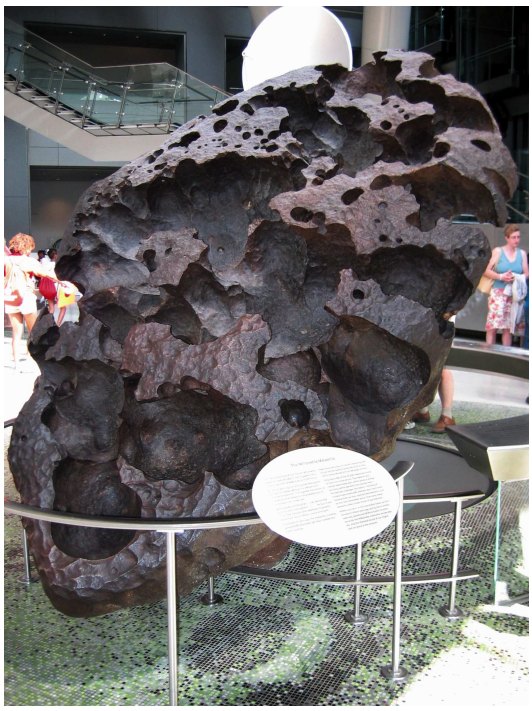

Figure 2: The Willamette meteorite. Image: Dante Alighieri (12 July 2005). Wikimedia Commons License.

4 MEDIA CAMPAIGNS AND THE PUBLIC USE OF NATIVE AMERICAN ORAL TRADITIONS

Colonial interest in the site arguably began in 1891 when a prospector found pieces of metallic iron containing small diamonds in the area. Foote (1891) first reported the meteorites and crater in the literature. Since then, thousands of meteoritic fragments associated with the crater have been collected, totalling

Figure 3: Aerial view of Meteor Crater near Winslow, Arizona. Image: Shane Torgerson, Wikimedia Commons License.

over 20 tons in weight. As early as 1931, most of the larger fragments had been removed, leaving only a few small fragments *in situ* (E.B.F.L., 1931: 18).

According to Anonymous (1906b), Native Americans trading meteoritic iron with whites is what lead to the latter identifying the crater (revealing, in turn, that the whites intended to secretly locate and steal the supposed mine from the Native American traders):

> … there was suspected the Apache and Navajo Indians in the vicinity of what is now Holbrook, Arizona, frequently brought to traders chunks of iron ore so pure and containing so much gold and silver that they were readily bought at the rate of 5/ a pound. The whites naturally supposed that the Indians were working a rich mine somewhere near. They followed them out on the plains and into the mountains in vain endeavours to locate such a mine. But they did find loose chunks of ore scattered over a certain part of the plain and were much puzzled thereat. Finally, a travelling geologist pronounced this ore to be of meteoric origin. He declared that at some ancient period a great meteor had fallen in that region, burying itself in the earth after shedding these scattered fragments. Eventually search revealed the cavity [Meteor Crater] already mentioned.

Known as *Coon Butte* or *Coon Crater*, Meteor Crater was initially believed by the scientific community to have formed from a volcanic eruption (e.g. Kring, 2007), despite the presence of abundant meteorite fragments. The crater is known colloquially to scientists as 'Barringer Crater' in honour of Daniel Moreau Barringer (Grieve, 1990), who conducted much of the early research at the site and pushed the hypothesis that it formed from a meteorite impact and not a volcanic explosion (Barringer, 1909). Although a majority of the scientific community had accepted Barringer's impact hypothesis by the 1930's, it was not until 1960 that the hypothesis was confirmed by geologist Eugene Shoemaker (Shoemaker, 1960).

Media reports in the early 1900s state that Native American oral traditions attribute the crater's formation to an object that fell from the sky and struck the land. Some scientists have dismissed the traditions as fabrications (e.g. Blackwelder. 1932: 559; Ley, 1966: 244), while Young-Earth Creationists (DeYoung, 1994) and 'Atlantis' researchers (e.g. Joseph, 1996) exploited these stories to support pseudo-scientific arguments. Creationists claim that Native American traditions of the crater originated from first-hand experience witnessing the event, a position based on (now refuted) radiometric dating techniques that gave an age of only 2,700 years (Wood, 1981) rather than the accepted scientific age of >50,000 years.

Evidence of human presence in America is

constantly revised and challenged, but the current archaeological evidence places humans in America within the last 20,000 years (Gremillion et al., 2008; Waters et al., 2011), with some higher estimates exceeding 40,000 years (e.g. Santos et al., 2003)—some 10,000 to 20,000 years after the accepted formation date of the crater. Are these oral traditions genuine or are they fabrications? Are they conflated descriptions of nearby volcanic eruptions or are they misappropriated or misinterpreted traditions used to drum-up support for financial interests to exploit the crater's natural resources? The search for answers begins with Daniel Barringer.

Daniel Barringer (Figure 4)[2] was a geologist and lawyer who made his fortune through mining. It was a combination of his entrepreneurial drive and strong personality that led to much of the attention the crater gained in the public eye. During a casual conversation with Samuel J. Holsinger in 1902, Barringer learned about the crater and the fragments of meteoritic iron surrounding it. At the time, it was still widely believed that the crater had formed by volcanism. He believed that if the crater had been formed from a meteorite impact, then a giant mass of the meteorite should still lay beneath it. Given his entrepreneurial spirit, he quickly garnered support from scientist Benjamin C. Tilghman II, founded the Standard Iron Company, and began securing mining patents for the crater and surrounding land. To secure funds for mining the crater, he had to convince the scientific community that it was indeed a meteorite crater.

After years of investigation at the site, Barringer and Tilghman presented their findings to the National Academy of Sciences in 1906 (Tilghman, 1905). An article in the *New York Tribune* on 21 January 1906 discusses Barringer's efforts to drill the crater floor in search of the impacting meteorite. This is the first time Native American traditions of the crater's formation are discussed in the literature (Anonymous, 1906a):

> The Indians nearby have a legend about a huge star falling out of the heavens and sizzling the tribe with its brightness. Then there was a great shock and sudden darkness, and ever since then the Indians have regarded Meteorite mountain with awe.

In 1907, Arthur Chapman (1907: 83–84) published a short article that mentions the 'legend', noting that the formation hypothesis from both the scientific and Native American perspective are the same:

> It is here that, according to the theory of scientists and the traditions of the Indians, a giant meteorite, as large in circumference as the rim of the bowl would indicate, struck the earth in ages past. The Moki Indians, whose strange homes are not far away, have a tradition of a blazing star which fell ages ago and which appalled the savages of that time, so dazzling was its light and such was the shock when it struck the earth.

The origins of this supposed legend are unknown, but it is nearly identical to the one reported the year before by Barringer. Barringer gave a second lecture to the Academy in

Figure 4: Daniel Barringer, 1860–1929 (Wikimedia Commons).

1909. It was at this lecture that Elihu Thomson, an English-born engineer, inventor, and co-founder of General Electric, first learned of the crater. Thompson was excited by the hypothesis the crater formed from a meteorite impact and the prospect that it contained rich mineral sources. He began a close partnership with Barringer to prove the crater's meteoritic origin. Thomson first visited the crater in April 1911, describing this visit and subsequent experiences in a lecture given before the American Academy of Arts and Sciences on 10 January 1912 (Thomson, 1912a). In this lecture, he mentions the supposed legend:

> It is stated that the Indian tribes inhabiting the region in a reservation just north of the railroad have an ancient tradition of the fall of a large body of fire from the sky which killed a number of their tribe. It is also stated that they now hold the spot in some

> superstitious awe from the fact that they send to the crater slopes for the white silica, which is sprinkled about during their ghost dances. I cannot, however, personally vouch for this without further investigation.

Three months later, in April 1912, Thomson (1912b) gave a lecture to the Schenectady Local Section of the American Institute of Electrical Engineers. He provided more details about the Native American traditions regarding the crater's formation (Thomson, 1912b: 203–204, repeated in Thomson, 1912c):

> North of this crater there is a large Indian reservation where the Navajo Indians live. These Indians, it is said, have a tradition handed down from generation to generation, which says that three large bodies fell out of the sky, and one of them struck the earth at the south of the present railroad tracks, i.e., where the present meteor crater is; and that when that body fell a number of their tribe were killed. These Indians now apparently send to this crater when they have their ghost dances, and get the white silica to sprinkle around where they dance, indicating that they still retain some superstition in regard to this peculiar natural phenomenon.

It is not clear what information he was given—and by whom—between his first lecture to the AAAS and the AIEE. In his second lecture, Thomson seems more confident and his description suggests he confirmed that oral traditions about the crater's formation existed among the Navajo. Was this legend given to him by a Navajo elder or contact? Was it given to him by a non-Indigenous person? How reliable was this person? The answers to these questions remain unknown.

The interest generated led to drilling the crater floor at great cost, yet the venture revealed nothing.[3] This failure was cause for deep concern for Benjamin Tilghman, who pulled out of the project in 1910. After a decade of promoting their views and seeking investments, Barringer and Thomson remained convinced that a vast fortune in meteoritic iron lay beneath the crater and pushed forward. In 1912, they spent significant funds to drill for the meteorite (Barringer, 1905; Thomson, 1912a). Despite failing to find a mass of meteorite, Barringer and Thomson were not deterred. They were keen to recruit investors, as the process was quite costly. Thomson estimated that finding the meteoritic material beneath the crater would require 600 bore holes at $2,000 each, totalling $1.2 million (approximately US$31 million in 2019 currency).

Barringer and Thomson promoted their work and recruited investors, resulting in an explosion of media interest in the crater. Much of the media focus was on the potential commercial value of the nickel, iron, platinum, and diamond Barringer believed lay beneath the crater floor. These accounts featured the supposed Native American 'legends', each adding an increasing degree of poetic license.

A few months later, on 4 August 1912, *The Washington Post* featured an article on the crater and the commercial expedition to mine millions-of-dollars' worth of minerals from its depths (Anonymous, 1912a). It included further details of the alleged oral tradition:

> Mokis [Hopi] have a tradition of a blazing star which fell ages ago, when Old Man Coyote was a talking animal and when the oldest of the abandoned cliff houses in the southwest was new. The legend tells how the Mokis had offended the Great Spirit, and finally a warning was sent in the shape of a blazing star which lighted up the Earth for hundreds of miles around and whose shock was so terrific that several Moki villages were all but ruined. The Mokis heeded the warning, and since the falling of the blazing star they have so walked in the paths of rectitude that they are among the favored people of the Manitou.

This version is more detailed and contains information that is not included in either of Thomson's previously published accounts. It attributes the legend to the Hopi (also known as Moki at the time). Within months, newspapers across the globe—as far as Australia—had picked up the story and were publishing the legend. In 1914, Barringer (1914: 561) published a paper in the *Proceedings of the Academy of Natural Sciences of Philadelphia*, noting that:

> We well know from repeated borings by the Atchison, Topeka & Santa Fe R. R. Company that these strata contain very little water to-day and all the evidence is in favor of the crater's being of recent origin, the Indians of that section having a legend connected with the fall.

After years of research, the scientific consensus still held that the crater formed from explosive volcanism and not an extraterrestrial impact. In a final bid to drill for meteoritic iron in the crater, Barringer again sought investors, now claiming the meteoritic iron in the crater exceeded 10 million tons. By 1928, he had secured $200,000 ($2.99 million in 2019 currency) for further exploration. During his recruitment of investors, the media again promoted the scientific research about it being meteoritic in nature, including the alleged Native American traditions of its formation.

Drilling turned up nothing and in 1929 the

directors of the Standard Iron Company sought the consultation of astronomer Forest Ray Moulton. Moulton calculated that the meteorite would have been around 300,000 tons and that virtually all of it vaporized on impact, leaving little more than scattered fragments around the crater's vicinity.

The devastating news led to heated debate and arguments between investors and scientists. A final, lengthy, and in-depth analysis confirmed the meteorite vaporized on impact and no deposit of iron lay underneath the crater. After personal contributions of over $600,000 ($9 million in 2019 dollars) with no return on his investment, Barringer nearly went bankrupt. Soon after reading the arguments of Moulton, Barringer had a heart attack and died on 20 November 1929. He had correctly convinced the world the site was a meteorite crater but bankrupted himself trying to find a non-existent mineral fortune in its depths.

5 IDENTIFYING THE ALLEGED NATIVE AMERICAN 'LEGENDS'

Barringer and colleagues keen on finding a fortune in the crater promoted Native American oral traditions describing the formation of the crater. Were these traditions genuine, or were they misappropriated traditions unrelated to the crater? Or were they fabricated to increase commercial and scientific interest in the crater? Was there another explanation? We consider three primary explanations:

1. The first is that Navajo and/or Hopi *do* possess oral traditions about the crater and those traditions describe its formation as originating from the sky as a falling star. Similar oral traditions can be found around the world, including sites where it is highly likely that Indigenous people witnessed the event (such as the ~4.7 kyr Henbury craters in Australia), as well as places where the crater formed long before humans existed (e.g. the 142 Myr Tnorala/ Gosses Bluff crater in Australia; see Hamacher and Goldsmith, 2013).
2. The second is that the oral traditions describe in some way something falling or originating from the sky, but it is not attributed to the crater itself. Rather, it is from another location, such as the nearby volcanic ranges. In this context, the connection between the two is either coincidental or a deliberate misappropriation. Such a coincidence could have been exploited to generate interest in the crater for financial gain.
3. The third is that the alleged Native American oral traditions were fabricated or misappropriated to generate public and financial interest in the crater.

Possibility #1 could also be associated with a nearby impact crater that may have formed when people lived in the region but is not yet fully recognised or accepted by Western science. An example of this is probable Chinle crater in Arizona, reported by Shoemaker et al. (1995). This is a small (D = 23 × 34 m), shallow (d = 1.5 m) impact crater with an estimated age of about 150 to 250 years. It lies 8 km north of Chinle, AZ on the Navajo Nation and is associated with a 1 mm iron-nickel oxide fragment found in the crater fill. The Shoemaker team reported that two senior Navajo women (at the time between 70 and 80 years of age) independently remember the crater being much deeper during their childhood. Both women suggest that the impact was witnessed three to four generations ago. Shoemaker et al. say that many persons in the Navajo community thought that this crater was of impact origin. It is possible (albeit speculative) that Navajo people experienced the Chinle impact first-hand, which influenced their views and perceptions of the larger Meteor Crater.

Records of Native American oral traditions about the crater's formation before 1902 could exclude the third possibility (*fabrication*), as Barringer did not become interested in the crater until then. The earliest record identified to date is from 1906, years after Barringer has committed to drilling and exploring the site. By this point, belief among local residents was strongly supportive of the meteorite hypothesis. Guild (1907) does not mention any Native American traditions about the crater and states that:

> Interest in this phenomenon has been revived as the result of the adoption and elaboration on the part of a few writers of the local common talk of the inhabitants of the immediate neighborhood of the mountain. Here it is religiously believed that an immense meteor nearly one-half mile in diameter buried itself in the earth, forming a deep cavity with an upturned edge or rim very much as when a bullet is allowed to fall into soft mud.

However, *misappropriation* and/or alteration of Native American traditions to push the meteoritic narrative is a plausible explanation.

John Buddhue, a meteoriticist and science historian at the University of New Mexico, expressed doubt about the authenticity of the Native American legend(s) on two points (Ley 1966: 32):

1. No tribes living in the region were present when the crater was formed, and

2. No corresponding legends are found in the available literature on Hopi, Navajo, or Pueblo oral traditions.

A survey of research published on Hopi and Navajo astronomical traditions that were unrelated to media accounts of the crater (e.g. Begay and Maryboy 2006; Brew 1979; McCluskey 1977; Voth 1905) did not reveal any associated accounts or stories about the site or its formation. There is one tradition from the Hopi (Voth, 1905: 266) that describes a 'star' falling near a group of dancers. The story tells of a "… big star rising that came down and fell near the line of dancers, right in front of the head dancer …", immediately followed by a raid of warriors. This seems to describe a flaming projectile launched at the dancers by a war party rather than a literal interpretation of a meteorite fall.

By 1923, newspapers began publishing purported 'Native legends', some of which seemed to include an increasing degree of poetic license, while others claimed that there are no legends at all. This continued for more than 16 years:

> The Navajo Indians have a peculiar legend that three of their gods, desiring eternal rest, rode down from the stars on a cloud of flame, and alighted amidst thunder which rocked the plains, scattered stones to the winds as dust, and buried themselves so deep in the earth that they must never be disturbed … The Indians believe that anyone who disturbs these sleeping gods will come to harm. (Anonymous, 1923: 4).

> According to the Navajos, three of their gods, seeking eternal rest, rode to the earth on flaming blue thunderbolts that cleaved for them a deep and wide-mouthed grave and where those gods still lie, in their endless sleep, covered with rocks and iron and a pure white dust that is fine as flour. And terrible will be the fate of those who dare to desecrate their slumber, say the Navajo, as they knowingly nod their heads and declare that their gods can protect themselves, even in death. (Anonymous, 1924a: 24).

> The site of this celestial body has long been known to the Navajo Indians. According to tribal traditions, the arrival of the meteor betokened the flight of three of their god's, who, seeking endless repose, rode from the stars on roaring clouds of blue flame, to descend, accompanied by thunder that shook the mountains and reduced the rocks in the valley to an impalpable powder. To this day the "rock flour" is ritually used in certain of the sacred dances, and in fortune is predicted for all those engaged in the business of disturbing the sleep of the ancient Indian deities. (Anonymous, 1924b: 12).

> A great god left his place in the sky and descended to Earth in a burst of fire and smoke. To this day not one of them will disturb the fragments of meteoritic ore that lie thickly in the vicinity, lest the god be enraged. (Anonymous, 1929: 24).

These accounts do not mention three different traditions, as was described by Nininger in 1933. Rather, they describe the presence of three 'gods'. By 1939, publications were claiming that one oral tradition describes three 'gods' descending from the sky:

> The Hopi Indians have a legend about Meteor Crater. Three of their gods came down from the clouds one day. One came down here and the other two came down north of Meteor crater. It suggested three meteors fell, but no others have been found. (Cejnar, 1939: 5).

Some accounts claim Native Americans had no traditions about the crater at all, yet somehow still named it in reference to an impact event (though the Hopi/Navajo language name(s) is not given):

> Hopi and Navajo refused to let planes fly over Meteor Crater. They hold the place in great reverence but have no legends about the meteor but call the place "star-fell-down" (literal translation). (Abbott, 1930: 4).

There are various explanations for elements of the published descriptions. It is certain that the Canyon Diablo meteorites *did* have special and sacred significance. But with the increasing attention to the site (over which the Native American people had little control) by scientists and non-Native people, and the high financial value they gave to the meteorites, views could have shifted. Regardless, the core question of whether the legends are authentic, misappropriated, or fabricated still stands.

Researchers, such as Blackwelder (1932: 559), were sceptical about the veracity of the alleged Native American traditions:

> The stories of legends among the Indians regarding a great catastrophe may probably be dismissed as having little weight, for it is improbable that traditions of such matters would last at best more than a few centuries among such primitive tribes. A minimum age of 700 years is indicated by the fact the growth-rings on large cedars, a few of which scattered about the parapet, show that no important topographic change has taken place in that space of time.

Ley (1966: 244) claimed that stories about "… a fire-god who came from heaven to find a resting place in the ground …" seemed spurious. Ap-

parently, the authors who wrote about the legend (presumably Thompson and Barringer) were unable to provide any solid evidence that could verify the tradition, and Ley believed the stories to be an invention or hoax.

Vandiver (1937: 139–140) did not "… attach much weight …" to legends purported by Barringer that

> … describes the descent of one of their gods from the sky, in clouds of fire, to bury himself in that particular spot ... [and believed it] … improbable that legends could be carried down for more than a few centuries by such primitive people [sic].

This reflects a common colonial racist view held at the time (and one still held my many today).

Vandiver also believed that a

> … hole in the ground would not likely stir the imagination of the Indians, since they are familiar with the many volcanic craters of the San Francisco mountains, 50 miles or so away, and attach little importance to them.

Vandiver does not cite research to support his assertions, and the anthropological literature shows that the San Francisco volcanic craters *were indeed* important to the Navajo and Hopi, who experienced an eruption as recently as 1064 CE (e.g. Colton, 1932; Elson et al. 2002; 2011; Malotki, 2005). They attached *very* special significance to them. Plus, an impact structure the size and scale of Meteor Crater could hardly be dismissed as a mere 'hole in the ground'.

Doubts cast by Buddhue, Ley, and Vandiver tend to focus on the idea that because humans were not present in the region (or possibly in the Americas at all) when scientific analysis indicates the crater formed (~61,000 years ago), then they would have no reason to develop oral traditions about it. Or, if people did witness the event, the tradition would not have survived to modern times. Neither of these views is supported by emerging research, which suggests that oral traditions describing natural events can survive for thousands of years (e.g. Hamacher and Norris, 2009; Hamacher, 2011; Nunn and Reid, 2016) and that Indigenous people developed creation stories about the formation of natural features that coincides closely with the accepted Western scientific explanation, even before the feature was known to Western science (Hamacher and Goldsmith, 2014).

Still, some academics supported claims of Native legends and reported additional accounts. The meteoriticist Harvey H. Nininger (1933: 44) claimed that:

> The Native Americans of this vicinity have no less than three legends concerning the origin of this mighty crater. All of the legends agree in representing it as having been the site where the Great Spirit descended in a blazing fire and disappeared beneath the ground. Strict taboos were placed upon everything associated with the place and no 'good Indian' will visit the place to this day.

Nininger did not specify from whom or where these stories came. He did note that the crater and meteorite fragments were taboo to the Native American people with whom he interacted. They believed they would not be 'good Indians' if they did (Nininger 1933: 1–2). This is later supported by Heide (1964: 32), who stated "Indians still following tribal customs are not permitted to visit the crater …", nor did they participate in the search for meteoritic iron in the crater's vicinity.

Conflicting evidence comes from E.B.F.L. (1931: 18), who claimed that a "Native man" (identity and tribal group were not given) made a business of collecting meteorites in the area and selling them to prospectors, going so far as to hire hands to assist. Vandiver (1937: 139–140) was told that "… tons of [meteoritic iron] was collected by the Indians and sold to traders." Barringer (United States National Park Service, 1937: 140) claimed that "… the Indians will not carry away any of the iron …", but this could have been in reference to a time-period before substantial colonial economic interest in the site.

It is worth noting that colonisation forced most Indigenous communities into poverty, leading people to do things to make money for survival that they may not have done traditionally. It is possible that Native Americans of the area noticed white peoples' financial interests in meteorites and began collecting and selling them for cash. Nininger mentioned this exact scenario with regard to meteorites and tektites collected by Aboriginal Australians in the Western Desert and sold to scientists and colonists (Hamacher and O'Neill, 2013).

LaPaz (1950) claimed the crater was not taboo to the Hopi. Archaeological evidence indicates that the Hopi held meteorite fragments in high regard, trading them in pre-Columbian times (Buchwald, 1975: 399). Indeed, the locality had been known to Native American people in pre-Columbian times as pit dwellings from the twelfth century have been reported to exist on the outer south slope of the crater rim (E.B.F.L., 1931: 18).

The second possibility (of coincidental oral traditions) is that Native Americans were aware of meteorites and may have witnessed

the fall of one at another location (such as Chinle), which prompted an oral tradition describing the Canyon Diablo fragments as having a similar origin. An example is that of the Navajo Meteorites: two large nickel-iron fragments totalling 2,100 kg in mass that were found in the Arizona town of Navajo, 160 km from Meteor Crater and unrelated to that impact (Roy and Wyant, 1949):

> The Navajo meteorite … was known to the Navajo Indians since they came to this country about 1600(?) … and was covered up with rocks to keep the white man or other tribes from finding it as they thought it sacred. They called it "Pish le gin e gin" (black iron). They tell me that the [chisel] marks were there when they first found it and they think the prehistoric pottery-makers cut them in.

No age estimate was given for that fall, but had it been witnessed by Native people, it (or a similar fall) could have served as the foundation of the alleged Hopi stories described by Barringer and colleagues.

6 THE PUZZLE SOLVED?

One of the main arguments posed by scientists rejecting the authenticity of the Native legends was based on the relative age of the crater and the duration of time people had inhabited the region. During the early twentieth century, the age of the crater was a topic of heated debate. Estimates ranged from 700 years to 75,000 years (Hoyt, 1987: 332–333). With reports of Native American traditions describing the crater forming from a cosmic impact, a geologically younger age was often cited to explain them. This also better fit the hope by miners that iron rich material remained under the floor of the crater. The reason for this was simple: the younger the crater, the less material would have been weathered away by erosion.

Were any of the legends cited derived from literature or ethnography, aside from the word-of-mouth claims of those with vested interests in mining the crater? Some reports claimed that Hopi sites near the crater had suffered significant damage from the impact (e.g. Anonymous, 1912a). Some early researchers, such as Earnest Sutton (Anonymous, 1932: 10), suggested that trees found within the crater indicated a formation age of less than 1,000 years and that it may have wiped out Native American groups in the region. Sutton used dendrochronology to date the crater's formation to the thirteenth century. He then claimed that mummified human remains near the crater formed from the impact:

> With my own eyes I have seen mummified human beings sitting upright inside ruined buildings, as if something had suddenly sucked the life out of them.

At an anthropological meeting in Santa Fe, New Mexico in 1931, F. Martin Brown (1933) showed that villages near the crater had been buried under a layer of ash, the result of volcanic activity in the San Francisco Mountains 60 km away. Brown claimed that University of Arizona astronomer Andrew E. Douglass used wood samples from under the ash to develop a 'tree-ring calendar' that dated the destructive event to around 793 CE. This suggests that if Sutton's statement was accurate, the "… mummified human beings sitting upright inside ruined buildings …" were the result of an erupting volcanic ash and not a meteorite impact. Blackwelder (1932) believed the crater formed 40,000 to 75,000 years ago, based in-part on the presence of volcanic ash layers covering the crater and surrounding region. To his knowledge at the time, the last volcanic eruption in the region occurred in Pleistocene times. He seemed unaware of the research published by Robinson (1913) that demonstrated the most recent volcanic eruption occurred less than 1,000 years prior.

Brown used Douglass' work on the ash layer to support his claim that the impact that formed Meteor Crater was very young, thus suggesting the Native American traditions were descriptions of eye-witnessed events despite the solid evidence showing that the crater was tens-of-thousands of years old. Nash (1999) explained how pseudoscientists exploited Douglass' work on dendrochronology to support various fringe or refuted ideas.

A single reputable, published account from a Navajo or Hopi custodian of knowledge could clarify the argument. An article published in *Popular Science Monthly* in 1924 (Anonymous, 1924c) provides the only clear published evidence of Native American oral traditions related to Meteor Crater. The article provides the name and image of a Navajo wise man named Brown Hawk Wing (Figure 5). The article states that the Navajo tradition about the crater:

> Three of their gods, seeking eternal rest, rode to the Earth on flaming blue thunderbolts that cleaved for them a deep, wide-mouthed grave. Therein, these gods still lie.

This description is nearly identical to that of Anonymous (1924a: 24). Given the date of publication, is probably derived from the *Popular Science Monthly* article. The oral tradition attributes the crater's origin to a thunderbolt (a lightning strike with a simultaneous thunder-

clap), not the fall of a 'star' or meteor. The account given by Brown Hawk Wing matches the Navajo tradition described by Thompson (1912a), but it is inconsistent with the versions reported prior to this by Barringer and Chapman (1907). Early reports of the supposed legend give inconsistent descriptions of the 'object' that fell.

By examining the myriad versions of the supposed legends published in the media, it seems elements of the original tradition were confused, conflated, and changed slightly through the many public media retellings like a global game of *Telephones*. The first accounts describe the object as a 'star', while later it is described as a generic 'object'. There seemed to be confusion as to whether there was a single legend describing 'three gods' or 'three different traditions'. What fell was variously described as a star, meteor, object, thunderbolt, or a 'god'. The use of elaborative or poetic language increased over time, and the legend's origin seems to have shifted between the Hopi and Navajo. After successive retellings in the media, the elements and identity of the legend became clouded and confused. It is also possible that this could be a conflated description of the recent Chinle impact, but this remains uncertain.

According to Brown Hawk Wing, the Navajo legend attributed the crater's formation to *lighting* (thunderbolt), not a *star*. This, as well as the other reported traditions in the media articles, made it clear that the crater is a sacred site that should not be disturbed. There was never any mention of anyone consulting with the Navajo or Hopi to acquire their permission to mine the site (even if such a thing was not legally required or socially accepted at the time), nor was there any mention of anyone planning to recompensate the Navajo/Hopi for mining their sacred land.

7 CONCLUDING REMARKS

The structure known as Coon Butte was long known to Hopi and Navajo people, with archaeological evidence of its use stretching back to pre-Columbian times. When it was examined by Western scientists in the late 1800s and early 1900s, they believed it formed from volcanism. But locals of the area firmly held that it was a meteorite crater, with some authors describing the meteorite hypothesis as reaching religious status among the locals. After learning of the structure, Daniel Barringer believed Coon Butte was formed by the fall of a large meteorite and that a vast fortune in meteoritic minerals lay beneath the crater floor. He formed The Standard Iron Company at the turn of the twentieth century to promote this hypothesis and acquire mining rights in the crater. Around this time, public interest in the crater grew and media reports (driven by Barringer) began describing alleged 'Native legends', some of which claimed the crater formed from a 'falling star'. The language used to report the alleged Native legends seemed to undergo an ever-increasing degree of poetic description as well as confusion about the details. This casted doubt on their authenticity, particularly when they utilised Classical terminology (i.e. 'fiery chariots').

Figure 5: The Navajo wise-man, Brown Hawk Wing. Image: Anonymous (1924c).

In 1924, a magazine article featured the first published account that gave details about the legend directly from a named Navajo knowledge holder, Brown Hawk Wing. Brown Hawk Wing said the crater formed from a thunderbolt, not a 'falling star'. This directly confirms that the Navajo *do* have oral traditions about the formation of Meteor Crater, but they do *not* describe it originating from a 'falling star' (at least not the version given by Brown Hawk Wing). It is possible this is simply one of multiple oral traditions about the crater and does not necessarily represent a homogeneous and singular tradition. It is also possible that descriptions referring to it forming from a 'star' may have been misappropriated to promote the meteoritic theory of its origin.

Barringer and his colleagues had the economic motivation to spread and promote reports of Native American legends to support his view that the crater was meteoritic in origin, and thus contained a vast wealth of minerals. It is unknown if Barringer or someone working with him misappropriated the Navajo traditions, or if he merely repeated what he had been told by someone else. It is possible that others misappropriated the Native American traditions and relayed this to Barringer to encourage him to support their strongly held view, and thus use his funds and influence to prove it. Or, perhaps, legends were genuinely given by Navajo and/or Hopi elders to Barringer and colleagues, but the names of the knowledge holders were never published (until the account of Brown Hawk Wing). Media reports clearly changed specific details about the legends, but to what extent we are not certain. To date, we have not yet identified any Hopi traditions about the formation of the crater. Future work with Hopi and Navajo communities may reveal more information about their knowledge of the site and that work is ongoing.

Meteor Crater stands as one of numerous examples of colonial interests exploiting Indigenous traditions and land for financial gain, often using Western scientific discourse or technological needs as a motivational tool. This scientific community needs to recognise and understand the history and problematic nature of these actions to ensure these practices are not conducted in the future. The history of science is steeped in views of Eurocentric superiority. As such, it is easy for scientists to dismiss Indigenous traditions as 'myth and legend' and regard traditional warnings about disturbing sacred sites as mere 'superstition'. But these Knowledge Systems are not 'myth and legend'—they are systems of knowledge generated through observation, deduction, and experience and passed to successive generation through oral tradition. Western dismissal of Indigenous Knowledge is problematic, as it places Western interests and pursuits above those of the Indigenous people who have spent millennia developing that knowledge, commonly regarding Native American views as less worthy—a situation that is still ongoing in the scientific community.

To Indigenous people, these traditions describe laws that *must* be followed. Whether one considers it coincidence or the reality of traditional Law, it is worth mentioning that that Navajo warnings about severe punishment for disturbing the crater actually came to fruition. Early reports stated that

> … the Indians believe that anyone who disturbs these sleeping gods will come to harm … [and that] terrible will be the fate of those who dare to desecrate their slumber [a reference to the Navajo 'gods' in the crater floor].

The disruption and desecration of this sacred place for financial gain may have solidified the Western scientific view that the crater formed from a meteorite impact, but it ended in the loss of the wealth and life of Daniel Barringer.

8 NOTES

1. The Hopi names for 'stars' is *soohu*, 'meteors' is *soohu lööqö* (*soohubosdoga?),* and 'meteorites' *soobosvu* (Hunter et al., 1999).
2. For a detailed history of Meteor Crater research, see Barringer (1964), Burke (1991), Cokinos (2009), McCall et al. (2006) and Nininger (1972).
3. A general overview of Barringer's work at Meteor Crater is provided on the website of The Barringer Meteorite Crater, operated by the Barringer Crater Company, from which much of this history is taken. The author of the article is not provided. URL: http://www.barringercrater.com/about/history_1.php

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10 REFERENCES

Abbott, L. 1930. Indians refuse flights over Meteor Crater. *Times Herald* (Olean, NY, USA). 23 January, p. 4.

Agrawal, A., 1995. Dismantling the divide between Indigenous and scientific knowledge. *Development and Change*, 26, 413–439.

AMNH, n.d. *Willamette Meteorite Agreement*. American Museum of Natural History and the Confederated Tribes of the Grand Ronde Community, Oregon [http://www.amnh.org/exhibitions/permanent-exhibitions/rose-center-for-earth-and-space/dorothy-and-lewis-b.-cullman-hall-of-the-universe/willamette-meteorite-agreement]

Anonymous, 1906a. Did a meteor make it? *New York Tribune*, 21 January, p. 4.

Anonymous, 1906b. Digging for a £2,000,000 diamond meteor. *Camperdown Chronicle* (Victoria, Australia: 1877-1954), 29 March, p. 6.

Anonymous, 1912a. Digging for a diamond half a mile thick. *The Washington Post* (Washington,

D.C.), 4 August 1912, p. 4.
Anonymous, 1912b. The Most Wonderful Mining Venture. *The Cobar Herald* (Cobar, NSW, Australia), 1 November, p. 3.
Anonymous, 1923. *Oxford Register* (Oxford, KS, USA). 23 August, p. 4.
Anonymous, 1924a. How a meteor is mined. *The Springfield Leader* (Springfield, MO, USA). 20 January, p. 24.
Anonymous, 1924b. Mining a Meteor. *The World's News* (Sydney, NSW, Australia), 26 January, p. 12.
Anonymous, 1924c. A treasure that fell from the sky. *Popular Science Monthly*, January, p. 72.
Anonymous, 1925. The Greatest Meteorite. *The Cessnock Eagle and South Maitland Recorder* (Cessnock, NSW, Australia), 14 August, p. 8.
Anonymous, 1929. Arizona's giant meteor at last has been found by prospectors. *The Kansas City Star* (Kansas City, MO, USA), 21 October, p. 24.
Anonymous, 1932. Comet Calamity Wiped out Indian Tribe. *Townsville Daily Bulletin* (Townsville, QLD., Australia), 29 December 2, p. 10
Ayers, S., 2009. The tale of the falling star. *Verde Independent* (Cottonwood, AZ, USA), 06 September 2009 [https://www.verdenews.com/news/2009/jun/09/the-tale-of-a-falling-star/]
Barrientos, G., and Masse, W.B., 2014. The archaeology of cosmic impact: lessons from two mid-Holocene Argentine case studies. *Journal of Archaeological Method and Theory*, 21, 134–211.
Barringer, D.M., 1905. Coon Mountain and its crater. *Proceedings of the Academy of Natural Sciences of Philadelphia*, 57, 861–886.
Barringer, D.M., 1909. Meteor Crater (Formerly called Coon Mountain or Coon Butte) in northern central Arizona. National Academy of Sciences, 16 November 1909, Princeton University. *Republished by Andesite Press, 2017.*
Barringer, D.M., 1914. Further notes on Meteor Crater, Arizona. *Proceedings of the Academy of Natural Sciences of Philadelphia*, 66(3), 556–565.
Barringer, B., 1964. Daniel Moreau Barringer (1860–1929) and his crater (the beginning of the Crater Branch of Meteoritics). *Meteoritics*, 2(3), 186.
Barrows, T.T., Magee, J., Miller, G., and Fifeld, L.K., 2019. The age of Wolfe Creek meteorite crater (Kandimalal), Western Australia. *Meteoritics & Planetary Science*, 54, 2686–2697.
Begay, D., and Maryboy, N.C., 2010. *Sharing the Skies: Navajo astronomy*. Tucson: Rio Nuevo.
Blackwelder, E. 1932. The age of Meteor Crater. *Science*, 76, 557–560.
Brew, J.O., 1979. Hopi prehistory and history to 1850. In Sturtevant, W.C. (ed.), *Handbook of North American Indians. Volume 9: Southwest*. Washington, D.C., Smithsonian Institution. Pp. 514–523.
Brown, F.M., 1933. The age of Meteor Crater. *Science*, 77, 239–240.
Buchwald, V.F. 1975. *Handbook of Iron Meteorites. Volume II*. Berkeley, University of California Press.
Burke, J.G., 1991. *Cosmic Debris: Meteorites in History*. Berkeley, University of California Press.
Cejnar, J. 1939. Two girls guard mightiest fallen star. *The Edwardsville Intelligencer* (Illinois), 3 June, p. 5.
Chapman, A., 1907. Arizona's meteorite mountain. *Shields' Magazine*, 4-5, 83–86.
Clunies-Ross, M., 1986. Australian Aboriginal oral traditions. *Oral Tradition*, 1/2, 231–271.
Cokinos, C., 2009. *The Fallen Sky: An Intimate History of Shooting Stars*. Jeremy P. Tarcher/ Penguin Books.
Colton, H.S., 1932. Sunset Crater: the effect of a volcanic eruption on an ancient Pueblo people. *Geographical Review*, 22, 582–590.
David, B. and Hamacher, D.W., 2017. Environment and Landscape. In, Varela, S.L.L. (ed.), *Encyclopaedia of Archaeological Sciences*. New Jersey, John Wiley & Sons. Pp. 12–29.
DeYoung, D.B., 1994. Age of Arizona Meteor Crater. *Creation Research Society Quarterly*, 31, 163–158.
E.B.F.L. 1931. Meteor Mountain. *The Brisbane Courier* (Brisbane, Qld., Australia), 18 July 1, p. 18.
Elliott, F., 2008. *Western Science Coming to Know Indigenous Knowledge*. Unpublished PhD Thesis, University of Alberta, Edmonton, Canada.
Elson, M.D., Ort, M.H., Sheppard, P.R., Samples, T.L., Anderson, K.C., and May, E.M., 2011. A.D. 1064 No More? A Multidisciplinary Re-evaluation of the Date of the Eruption of Sunset Crater Volcano, Northern Arizona. 76th Annual Meeting of the Society for American Archaeology, 30 March – 3 April 2011. Sacramento, CA.
Elson, M.D., Ort, M.H., Hesse, S.J., and Duffield, W.A. 2002. Lava, corn, and ritual in the Northern Southwest. *American Antiquity*, 67, 119–135.
Foote, A.E., 1892. A new locality for meteoric iron with a preliminary notice of diamonds in the iron. *Proceedings of the American Association for the Advancement of Science*, 40, 279–283.
Giménez-Benítez, S.R., López, A.M., and Mammana, L.A., 2000. Meteorites of Campo del Cielo: impact on the Indian Culture. In Esteban, C., and Belmonte, J.A. (eds.), *Astronomy and Cultural Diversity.* Tenerife, Organismo Autónomo de Museos del Cabildo de Tenerife. Pp. 335–343.
Goldsmith, J., 2000. Cosmic impacts in the Kimberley. *Landscope Magazine*, 15(3), 28–34.
Gremillion, D.H., Auton, A., and Falush, D., 2008. Archaeolog: Pre-Siberian human migration to America: possible validation by HTLV-1 mutation analysis. *PLoS Genetics*, 4(5), e1000078.
Grieve, R.A.F. 1990. Impact cratering on the Earth. *Scientific American*, 262(4), 66–73.
Guild, F.N., 1907. Coon Mountain crater. *Science*, 26, 24–25.
Hamacher, D.W., 2011. Meteoritics and cosmology among the Aboriginal cultures of Central Australia. *Journal of Cosmology*, 13, 3743–3753.
Hamacher, D.W., and Goldsmith, J., 2013. Aboriginal oral traditions of Australian impact craters. *Journal of Astronomical History and Heritage*, 16, 295–311.
Hamacher, D.W., and Norris, R.P, 2009. Australian Aboriginal geomythology – eyewitness accounts of cosmic impacts. *Archaeoastronomy*, 22, 60–93.
Hamacher, D.W., and O'Neill, C., 2013. The dis-

covery and history of the Dalgaranga Meteorite Crater, Western Australia. *Australian Journal of Earth Sciences*, 60, 637–646.

Heide, F. 1964. *Meteorites*. Chicago, University of Chicago Press.

Henige, D., 2009. Impossible to disprove yet impossible to believe – the unforgiving epistemology of deep-time oral tradition. *History in Africa*, 36, 127–234.

Hill, K.C., Sekaquaptewa, E., and Black, M.E. (eds.), 1998. *Hopi Dictionary (Hopiikwa Lavlytutuveni): A Hopi-English Dictionary of the Third Mesa Dialect*. Tucson, University of Arizona Press.

Hoyt, W.G. 1987. *Coon Mountain Controversies: Meteor Crater and the Development of Impact Theory*. Tucson, University of Arizona Press

Hunter, D.A., Bosh, A.S., Stansberry, J.A., and Hunsberger, S.D., 1999. An astronomy outreach program for Navajo and Hopi schools. *Mercury*, 28(3), 18–24.

Joseph, F., 1996. Myth of the meteor. *The Ancient American*, 2(12), 37–39.

Kring, D., 2007. *Guidebook to the Geology of Barringer Meteorite Crater*. Houston, Lunar and Planetary Institute.

LaPaz, L., 1950. A preliminary report on Indian ruins discovered near the crest of the Barringer Meteorite Crater, Arizona. *Popular Astronomy*, 58, 400–401. Reprinted in *Contributions of the Meteoritical Society*, 4(16), 285–286.

Lekson, S.H., 2008. *A History of the Ancient Southwest*. Santa Fe, School for Advanced Research.

Ley, W., 1966. *Watchers of the Skies: An Informal History of Astronomy from Babylon to the Space Age.* New York, Viking Press.

Malbunka, M., Thornton, W., and Warning, L. 2007. *Tnorala – Baby Falling* (video). Featuring Mavis Malbunka, directed by W. Thornton, produced by L. Warning. Canberra, Ronin Films in conjunction with the Central Australian Aboriginal Media Association (Alice Spring, Australia).

Malotki, E. 2005. *Earth Fire: A Hopi Legend of the Sunset Crater Eruption*. Walnut, Kiva Publishing.

Masse, B.W., and Espenak, F., 2006. Sky as environment: solar eclipses and Hohokam Culture Change. In Doyel, D.E., and Dean. J.S. (eds.), *Environmental Change and Human Adaptation in the Ancient American Southwest*, Salt Lake City, University of Utah Press. Pp. 228–280.

Masse, W.B., Barber, E.W., Piccardi, L., and Barber, P.T., 2007. *Exploring the nature of myth and its role in science.* In Piccardi, L., and Masse, W.B. (eds.), *Myth and Geology*. London, Geological Society (Special Publications, 273). Pp. 9–28.

Mayor, A., 2005. *Fossil Legends of the First Americans*. Princeton, Princeton University Press.

McBeath, A., 2010. Meteorite veneration in the New World. *WGN – Journal of the International Meteor Organization*, 38, 193–198.

McCall, G.J.H., Bowden, A.J., and Howarth, R.J. (eds.), 2006. *The History of Meteoritics and Key Meteorite Collections*. London, Geological Society of London.

McCluskey, S.C., 1977. The astronomy of the Hopi Indians. *Journal for the History of Astronomy*, 8, 174–195.

Melosh H.J., and Collins, G.S., 2005. Planetary science: Meteor Crater formed by low-velocity impact. *Nature*, 434, 157.

Nash, S.E. 1999. *Time, Trees, and Prehistory: Tree-Ring Dating and the Development of North American Archaeology 1914–1950*. Salt Lake City, University of Utah Press.

Nininger, H.H., 1972. *Find a Falling Star.* New York, Paul S. Eriksson.

Nininger, H.H., 1933. *Our Stone-pelted Planet: A Book about Meteors and Meteorites.* Boston, Houghton Mifflin.

Nishiizumi, K., Kohl, C.P., Shoemaker, E.M., Arnold, J.R., Klein, J., Fink, D., and Middleton, R., 1991. In situ ^{10}Be-^{26}Al exposure ages at Meteor Crater, Arizona. *Geochimica et Cosmochimica Acta*, 55, 2699–2703.

Nunn, P.D., and Reid, N.J., 2016. Aboriginal memories of inundation of the Australian coast dating from more than 7000 years ago. *Australian Geographer*, 47, 11–47.

Page, J., 2003. Spider coming down. *Journal of Religion and Health,* 42, 111–116.

Prufer, O.H., 1961. Prehistoric Hopewell meteorite collecting: context and implications. *The Ohio Journal of Science*, 61, 341–352.

Robinson, H.H., 1913. *The San Francisco Volcanic Field Arizona*. U.S. Geological Survey (Professional Paper 76).

Roddy, D.J., and Shoemaker, E.M., 1995. Meteor Crater (Barringer Meteorite Crater), Arizona: summary of impact conditions. *Meteoritics*, 30, 567.

Roy, R.K., and Wyant, R.K., 1949. The Navajo Meteorite. *Geological Series of Field Museum of Natural History*, 7(8), 113–127.

Santos, G.M., Bird, M.I., Parenti, F., Fifield, L.K., Guidon, N., and Hausladen, P.A., 2003. A revised chronology of the lowest occupation layer of Pedra Furada Rock Shelter, Piauí, Brazil: the Pleistocene peopling of the Americas. *Quaternary Science Reviews*, 22, 2303–2310.

Schaber, G.G., 2005. *A Chronology of Activities from Conception through the End of Project Apollo (1960–1973*). U.S. Geological Survey, Open-File Report 2005-1190.

Shoemaker, E.M. 1960. *Impact Mechanics at Meteor Crater, Arizona.* PhD Thesis, Princeton University, Princeton, New Jersey, USA.

Shoemaker, E.M., and Kieffer, S.W., 1979. *Guidebook to the Geology of Meteor Crater, Arizona*. Tempe, Center for Meteorite Studies, Arizona State University.

Shoemaker, E.M., Shoemaker, C.S., Nishiizomi, K., Kohl, C.P., Arnold, J.R., Klein, J., et al., 1990. Ages of Australian meteorite craters – a preliminary report. *Meteoritics*, 25, 409.

Shoemaker, E.M., Roddy, D.J., Moore, C.B., Pfeilsticker, R., Curley, C.L., Dunkelmans, T.et al., 1995. Impact Crater identified on the Navajo Nation near Chinle, Arizona. *Meteoritics*, 30, 578–579.

Thomson, E., 1912a. The fall of a meteorite. *Pro-*

ceedings of the American Academy of Arts and Sciences, 47, 721–733.
Thomson, E., 1912b. Hunt for a great meteor and its lessons. *General Electric Review*, 15, 201–207. (see also Supplement No. 1896 in *Scientific American*, 4 May 1912)
Thomson, E., 1912c. Hunt for a great meteor: the commercial possibilities at stake. *Scientific American (Supplement)*, 1896, 282–283 (4 May 1912).
Tilghman, B.C., 1905. Coon Butte, Arizona. *Proceedings of the Academy of Natural Sciences of Philadelphia*, 57, 887.
United States National Park Service, 1937. *Southwestern Monuments: Monthly Report*. Washington D.C., The Service.
Vandiver, V.W., 1937. *Meteor Crater, Arizona*. In *Southwestern Monuments* (Supplement), 136–154.
Vansina, J., 1985. *Oral Tradition as History.* Suffolk, James Currey.
Vitaliano, D., 1968. Geomythology. *Folklore Institute Journal*, 5(1), 5–30.
Voth, H.R., 1905. *The Traditions of the Hopi*. Chicago, Field Columbian Museum Publication 96, (Anthropological Series, Volume 8).
Waters, M.R., Forman, S.L., Jennings, T.A., Nordt, L.C., Driese, S.G., Feinberg, J.M., et al., 2011. The Buttermilk Creek Complex and the origins of Clovis at the Debra L. Friedkin site, Texas. *Science*, 331, 1599–1603.
Wood, J.A., 1981. Long playing records. *Natural History Magazine*, 22, 60.
Zeigler, K., Semken, S., and Moore, C., 2013. *Meteor Crater: from Misunderstanding to Obsession to Scientific Icon*. 64th New Mexico Geological Survey Fall Field Conference, First Day Road Log. Pp. 22–23.

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