METEOR CRATER, ARIZONA

by

CLYDE FISHER

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GUIDE LEAFLET SERIES, No. 92

The American Museum of Natural History

New York, New York

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AMERICAN MUSEUM OF NATURAL HISTORY

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THE METEOR SHOWER OF 1833.

An old wood-cut from Grondell's "*Music of the Spheres*" illustrating the Leonid shower of November 13, 1833, the greatest phenomenon of the kind on record. Compared to a fall of snowflakes. (See cut at top of page 13.)

Meteor Crater, Arizona

Where a huge, dense mass of iron meteorites struck the earth, probably 50,000 years ago, the impact of which crushed and dislodged some 300,000,000 tons of rock

By Clyde Fisher,

Curator of Astronomy and of the Hayden Planetarium, American Museum of Natural History

A METEOR shower is one of the most impressive phenomena in the whole realm of nature. Its sudden appearance, together with the suggestion of falling or shooting stars, excites wonder and fear, especially in untutored and primitive minds. Various tribes of American Indians used the November shower of 1833, the greatest meteor shower on record,—"the rain of stars,"—as a milestone in their calendars.

While showers or swarms of meteors are comparatively infrequent, the adventitious or occasional meteors are extremely common. It is estimated that about 20,000,000 meteors enter the earth's atmosphere every twenty-four hours. Most of these are exceedingly small, weighing perhaps only a few grains each. When we recall that there are 7,000 grains in a pound, Avoirdupois, we realize how tiny these meteors must be. Practically all of the meteors that penetrate the earth's atmosphere, day after day, are burned up due to the heat generated by friction with the air, and consequently do not reach the earth.

Few fall to the earth

Occasionally, of course, one comes clear through to the earth, and, if found, it is called arbitrarily a "meteorite", the name "meteor" usually being reserved for those which enter the earth's atmosphere, but which do not come through to the earth. Nearly 1,000 falls of meteorites are known, of which more than 550 are represented in the collections of the American Museum of Natural History.

Half the falls observed

Although nearly 500 falls of meteorites have actually been observed, the phenomenon still attracts much attention,—and well it might, for these are the only direct messengers from space that come to the earth, the only heavenly bodies besides the earth that we can actually touch. A recent fall to be observed was that of July 1, 1933, when two masses of stony meteorite were seen to fall near Spartanburg, South Carolina, one weighing about twelve pounds and the other about half as much. This fall occurred in the daytime, and was observed by several persons.

During the last few years it seems that more than the usual number of large meteors, sometimes called fire-balls or bolides, have been observed. On March 24, 1933, a gigantic meteor flashed across five southwestern states. An airmail pilot flying near Amarillo, Texas, declared that it looked as big as the hangar at the Wichita Airport. Some most unusual and striking photographs of the train left by this fire-ball were secured at Timpas, Colorado, by Mr. C. R. West. In northeastern New Mexico Mr. Charles M. Brown succeeded in photographing the meteor, which showed a cork-screw train at the moment,—securing an absolutely unique photograph. Professor H. H. Nininger succeeded in locating a number of pieces of this fall in northeastern New Mexico, along a line twenty-nine miles long, for which success he deserves much credit. It proved to be a stone meteorite or rather a group of meteorites, one specimen of which, picked up near Pasamonte, New Mexico, was shown to me by Professor Nininger. On September 27, 1934, another huge meteor was observed in California by an airplane pilot who thought it necessary to swerve his plane to keep from colliding with it.

In this case no meteoric material constituting a fall has been located. On March 14, 1936, a brilliant fire-ball swept over a half-dozen northeastern states, and although a number of supposed fragments of this meteor have been picked up, none has yet proved to be a real meteorite.

Most great falls prehistoric

The greatest falls of meteoric material known on the face of the earth were not observed. In fact, with the exception of the Siberian fall of June 30, 1908, all of these occurred without much doubt in prehistoric times. The first crater, the cause of which was determined to be due to the impact of a meteorite or mass of meteorites, was Meteor Crater in Arizona. It was not until the early years of this century that the theory that this crater was caused by the impact of meteoric or cometary material was set forth by Mr. Daniel Moreau Barringer, geologist and mining engineer of Philadelphia, and to him must be given the credit for convincing scientists of the truth of his theory.

Meteor Crater is best seen from the air, and consequently the most satisfactory photographs have been made from an airplane. A huge circular crater, nearly a mile in diameter and nearly six hundred feet deep, with a conspicuous elevated rim, formed in solid limestone and sandstone, constitutes an impressive challenge to one's innate desire to understand the causes of things. Svante Arrhenius, the great Swedish scientist, author of the electrolytic theory of matter, is said to have declared that Meteor Crater is the most interesting spot on Earth.

Located in Coconino County, in north-central Arizona, about twenty miles west of Winslow and thirty-five miles east of Flagstaff, the crater is easily reached by the Santa Fé Railroad or by U. S. Highway 66.

First seen by white men some sixty years ago, although doubtless known to the Indians long before, it was formerly known as Coon Butte or Coon Mountain, the latter part of the name referring to the elevated rim.

Dr. Charles R. Toothaker, Curator of the Philadelphia Commercial Museum, who had much to do with the Meteor Crater iron in the early days, writes me as follows:

"It appears that in 1886 some shepherds were in the neighborhood of Cañon Diablo, Arizona, and one of them named Mathias Armijo found a piece of this iron and thought it was silver. Some time later, a man staked a claim and put the samples in the hands of a chemical firm named M. B. Booth & Co., in Albuquerque, New Mexico, in March 1891.

"Dr. A. E. Foote of Philadelphia was at that time a dealer in mineral specimens and I was employed by him. I remember when the first news of this matter reached Dr. Foote. He went to Cañon Diablo at once and sent back a piece of the iron which was immediately put in the hands of Professor G. A. Koenig, Professor of Chemistry in the University of Pennsylvania. Koenig analyzed it and discovered diamonds in this iron."

Crater at first misunderstood

This crater was at first explained by the scientists of the U. S. Geological Survey as the result of a steam explosion. Because of the absence of lava and other evidence of volcanism, no scientists have believed it to be a volcanic crater. One writer advanced the theory that it was a limestone-sink. But the credit for the conception and establishment of the theory that is now well-nigh universally accepted goes to Mr. Barringer,—and a magnificent conception it was. He set forth the idea that this crater was the result of the impact of a huge, dense mass of iron meteorites, possibly the head of a small comet, and this theory has now come to be held by nearly all geologists, physicists and astronomers.

This meteoric mass penetrated 40 to 50 feet of purplish-red sandstone (Moencopie Formation —Triassic), which lies next below the thin soil of the surrounding plain; then crashed through some 300 feet of Kaibab Limestone (Permian Age), the same rock that outcrops in the Grand Canyon of the Colorado in northwestern Arizona, and that caps the eroded pinnacles in Bryce Canyon in Utah; then it plowed into the Coconino Sandstone (Permian Age), which underlies the Kaibab Limestone, shattering this stratum to a depth of some 600 feet, or practically to the Supai Sandstone or "Red Beds" (Permian) underneath.

The meteoric origin of the Crater is suggested by the occurrence of literally thousands of pieces of meteoric iron around the crater.

These fragments were found as far as four or five miles from the crater on all sides, but the nearer the Crater, the more numerous they were. In other words, Meteor Crater is about in the exact center of an area from which have been collected many more specimens of meteoric iron than have ever been found on all of the rest of the earth's surface.

The larger specimens

The largest piece of which I have knowledge is in the Colorado Museum of Natural History in Denver, and it weighs 1,406 pounds. For this information I am indebted to Professor H. H. Nininger, Curator of Meteorites in that Museum. The second-largest piece is in the American Museum of Natural History and weighs 1055 pounds (re-weighed in 1935 upon removal into the Hayden Planetarium). The third-largest piece, now in the Field Museum of Natural History, weighs 1,013 pounds, according to the late Professor O. C. Farrington, Curator of Geology in that Museum. The fourth-largest piece of which I have knowledge is in the Smithsonian Institution collection in charge of Mr. E. P. Henderson, Assistant Curator of Physical Geology. It is labeled and recorded as weighing 1,000 pounds. Mr. Henderson informs me that they also have in their collection another piece weighing 960 pounds and still another weighing 746 pounds, besides a great many others of lesser weight. Another large piece is located near the front door of the Fred Harvey Indian Building in Albuquerque, New Mexico, which, according to Mr. H. Schweizer, weighs 625 pounds. It is estimated that between ten and fifteen tons of meteoric iron have been shipped away from Meteor Crater, all of which has been collected within about five miles of the crater, most of it in the immediate vicinity.

Meteorites have been known to burst in the air just before striking the earth, but very few, if any, of the individual pieces of Meteor Crater iron, whether large or small, show evidence of the bursting in air of an enormous meteorite. For this reason it is believed that the crater was formed by a huge meteorite accompanied by thousands of small ones, or more probably by a huge, dense mass of comparatively small, iron meteorites.

Composition

The meteoric iron from the vicinity of Meteor Crater, known as Canyon Diablo iron, named from a gorge located about three miles to the westward, is remarkable in its composition, for it contains 91 to 92 per cent of iron, some 7 per cent of nickel (common in meteoric iron), traces of cobalt (also common in meteoric iron), silicon, sulphur, phosphorus, carbon, iridium, and platinum, as well as traces of a few other elements. Troilite, a sulphide of iron, found only in meteorites, occurs. Silicon carbide (moissanite) occurs in this iron, and for a time was not known to occur elsewhere in nature. Silicon carbide is manufactured under the trade name of "Carborundum," at Niagara Falls, New York. It is next to diamond in hardness, with the exception of boron carbide. Probably correlated with the silicon carbide is the occurrence of diamonds, all extremely small. As stated in Dr. Toothaker's letter quoted above, Dr. G. A. Koenig, Professor of Chemistry in the University of Pennsylvania, was the first to isolate diamonds from this meteoric iron, and this was in 1891. These diamonds were very small, one mentioned in the report having a diameter of one-half millimeter. The material analyzed was from a forty-pound meteorite brought from Meteor Crater by Dr. A. E. Foote of Philadelphia, who, in this same year, was the first to bring this crater prominently before the scientific world. Later five diamonds were secured from this iron by Dr. J. W. Mallet, F.R.S., Professor of Chemistry, University of Virginia. It was thought that the platinum, along with the nickel, would promise a profitable commercial enterprise. In fact, it was this idea that prompted the mining ventures and the explorations which have given us so much interesting information. Considering its composition, it is not surprising to know that the late Dr. George P. Merrill, Head Curator of Geology in the U. S. National Museum, and one of the leading authorities on Meteorites, stated that Canyon Diablo iron is one of the hardest and toughest of all known meteoric irons.

Widmannstättian lines

When polished and etched with nitric acid, the Canyon Diablo iron shows definite and

Photograph from Yerkes Observatory

Craters of the Moon

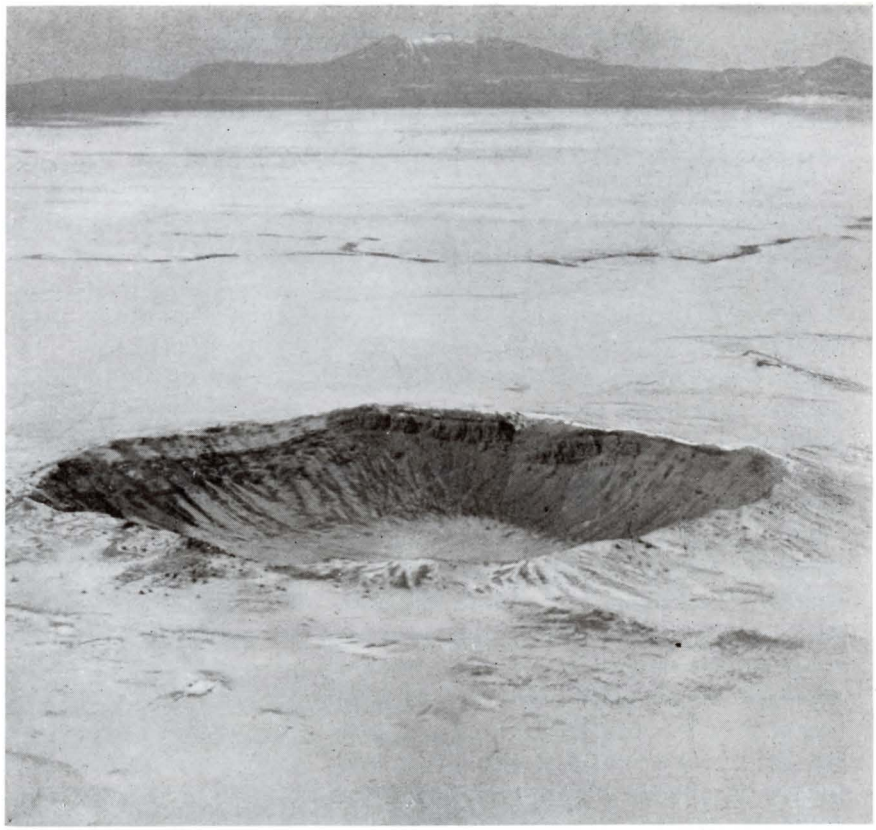
Above: The moon at gibbous phase between first quarter and full, showing many of the 30,000 craters on the side which is always turned toward the earth. The similarity of these lunar craters to Meteor Crater in Arizona is evident

Below: The elevated rim of Meteor Crater from a distance of two or three miles. It varies in height from 130 to 160 feet

Photograph by Clyde Fisher

Photograph by Clyde Fisher

Right: Meteor Crater, blanketed with snow, as seen from a plane; San Francisco Peaks, from forty to fifty miles distant, are shown in the background; Canyon Diablo, about three miles to the westward, may be seen in the middle ground



Meteor Crater

Below:
Meteor Crater from a plane on an early summer morning. The automobile road connecting U. S. Highway 66 with the north rim shows in the lower right-hand corner

Photograph by Clyde Fisher

pronounced Widmannstättian figures. These are the geometrical markings on the polished surface which are caused by internal crystallization. In this form they are found only in meteorites.

Besides the unoxidized meteoric iron, there have been found at the Crater many so-called "shale-balls", which are generally rounded or globular masses of disintegrating meteoric iron and nickel oxide, many of them containing solid nickel-iron centers. The late Professor O. C. Farrington, who was certainly one of the greatest students of meteorites, believed the shale-balls to be the result of terrestrial oxidation, and not that oxidation occurring when passing through the air.

More than one hundred shale-balls have been found, the heaviest weighing more than forty pounds. Some contain microscopic diamonds. Besides the typical shale-balls there are in and about the crater great quantities of oxidized iron-shale, which without much doubt came from shale-balls. This gives a suggestion as to the fate of some of the Meteor Crater iron. That most of these irons are the residuals of shale-balls, was the confident opinion of Mr. D. M. Barringer, who pointed out that the rounded shape of the latter was probably due to the gentle abrasive action of the members of the cluster during their years of journeying through space.

In determining the origin of the crater, the composition of the elevated rim is significant. This rim, which is 130 to 160 feet higher than the surrounding plain, and one and one-half miles in outside diameter, can easily be seen from more than ten miles away. It is made up largely of boulders and smaller fragments of Kaibab limestone and Coconino sandstone. Some huge boulders were ejected from the crater and thrown over the rim to the distance of a mile or more. It is true, of course, that the ejected boulders occur more abundantly as one approaches the crater.

Much of the Coconino sandstone has been reduced to a fine rock-flour, so fine that it requires a microscope to show that it consists of shattered or pulverized sand-grains. This rock-flour or "star-dust," as it has been called, composes a great part of the rim, nearly three miles in circumference, and it has also been found 850 feet deep in the crater. There are literally millions of tons of this fine powder, white as snow. It is estimated that it constitutes 15 to 20 per cent of all material thrown out by the impact.

Of all the evidence that Meteor Crater was caused by impact, perhaps the most convincing to geologists is the fact that some of the Coconino sandstone was changed into a vesicular, metamorphosed rock, looking not unlike pumice stone and very light. In fact the quartz has been fused and is now amorphous and not crystalline. This silica-glass or fused quartz has been named by the mineralogists "Le Chatelierite."

Exploded theories

The limestone-sink theory could not explain the elevated rim made up of boulders, fragments and rock-flour. It could not explain the presence of rock-flour and fused quartz at all. It could not explain the presence, in the rim, of Coconino sandstone boulders which came from a stratum that underlies the Kaibab limestone.

A steam blow-out theory might account for the rock-flour, although this seems to the writer extremely doubtful, but it seems certain that no scientist would maintain that it is competent to account for the silica-glass or Le Chatelierite. Dr. George P. Merrill states that there is no record of a sudden outburst of volcanic action wherein the heat generated was sufficient to fuse crystalline quartz. The steam blow-out theory is further weakened by the fact that there are no igneous or eruptive rocks in or around the Crater or in the neighborhood, and by the fact that there is no evidence of solfataric activity, and by the finding of unaltered sandstone (Supai) in place in the bottom of the crater in its proper stratigraphical position, shown by the cores of numerous drill-holes sunk in the floor of the crater.

Probability

The fact that the crater is in the center of a meteor fall, would be looked upon as a coincidence by the advocates of both the limestone-sink theory and the steam blow-out theory. But the finding of meteoric material mixed with the ejected rock, and underneath the lake deposits in the bottom of the crater, and

Photograph by Clyde Fisher

Right:

Meteor Crater in Arizona, located about twenty miles west of Winslow and thirty-five miles east of Flagstaff, photographed from a plane in winter, when snow covered the landscape, including the bottom of the crater

Photograph by Ruth Anna Fisher

Left: Clyde Fisher with Jack Irish, the pilot on his first flight over Meteor Crater

Below: Clyde Fisher surveying the Crater from the north rim. Note the sizable buildings of the mining company on the crater floor

Photograph by Clyde Fishe

even 500 or 600 feet below the crater floor, indicates that the meteor fall occurred at the same time that the crater was formed, that is, that the excavated material and the meteorites got there at the same time. The probability that these two unusual phenomena occurred at the same time and at the same place is infinitesimal.

The question that naturally arises is how large a mass of meteoric iron would be necessary to produce the result,—to plow into solid rock and form a crater about four-fifths of a mile in diameter and nearly 600 feet deep!

It has been variously estimated that the mass of meteoric iron weighed from 100,000 tons to as much as 10,000,000 tons, that it was several hundred feet in diameter if the larger estimates are correct, and that it was moving from seven to forty miles a second.

The amount of rock dislodged and partly thrown out of the crater has been estimated at over 300,000,000 tons. The true crater is filled to one-half its depth with rock fragments which rolled or fell back.

On the bottom of Meteor Crater there are now 70 to 90 feet of lacustrine or lake sediments formed when this was a small lake. In these deposits many fossil shells were found, which were identified by Dr. William H. Dall, Curator, Division of Mollusks, U. S. National Museum, as "all recent species local to the region of southwestern United States."

While it is now true that practically all astronomers, physicists and geologists agree that this crater was caused by the impact of a huge mass of meteoric iron, the testimony of a few of the leading scientists in these fields, given before such unanimity of opinion had been reached, would not be out of place. Following are verbatim statements from a few:

Dr. Elihu Thomson, Director of the Thomson Laboratory of the General Electric Company,—"There can be no question of the Crater being made by masses of meteoric iron, and that an enormous mass of such iron remains buried under the south wall of the Crater."

Dr. W. F. Magie, former head of the Palmer Physical Laboratory, and Dean of the Faculty of Princeton University, who spent two weeks at the Crater making careful studies;—"There is no reasonable doubt that the Crater was formed by the fall of a meteor and this meteor is buried in it."

Dr. Henry Norris Russell, Head of the Department of Astronomy, Princeton University,—"I have examined the Crater on the ground, as well as the other evidence, and I am thoroughly convinced of its meteoric origin."

Position of meteorite

If this crater was formed by impact, where is the main mass of the meteoric iron? Mr. Barringer and his associates first attempted to answer this question by drilling some twenty-five holes in the floor of the crater. These holes were drilled in the bottom of the crater because it was then believed that the nearly circular shape of the crater indicated that the meteorite had descended vertically or nearly so. No large piece of meteoric material was ever struck in these holes. Mr. Barringer's son, Daniel Moreau Barringer, Jr., tells us how his father was accidentally led to the discovery that the fall of this meteorite was not vertical, but at an angle. The son writes as follows: "Largely by accident, my father observed one day that by firing a rifle into mud he could make an excellent replica of the Crater, and, moreover, that the rifle need not be fired vertically downward, but might be held even less than 45 degrees from the horizontal. Naturally one would suppose that a shot at such an angle would make an elongated hole. But it will not. The hole will be just as round as though the shot had come straight down, although the projectile will lodge under one edge of the hole instead of in the center. A charge of shot fired from a shotgun at close range will produce the same effect." This observation led the elder Mr. Barringer to make a closer examination of the crater, the results of which indicated with great certainty that the mass had come from the north at a comparatively low angle.

Thereupon a drill-hole some 1400 feet deep was sunk on the south rim. Beginning at a depth of 1000 feet, a series of hard bodies carrying nickel, and clearly meteoric in origin, were struck. Of this boring, Mr. Barringer reported, "Eventually this hole (the last boring sunk through the south rim, it having been determined that the mass approached from the

north at an angle of approximately 45°) encountered what is beyond doubt the upper part of the buried cluster of iron meteorites, finding it exactly in the predicted position." It is significant that geophysical investigations, both magnetic and electrical, as well as the geological evidence, all pointed to a large mass of meteoric iron under the southern rim; and two recent drill-holes in the southwestern part of the bowl about 1000 feet from the previous drill-hole on the rim, have also encountered numerous meteorites.

Volatilization ?

It has been suggested that the energy of onward motion, when the meteoric body was suddenly stopped, would have been transformed into sufficient heat to vaporize all or part of the main body. Mr. Barringer believed, however, that due largely to being checked by the air, the meteoric body struck at too low a velocity to have been vaporized. The absence of stains, such as would be caused by the vapor which would have been formed by volatilization of the iron, he believed, strongly supported this view.

Dr. F. R. Moulton, formerly Professor of Astronomy in the University of Chicago, co-author of the Planetesimal Hypothesis, and leading student of celestial mechanics, arrived at the following conclusions:

"My interpretation of the probable event is roughly as follows: The dense part of the swarm was something like 2,000 feet in diameter and its mass was from 100,000 to 500,000 tons. It crashed into the rock to a depth of something like 800 to 1000 feet, carrying with it a large mass of greatly condensed (and consequently heated) air, which was further condensed on penetrating the rock. Ejected rock was thrown out not only by the condensed air and the steam generated, but also by volatilization of a considerable amount of the meteor and rock materials with which it came in contact."

Explosion ?

Dr. Moulton discusses the fate of meteors of various masses in his ASTRONOMY (1931), closing with the following sentences: "But a meteorite weighing thousands of tons would not be greatly retarded by the air and would strike the surface at a high velocity. At a speed of 20 kilometers per second the resistance of surface soil or rock, due to its inertia alone, would amount to 32×10^9 grams per square centimeter; at 14 kilometers per second the resistance would be about half as great. Either of these pressures would be sufficiently great to cause the material of the meteorite to flow as though it were a gas. The energy given up in a tenth of a second would be sufficient to vaporize both the meteorite and the material it encountered—there would be in effect a violent explosion that would produce a circular crater, regardless of the direction of impact, which alone would remain as evidence of the event." The recent studies of Professor C. C. Wylie, of the University of Iowa, on the explosive effects of high-speed bullets upon striking a target evidently support the conclusions of Dr. Moulton. The stubborn reply to these theoretical conclusions, however, is the fact that thousands of meteorites of the original mass, several of which are mentioned on pages 4 and 5, *did remain* about the crater.

An inevitable question arises: What is the age of Meteor Crater? It is certainly young, geologically speaking. The sharp angles of the boulders and smaller fragments in the rim and talus indicate that. A Juniper tree growing on the south rim is said to put it back at least 700 years, because it had that number of annual rings. The presence of lapilli and volcanic ash found in the lake deposits in the bottom of the crater correlate it with the last volcanic eruptions in the nearby mountains of Arizona. These, together with other evidences of the lake deposits, etc. point to a probable age of 40,000 to 75,000 years,—a conclusion arrived at by Dr. Eliot Blackwelder, Professor of Geology in Stanford University, who has made careful studies on two visits to the crater.

Craters of the moon

A comparison of Meteor Crater with the craters on the moon has led some scientists to believe that the latter were also caused by impact. While it is probably true that the majority of astronomers accept the volcanic theory of the origin of the moon's craters, there is much evidence in favor of the impact theory.

The difference in opinion among scientists

Above: THE HOBA METEORITE. The largest known meteorite, located near Grootfontein, S. W. Africa, estimated to weigh from 50 to 70 tons. The second person from the left is Dr. L. J. Spencer, who has charge of the meteorites in the British Museum of Natural History.

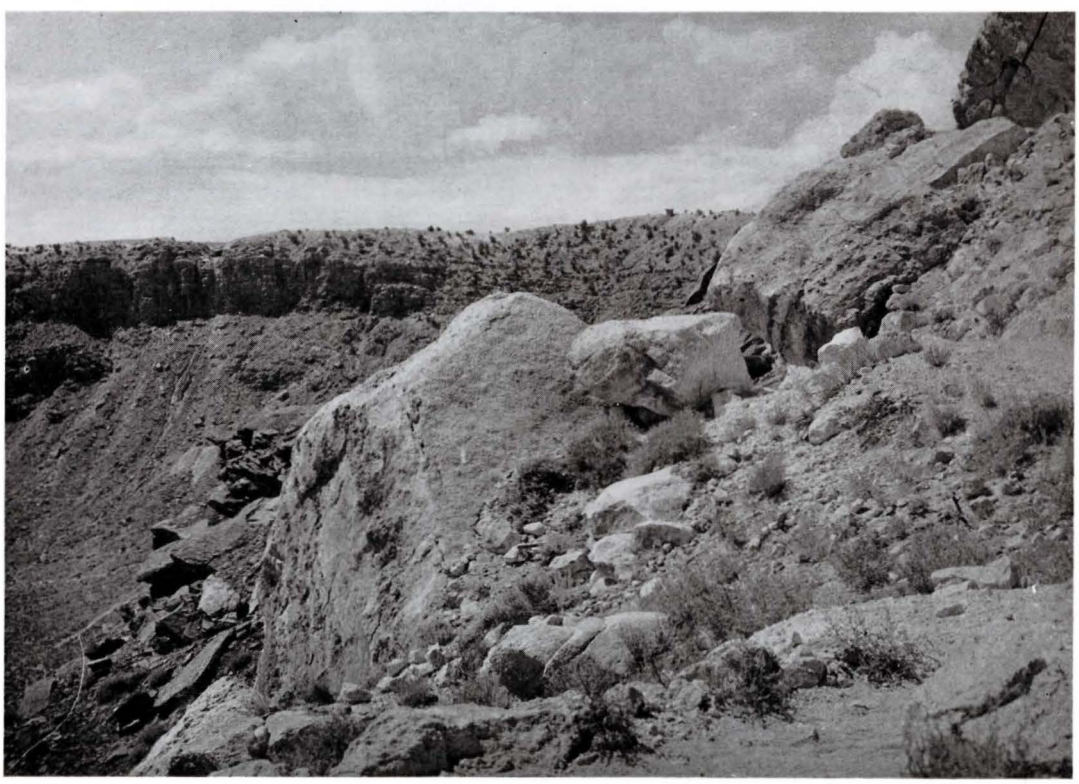
Below: THE AHNIGHITO METEORITE. The Ahnighito, weighing 36½ tons, the largest meteorite in any museum, brought from Greenland in 1897 by Peary. Three other large iron meteorites, pretty surely of the same fall as the Ahnighito, were found nearby. Pieces of one of these had been laboriously hammered off by the Eskimos for knives.

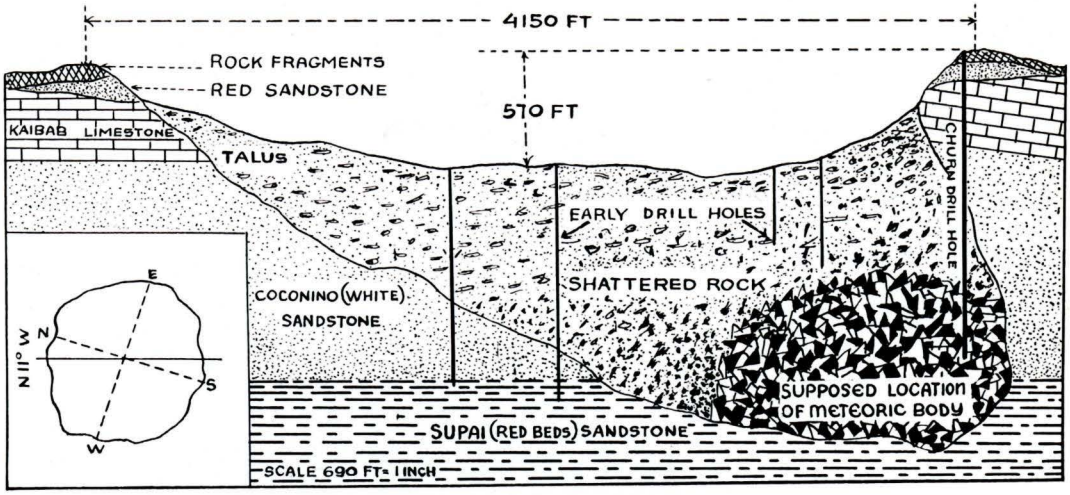
From Tenth Annual Report of the Bureau of Ethnology.

Above: SIOUX CALENDAR SHOWING METEOR SHOWER. The Winter Count of Lone Dog, a Sioux warrior, showing the Leonid meteor shower of November, 1833,—when "the stars fell", as the Indians all agreed. The record is in the middle of second coil of the spiral from the bottom. In the original, in the Smithsonian Institution the crescent moon is black and the meteors are red. (See cut on page 2.)

Below: BOULDERS IN THE WALL OF METEOR CRATER. Portion of the wall of the crater showing some of the larger boulders left as a result of the impact.

Photograph by Clyde Fisher





can well be illustrated by the fact that the authors of the Planetesimal Hypothesis of the origin of the Solar System disagree. Professor T. C. Chamberlin was definitely opposed to the impact theory for the origin of the lunar craters, while Professor F. R. Moulton says that these craters may have been caused by the impact of planetesimals.

Some of the difficulties with the volcanic theory are as follows: volcanic craters on the earth are far less numerous than the craters on the moon, and yet the former belong to several types, while nearly all of those on the moon show great similarity, none on the earth being like the typical craters on the moon.

There are 30,000 craters on this side of the moon, and yet not a single lava-flow can be seen. There are no fissures on the moon from which lava has flowed.

As pointed out by Mr. D. M. Barringer, in his thorough-going work on this subject, there is not a single conical mountain peak on the moon which is similar to Fuji, Aetna, Vesuvius, Orizaba and other volcanoes of this type, made by the effusion of lava from a central vent and the building up of the mountain mass higher and higher as it flows down the sides.

Volcanic craters on the earth do not have central conical hills like those in so many of the lunar craters.

Finally the fact that the moon is not large enough ever to have held an atmosphere indicates that it could never have had enough water or oxygen to cause either the types of volcanic craters found on the earth or the far more abundant craters on the moon. Scientists who have studied volcanism hardly need to assure us, as they unanimously do, that there can be no volcanic phenomena in the absence of water and oxygen.

On the other hand, the impact theory, set forth by Richard A. Proctor in his book entitled "The Moon," has other facts in its favor.

The floors of the craters on the moon, as Mr. Barringer has stated, are usually far below the surrounding surface, as is true in Meteor Crater in Arizona, whereas the floor of a terrestrial volcanic crater is usually above the original surface surrounding the volcano.

The only explanation that has come to the writer's knowledge for the formation of the rift through the lunar Alps is that it may have been caused by a huge meteorite or planetesimal which struck the moon tangentially.

The central peaks

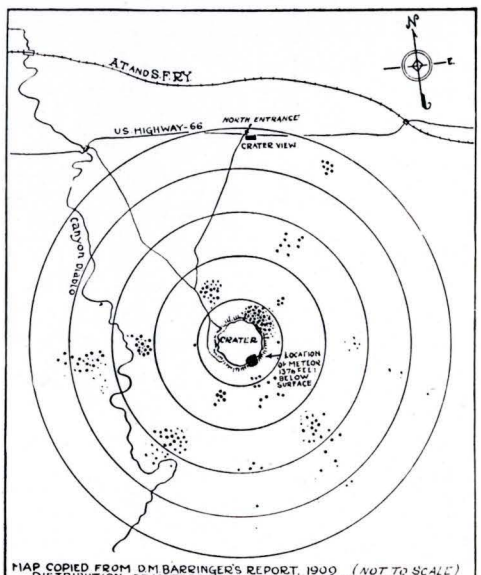
The central conical hills furnish strong evidence of the impact theory of the origin of the craters on the moon, as a study of splashes has shown. This is made clear by high-speed motion pictures of drops of liquids or, of small solid bodies, falling into liquids at rest. It is also shown by miniature craters produced by shooting bullets, or charges of shot from a shotgun at close range, into mud or other plastic media. At first, the circular shape of the craters on the moon did not seem to fit in with

this theory, but experiment has shown that the craters would be circular even when the projectile arrives at a rather low angle.

The impact theory would explain the light-colored streaks which radiate from the craters Copernicus, Tycho, and others, in that they are probably made of rock-flour produced in exactly the same way as that at Meteor Crater in Arizona, and splashed out at the time of the impact. The great length of these streaks on the moon, and also the large size of the lunar craters are probably correlated with the small surface gravity on the moon, which is about one-sixth that on the earth, and with the absence of atmosphere on the moon.

The fact that there are so few impact craters on the earth as compared with those on the moon,—assuming that those on the moon were caused by impact,—is probably due to erosion. Water erosion, wind erosion, freezing and thawing, etc., have been active on the earth for millions of years, while on the moon, since there is no water and no air, there has been no erosion, except that very slight effect caused by the impact of meteors in the absence of the cushion of air, as pointed out in his book entitled "Meteors" (p. 254), by Dr. Charles P. Olivier, Professor of Astronomy in the University of Pennsylvania and President of the American Meteor Society.

Until recently it was believed that Meteor Crater was the only one of its kind on the face of the earth, while there are 30,000 on the side of the moon turned toward the earth. But more and more are being identified on the earth. The meteorite craters so far studied are distributed as follows: one near Winslow, Arizona; one near Odessa, Texas, identified as a meteor crater by Mr. Daniel Moreau Barringer, Jr.; one near Haviland, Kiowa County, Kansas, identified as a meteor crater by Professor H. H. Nininger; a group of some thirteen near Henbury in Central Australia; a group of six craters on the Baltic island of Saaremaa (Oesel) belonging to Estonia, which the writer had the opportunity of visiting in the summer of 1936, identified as meteor craters by Mr. I. Reinvald in 1927; the Wabar craters in Arabia; the Siberian craters; a doubtful one at Ashanti, in West Africa; a very doubtful group near the coast of South Carolina; a supposed crater in Persian Baluchistan; and the



MAP SHOWING DISTRIBUTION OF METEORIC MATERIALS AROUND METEOR CRATER

Campo del Cielo craters in Argentina. No meteorites have been found at the Estonian craters, none at the Siberian craters, and none at the South Carolinian craters.

Certainly no other meteor crater has been so thoroughly studied as the one in Arizona, and judging from a comparison of these studies with the published descriptions of meteor craters in other parts of the world, certainly none is more interesting or impressive.

Our poet-astronomer, William Tyler Olcott, has paid tribute to this gigantic bowl in the following lines, titled "Meteor Crater, Arizona."

You were a black moth winging through the night,
A bit of cosmos shorn from molten matter,
One of a swarm with beating wings that batter
The source and all reflections of the light.

You were the silent echo of a voice,
A slave to might beneath the lashes bending,
And then you plunged to death in flames descending,
In answer to predestinated choice.

You now within a mausoleum lie,
And men gaze on your sepulchre in wonder,
Far down beneath the earth you rent asunder,
You rest secure and dream of star and sky.