METEOR CRATER: FROM MISUNDERSTANDING TO OBSESSION TO SCIENTIFIC ICON

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Although its true origin was not initially well understood, today Meteor Crater (also called Barringer Crater) is widely acknowledged to be the first recognized astrobleme or impact crater on Earth. A bowl-shaped feature with a diameter of about 1.2 km (0.75 mi), a depth of 180 m (600 ft), and surrounded by a rim rising 30 to 60 m (100 to 200 ft) above the surrounding surface, it is the largest known impact crater with extant associated meteorite fragments (Shoemaker, 1987). The meteorite fragments are collectively known as the Canyon Diablo meteorite. Owing to its high-desert Colorado Plateau location, the roughly 50 ka astrobleme is among the least eroded and best exposed of such structures. These attributes have rendered it one of the world's most intensely studied (Shoemaker, 1987). Undisputed recognition of Meteor Crater as the result of an extraterrestrial impact opened the field of astrogeology, and influenced geoscientific thinking on a host of topics from planetary evolution to mass extinction. However, this recognition—as obvious as it may seem now—was not immediate.

The original inhabitants of the region around Meteor Crater certainly knew of it. For example, the Diné (Navajo) name for it is *'Adah Hosh {ání,* meaning "many cacti descending from a height," probably referring to desert plants on its slopes and floor. The first transcribed record of Meteor Crater comes from European settlers entering central Arizona in the 1800s. They thought the immense hole in the ground was the result of a volcano (Southgate and Barringer, 2002). In 1891, Grove Karl Gilbert, who was the U.S. Geological Survey's chief geologist, examined the feature and decided that it was due to a volcanic "steam explosion." Suggestions that it might be an impact crater had been voiced, and Gilbert was willing to consider the idea. However, he decided against the possibility of an impact because he argued that the volume of material ejected from the crater and the volume of the impactor material should be present around the rim (Southgate and Barringer, 2002). By his calculations, the volume of the impactor was missing. In addition, he believed that there should still be large pieces of the impactor and they should cause a large magnetic anomaly, which was not present. Interestingly, in 1892, Gilbert was among the first to propose that the craters of the moon were impact-derived, rather than volcanic.

In 1902, Daniel M. Barringer, a mining engineer and businessman from North Carolina, heard the tale of Coon Butte (or Coon Mountain) from Samuel Holsinger, a local government agent. Holsinger, in the midst of regaling Barringer with tales of the wilds of Arizona, mentioned that the local legend was that the gaping hole had been formed by a meteor (Southgate and Barringer, 2002). Barringer, owner of the Standard Iron Company, was certain that if he could find the meteor, which was presumably iron-rich, his company would own a tremendous resource. He also played up the potential for platinum to further entice investors. In 1903, Barringer suggested the possibility of an impact crater and his company staked a mining claim to the area in and around the crater, as well as obtaining a land patent for the 640 acres (2.6 km^2) around the edge.

From 1903 to 1905, Barringer's company conducted research within and around the feature and concluded it was indeed an impact crater. They estimated the mass of the impactor at around 100 million tons. With iron ore at $125/ton in the early 1900s, Barringer stood to make a fortune of over $1 billion in 1903 dollars. Barringer presented his findings to the U.S. Geological Survey and published his idea in the Proceedings of the Academy of Natural Sciences in 1906 (Barringer, 1906). However, his arguments were met with skepticism. For 27 years, Barringer sought the main body of the impactor, even drilling some 400 m into the center of the crater in an attempt to relocate it. During this process, Barringer burned through money and friendships, obsessed with proving that he was right (Southgate and Barringer, 2002).

Skepticism on the part of some geologists continued into the 1950s, even though scientists like Herman Leroy Fairchild (1930) agreed with Barringer's hypothesis. But the Cold War-era testing of nuclear bombs in Nevada began in this same time interval, now making it possible for geologists to directly study fresh craters formed by enormous explosions. Eugene Shoemaker recognized that the structural features of such anthropogenic craters, which result from shock waves propagating either from a shallow explosion or the penetration of a high-velocity projectile (Shoemaker, 1960, 1963), are essentially the same as those seen at Meteor Crater. The fact that the impact penetrated and overturned the distinctive local sequence of Coconino Sandstone, Toroweap Formation, Kaibab Limestone, and Moenkopi Formation facilitated understanding of this process. Further, the presence of Coconino Sandstone provided abundant quartz that enabled Shoemaker and colleagues to confirm the impact origin of Meteor Crater, by documenting the presence of coesite and stishovite: two silica polymorphs formed under conditions of instantaneous high overpressure, and rare in terrestrial environments (Chao et al., 1960). Because weapons testing also enabled quantification of the dynamics of cratering, it also became possible to use computer modeling to estimate that the energy of the Meteor Crater impact was roughly equivalent to 20 to 40 megatons of TNT, corresponding to the oblique impact of an iron-nickel asteroid (referred to as the Canyon Diablo asteroid) about 10 to 50 m (33 to 164 ft) in diameter, traveling up to about 20 km/s (12 mi/s) (Roddy et al., 1980; Roddy and Shoemaker, 1995; Kring, 2007). The Canyon Diablo asteroid is actually considered to be at the small end of the size range of bolides that produce impact craters, and more recent findings suggest that the impact energy may have been closer to 10 megatons (see Kring, 2007, for a review).

Further detail on the geology of Meteor Crater, including the stratigraphy of the impact site, can be found in the compilation by Briley and Moore (1976) and the guidebooks by Shoemaker and Kieffer (1974), Shoemaker (1987), and Kring (2007). A handbook by French (1998) reviews the dynamics and geology of impact structures in general. For the Guidebook to the Geology of Barringer Meteorite Crater, Arizona (a.k.a. Meteor Crater) by David A. Kring, please see http://www.lpi.usra.edu/publications/books/barringer_crater_guidebook/.

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