The meteorite search

By D. Moreau Barringer

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At the end of the last century it was known that meteorites occasionally fell out of the sky. But only a handful of men believed the larger meteorites left scars on the surface of the earth that could be observed and studied by geological methods. Among these was my father, Daniel Moreau Barringer, whose ideas on this subject have had a great effect on scientific thought. It was partly his persistence, in the face of apathy, opposition, and even ridicule, that brought about acceptance by the scientific community of the meteoritic origin of the great crater in northeastern Arizona that now bears his name.

A visitor approaching the Barringer Meteor Crater on the dry Arizona flatland sees first a gray, truncated hill that resembles a mesa. Made up of over three hundred million tons of rock and earth, the crater's rim rises more than 150 feet above the surrounding plain. The bowl of the crater is nearly a mile across at its largest diameter, and about three miles in circumference. The crater's depth is 570 feet.

For some unknown reason, the earliest discoverers of the crater called it Franklin's Hole. Indians had long been familiar with it; the Hopi tribe gathered finely powdered white silica at the crater and used this "rock flour" at their ceremonies. Around 1870, the crater was known as Coon Butte, although even at this comparatively recent date, few travelers had visited it. It was not until the last decade of the nineteenth century that a scientific investigation was made. Dr. G. K. Gilbert of the U.S. Geological Survey visited the crater and concluded that the hole had been formed by a steam or other gaseous explosion. Gilbert's team collected many meteorites from the site, but explained their presence as a coincidence. Gilbert theorized that meteorites had just happened to arrive at the exact moment of the explosion or perhaps had triggered it.

Shortly after the first investigation of the crater, the Atlantic and Pacific Railroad became interested in it as a possible mine site. Dr. A. E. Foote, a leading geologist, examined the crater for the railroad and confirmed the presence of meteorites. Although neither Foote nor Gilbert reported finding any trace of lava, obsidian, or other volcanic products, the scientific consensus at the end of the century held that "Crater Mountain" in all probability represented the last vestige of a once-active volcano.

In 1902, Daniel Moreau Barringer developed an interest in the crater controversy. My father was a consulting mining engineer and geologist of Philadelphia, then at work in the Southwest. From the beginning, he believed the crater must have been caused by a meteoritic impact. His reasoning was simple. First, the crater was an unexplained hole in the ground; around it, on the same square mile of land, lay thousands, perhaps millions, of iron meteorites—more than had been found in all the rest of the world. Since there are about 57 million square miles of land on the surface of the earth, it seemed to my father that the chances that the hole had been made by meteorites were in the order of 57 million to one. Moreover, results of his excavations showed that the meteoritic fragments were arranged, with respect to the terrestrial rocks with which they were found, in such a way that their arrival had to be simultaneous with the explosion that formed the crater. The odds against a meteorite shower arriving at that spot exactly at the time of a natural disturbance, but not being responsible for it, were so great that it would have been meaningless to have calculated them. Thus my father looked for the buried meteoritic mass and for more evidence to support his theory that the crater had been caused by meteorite impact, a quest that occupied the last thirty years of his life.

Crater Floor Drilled

By the end of 1909, he had drilled 28 holes at the crater and had sunk a number of shafts as well. Although this drilling and digging failed to uncover any large meteorites, the cores revealed that rocks from different strata were mixed together at depths more than a thousand feet below the crater floor. But under that level lay the Supai sandstone in undisturbed layers. The crater, then, could not have been made by a force from below, like a volcano.

In succeeding years, Daniel Moreau Barringer pressed his attempts to uncover meteorites from beneath the floor of the crater. The most significant results came in 1919. The United States Smelting Refining and Mining Exploration Company, following his instructions, set up an eight-inch churn drill near the center of the south rim, directly above the high point of the arched rock strata. At one thousand feet, the drill encountered obstacles that proved to be meteoritic fragments; the final discovery is reported in the log as follows: "The expert drillman says he has drilled in all sorts of formations but has never encountered anything like this. From the saw-toothed appearance of the drill bits, he says we must be passing through streaks of solid metal . . . started reaming at 8:00 A.M. and at 11:00 A.M. had reamed only one foot. At 11:00, rotary operating nicely when bit stuck in bottom of hole and stopped rotary." When efforts to free the bit failed, the hole was abandoned, but the drill had reached a depth of 1,376 feet and many pieces of oxidized meteoritic material containing nickel and platinum had been brought up. The searchers, therefore, assumed that their probe had reached the main meteorite cluster and was halted near the resting place of the greatest meteorite mass. Because of a heavy flow of water, a subsequent shaft could not be sunk much below water level. However, when my father died in 1929, it was with the belief that the approximately 1,300-foot penetration of U.S. Smelting had proved his case. Since his death, of course, the scientific community has agreed on the crater's meteoritic origin.

The science of meteoritics has advanced remarkably since my father's time. If in his day men characterized as fanciful the idea of meteorite scars on earth, today scientists avidly seek out

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D. Moreau Barringer died in 1962. This article is based on a paper he gave to the New Jersey Geological Society, and papers by him and N. S. Gentieu in *Foote Prints*, journal of the Foote Mineral Co., Philadelphia.

craters. Perhaps the first step in recognizing meteorite craters that no longer look like craters was taken by Beals and Millman, the Canadians who investigated two sites in Ontario that have since been accepted as meteorite craters of early Paleozoic Age. In both these sites, known as the Brent and Holleford Craters, the meteorites struck on an ancient Precambrian surface and gouged holes of the typical circular shape. Both craters then underwent extensive erosion that largely obliterated the rims. The craters were also submerged beneath Paleozoic seas that filled their cavities with sediments. Later they were exposed to subaerial erosion as well as to glaciation, and today can be discerned on aerial photographs only as wide and very shallow circular depressions.

The typical underground structure of an impact crater, however, has been impressively established by core drilling at each of these Canadian sites. It is clear that some craters of larger size than the Barringer Crater are filled, first, with a hardened layer of breccia from the fallout of the target rocks; second, by talus from the crater walls; third by subaqueous rocks of much later date.

Since the work on the Brent and Holleford sites, at least half a dozen other areas in the Canadian Precambrian shield have been singled out for similar speculation. These include a six-mile circular bay on the edge of Reindeer Lake, Saskatchewan; two almost tangential circular lakes in Quebec (collectively called Clearwater Lake), each twenty miles or so in diameter; and the lake at the bottom of Chubb Crater on the Ungava Peninsula near Hudson Strait.

Coesite Provides Evidence

Recently, by one of those fortunate coincidences that have often assisted research, a new silica form, called coesite after its discoverer, Loring Coes, Jr., has become a criterion for the recognition of meteorite scars. Coes, a scientist of the Norton Company, found that under a pressure of 20 kilobars or more, ordinary silica assumed a new and considerably denser form with a specific gravity of nearly 3. This density results from a tighter packing of the silicon and oxygen atoms than is found in ordinary forms of SiO_2.

Coesite remained a laboratory curiosity until two investigators working for the United States Geological Survey recognized, in samples of crushed sandstone from the Barringer Crater, the typical X-ray diffraction pattern of coesite. It has since been determined that an appreciable percentage of the crushed and altered sandstone that partially fills the Barringer Crater is coesite. Outside the laboratory, no known crustal process, including volcanic eruptions and nuclear explosions, produces pressures in the range of 20,000 atmospheres. The discoverers of coesite in the crater therefore reasoned that only the impact of a great meteorite could naturally develop such pressures on the surface of the earth. Subsequently, Stishov, in Russia, discovered an even denser form of silica (now called stishovite), with a specific gravity of about 4.5. It was reported to form under a pressure of 160 kilobars (later, I believe, revised to 120 kilobars). This is roughly eight times as great as the force required to produce coesite. Stishovite has been identified in very small quantities in material from the Barringer Crater. Coesite and/or stishovite also have been found in other craters, including a twenty-mile circular valley in Germany called the Rieskessel, and a lake area in Ashanti Province, Ghana.

It is now thought by some that South Africa's Vredefort Ring, a circular outcropping of sedimentary rocks fifty miles in diameter, is of meteoritic origin. Here it would appear that the removal of a large mass of crust caused by the impact of such a gigantic meteorite allowed the liquefaction and intrusion of a quantity of deep-seated sial rock. The lower part of this solidified into granite; the upper part may have been a finer-grained intrusive or extrusive rock that erosion has since removed. The rim is also gone. Only the "roots" of the crater are left—a circular area of granite surrounded by radially dipping sedimentaries.

Other developments have also far surpassed the techniques used in my father's day. Dr. Robert Dietz, of the U. S. Navy Electronics Laboratory, has studied structures named shatter cones. Shatter cones have been identified in sandstone, limestone, and certain igneous rocks, but apparently also occur in any other rock of sufficient cohesion. A fractured surface of such a rock exhibits a series of intergrown and overlapping conical structures, with apices all pointing one way, and sides outlined by minor faulting. Shatter cones probably result from the violent shock wave accompanied by tremendous momentary pressure that radiates from a center of meteoritic impact. They would naturally be expected to occur below the crater formed by such an impact, and hence are not likely to be accessible unless the site has eroded to a great depth. But geologists have found shatter cones in connection with at least six formations—in Tennessee, Indiana, and Texas—hitherto called cryptovolcanic. Shatter cones have also been observed at the Steinheim Basin and the Rieskessel in Germany and the Vredefort Ring in South Africa. Only one doubtful specimen has been found at the Barringer Crater, which may be because erosion has not yet exposed the rocks that lay below the center of impact of that collision.

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At its largest diameter, the 570-foot-deep crater is nearly a mile across. The bowl's circumference is three miles. The pressure required for the conversion of quartz to coesite, or the intense shock wave that can create shatter cones. Similarly, it would seem that infalling meteorites cannot be smaller than a certain minimum size if they are to produce these effects. For instance, the Arizona meteorite, which made a hole four thousand feet in diameter, was capable of producing coesite, but a meteorite that fell at Odessa, Texas, and made a hole about five hundred feet in diameter, seems to have been too small.

Lost and Found Meteorites

There is another very large unanswered question with regard to meteorite impacts—what has become of the meteorite? The opinion is widespread that any meteorite above a certain critical size retains a large fraction of its original velocity when it strikes the ground; therefore the conversion of this tremendous energy is sufficient to vaporize both the projectile and part of the target. The impact may spread the resulting vapor, which eventually resolidifies, over such a wide area that finding the original meteorite would be impossible. This explanation has been given for the failure so far clearly to define the mass that made the Barringer Crater, and for the unsuccessful effort to locate the mass under the main Odessa crater.

Yet this theory runs into some remarkable contradictions. Alongside the main crater at Odessa, Texas, a smaller crater, some 75 feet in diameter, was discovered by magnetometric survey. It was completely excavated. From its center, a compact mass of about six tons of nickel-iron oxide was recovered. Moreover, Peary's 34-ton meteorite from Greenland (now in The American Museum-Hayden Planetarium), or the 85-ton Hoba meteorite in southwestern Africa obviously did not volatilize; they are now here on the earth in recognizable form.

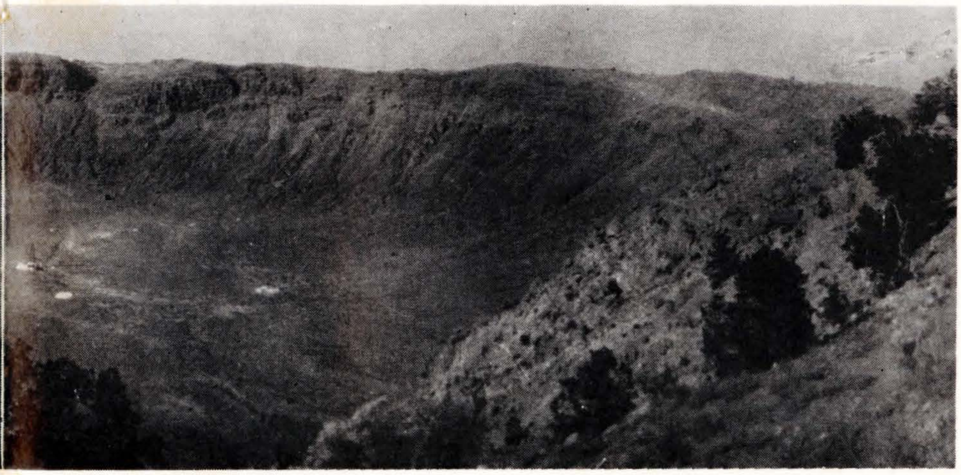
Then too, we are faced with the fact that around the Barringer Crater have been found many thousands of solid iron meteorites that are probably pretty much unaltered from their form in outer space. Some of them may show a fusion crust on the outside, and most display the so-called Widmanstätten figures. This crystalline structure, first noted in 1808 by Alois von Widmanstätten of Vienna, appears when a polished surface of meteoritic iron has been etched. It has been demonstrated that the structure is destroyed by moderate temperatures of 1,000° F. or less. Clearly, the solid iron chunks around the Barringer Crater did not get heated to anywhere near volatilization temperature.

Another important difficulty in the way of the explosion hypothesis is posed by the structure of the rim of the Barringer Crater. If the major crater-forming force was that of an atomizing explosion, its effect should be accurately symmetrical about a central point. An explosion would act equally in all directions and would far surpass the excavating effect of the motion of the meteorite itself. Yet the symmetry of the crater is not radial around a point, but is on either side of a line forming a north-south diameter. This structure is so clearly determined that the question of its origin must be answered before one can accept the thesis that the entire crater-forming effect was due to an explosion. Furthermore, the concentration of meteoritic material deep below the southern and southwestern portions of the crater floor must be explained. The questions surrounding this subject can only be resolved by thorough underground exploration of one or more big craters, a task that would involve an amount of money not so far available.

The most recent crater-forming meteorite fell on the Soviet Union, in the easternmost province of Siberia, in 1947. This meteorite either broke into a great many pieces in the atmosphere, or consisted originally of a cluster of small fragments. It gave rise to some 120 craters spread over a small area, the largest of them about 20 yards in diameter. The shower sprinkled the ground in between with thousands of iron fragments that apparently struck at a very moderate rate of speed. Although many of them showed signs of fusion and deformation in the atmosphere, they retained neither enough heat nor speed to char the wood of the trees they struck. Some were even found imbedded in standing tree trunks, with no sign of heat effect on the wood.

Can we forecast another dramatic fall like the recent Siberian one? Although the supply of large meteorites in the solar system may have been reduced radically over the earth's life span, I certainly think we can expect more large meteorites to drop in the future. Time and place, however, are completely unpredictable. And because two-thirds of the earth's surface is covered with water, a new meteorite is more likely than not to land in the ocean and leave no traces.

In discussing the Barringer Crater and related topics, I have not, of course, been able to mention all the advances in meteoritics that have come about since my father's early contribution, nor have I touched upon some fascinating subjects, such as tektites—the small lumps of siliceous glass thought of by some as spray or splash resulting from meteoritic impacts. But one of the most interesting historical facets of the science of meteorites is the Barringer Crater itself. To the crater come an increasing number of visitors. They inspect the museum on the northern rim, observe the crater bowl through the panoramic picture window, and the more ambitious of these meteoritic amateurs often hike the three miles around the crater's rim. Many descend to the bottom of the hole where Daniel Moreau Barringer began his lifelong exploration for the lost meteorite—where crater and impact research began, and the modern science of meteoritics took a valuable, exciting step forward.



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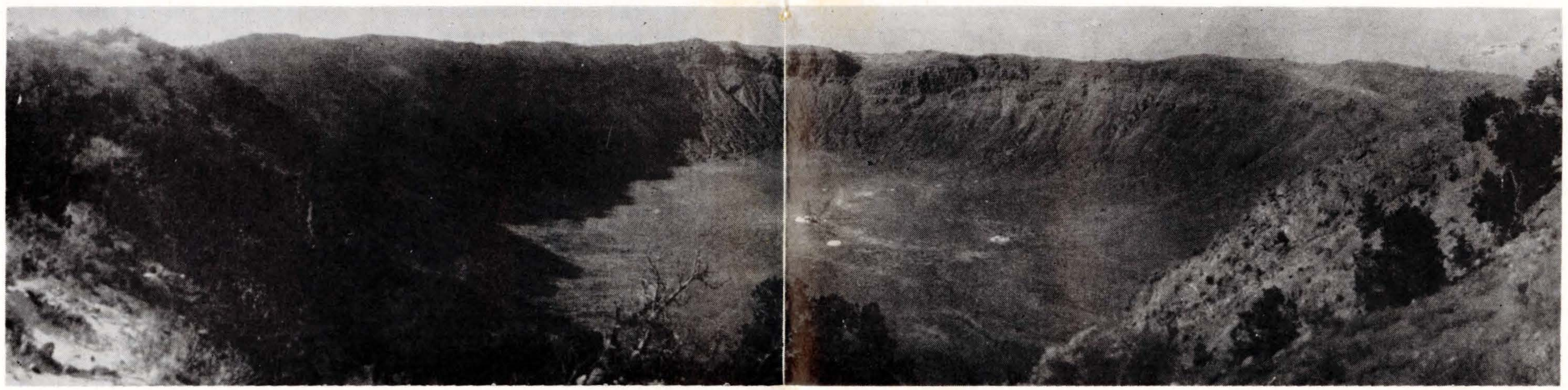

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