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ORIGIN OF METEOR CRATER (COON BUTTE), ARIZONA*

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(Read before the Society, December 29, 1906)

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INTRODUCTION

The remarkable crateriform pit in central Arizona, famous on account of its association with the Canyon Diablo siderites and through the writings of Dr G. K. Gilbert, has lately come into special geologic interest through the explorations of the Standard Iron company. Appreciating the money value of the rare elements associated with a large quantity of meteoric iron and believing that an enormous mass was imbedded in the crater, four men with commendable enterprise and scientific interest, backed by financial ability, acquired the crater and adjacent land under mining law, and for four years have been probing the crater and its rim. Recently two of the company, Mr D. M. Barringer and B. C. Tilghman, have published articles giving the results, to that date, of their explorations.†

* Manuscript received by Secretary of the Society from Censor October 31, 1907.

† D. M. Barringer: Coon mountain and its crater. Proc. Acad. Nat. Sci., Philadelphia, December, 1905, pp. 861-886.

B. C. Tilghman: Coon Butte, Arizona. Ibid., pp. 887-914.

The writings of Doctor Gilbert are in the 13th Ann. Rept. U. S. Geological Survey, part 1, p. 98; 14th Ann. Rept., p. 187; Science (new series), vol. 3, 1896, pp. 1-13, with illustrations; Geological Society of Washington, presidential address, March, 1896.

The original descriptions of the Canyon Diablo siderites, with notice of the crater, was published by A. E. Foote in Proc. Am. Assoc. Adv. Sci., vol. 40, 1892, pp. 279-283; also in Amer. Jour. of Sci., vol. 42, 1891, p. 413.

A detailed analysis of the siderite was published by O. A. Derby, in Amer. Jour. of

Up to the present time more than 50 pits and trenches have been excavated in the debris of the outer slopes; seven shafts have been dug in the floor of the crater, three of them to the depth of 200 feet or over; and eight drill holes have been sunk in the central part of the crater, four of which passed entirely through the white sandstone and penetrated the underlying dark red sandstone at a depth of 880 feet below the crater floor, to a total depth of over 1,050 feet.

These explorations have developed a mass of new and important facts which favor the theory of meteoric impact origin, and certainly rule out the hypothesis of igneous or volcanic origin. The writer visited the crater during the past summer and studied the phenomena under the guidance of Mr S. J. Holsinger, one of the mining company, who has been camping on the crater rim for four years and directing the exploration.

Professor Branner had visited the crater a few weeks earlier, and the writer agrees with him that if the phenomena are not of meteoric origin then they constitute the most interesting geological puzzle of the present time.

To Messrs Barringer, Tilghman, and Holsinger the writer is under obligation for courteous assistance. Their two papers, noted above, contain an array of interesting facts relating to the crater phenomena. The purpose of this writing is to bring before the Geological Society the more salient and important facts.

The Rock Strata

The rocks belong in the Grand Canyon series. The outcrops in the crater and the deep drilling give the following section:

1. Red sandstone, thickness 30 to 40 feet.
2. Aubrey limestone, yellowish, 250 ± feet.

Sci., vol. 49, February, 1905, pp. 101-110. Other writers on the irons are Brezina, Cohen, and Huntington.

The stony meteorite referred to by Mr Barringer (p. 883 of his paper) was described by J. W. Mallet, in Amer. Jour. of Sci., vol. 21, May, 1906, pp. 347-355.

Dr J. C. Branner presented the papers of Messrs Barringer and Tilghman before Section E, American Association for the Advancement of Science, at the Ithaca meeting, June 29, 1906, with the results of his own study of the phenomena, which favored the view of meteoric origin of the crater. This is reported in Science, vol. 24, September 21, 1906, pp. 370-371.

At the 10th Session of the International Geological Congress, in Mexico, September 14, 1906, H. L. Fairchild presented the new facts favoring the impact origin of the crater, and exhibited the various materials. The record will be found in Compte Rendu, X Session, Congres Geol. Inter., Mexico, 1906.

O. C. Farrington has analyzed the siderite oxides ("iron shales"), and discussed their origin and relation to the typical Canyon Diablo irons, in Amer. Jour. of Sci., vol. 22, October, 1906, pp. 303-309.

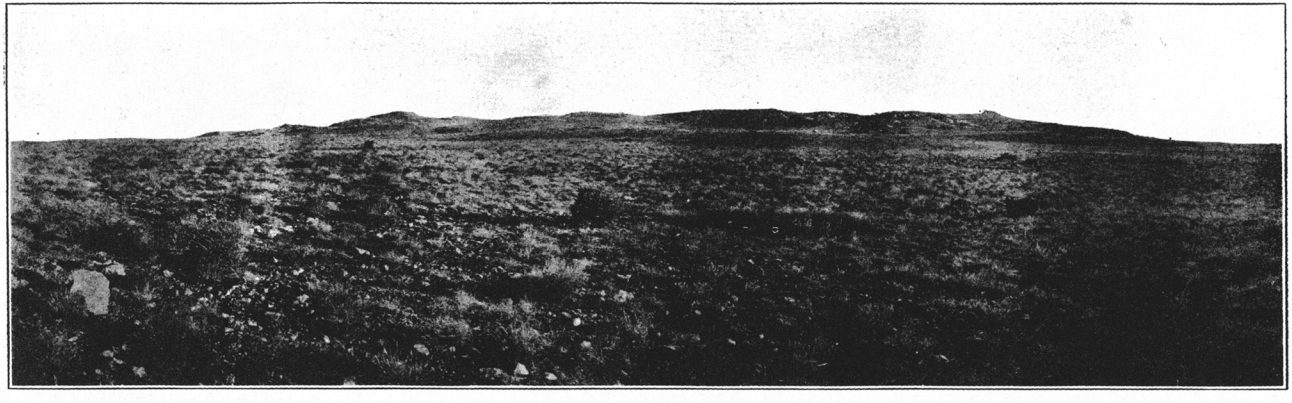

FIGURE 1.—DISTANT VIEW OF THE CRATER RIM, LOOKING EAST

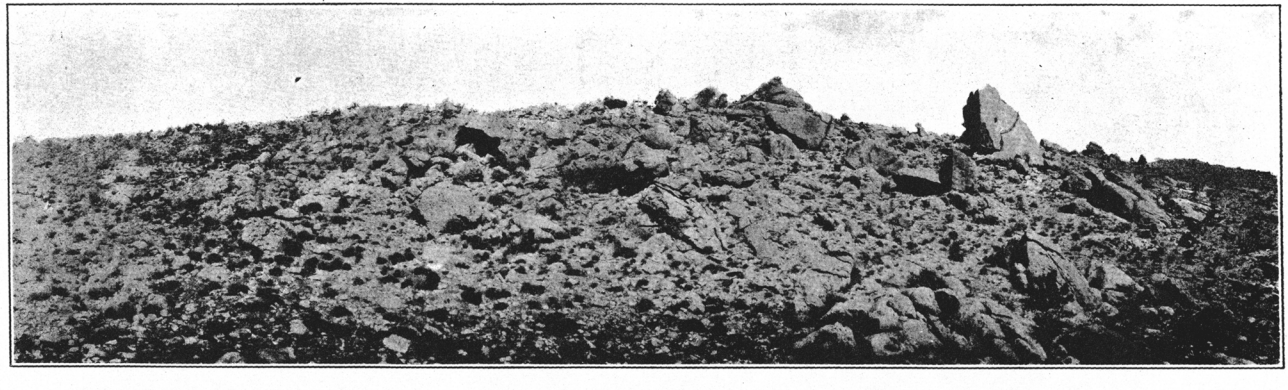

FIGURE 2.—WRECKAGE FROM THE CRATER. WEST SIDE OF RIM. THE LARGE BLOCK IS LIMESTONE, 30 X 25 FEET

METEOR CRATER, ARIZONA

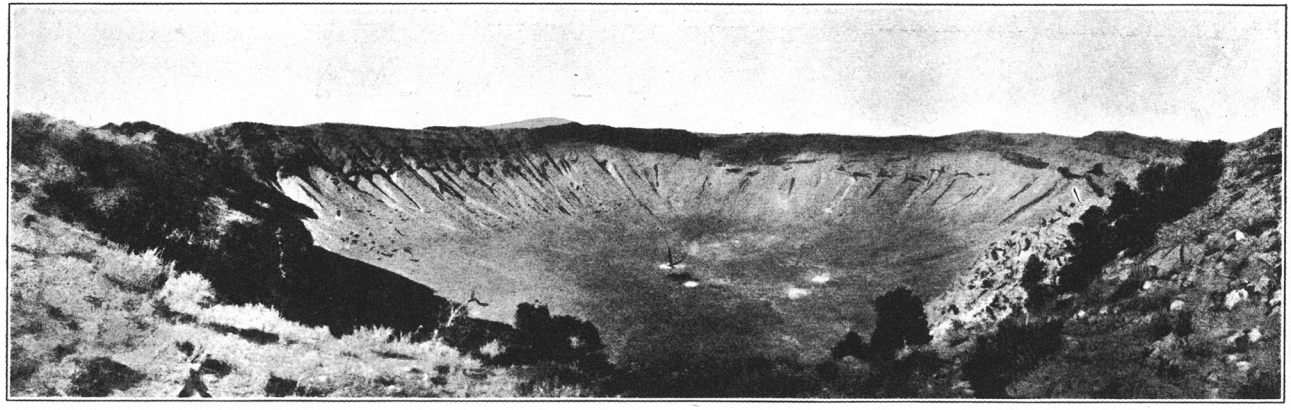

FIGURE 1.—GENERAL VIEW OF CRATER, LOOKING NORTH

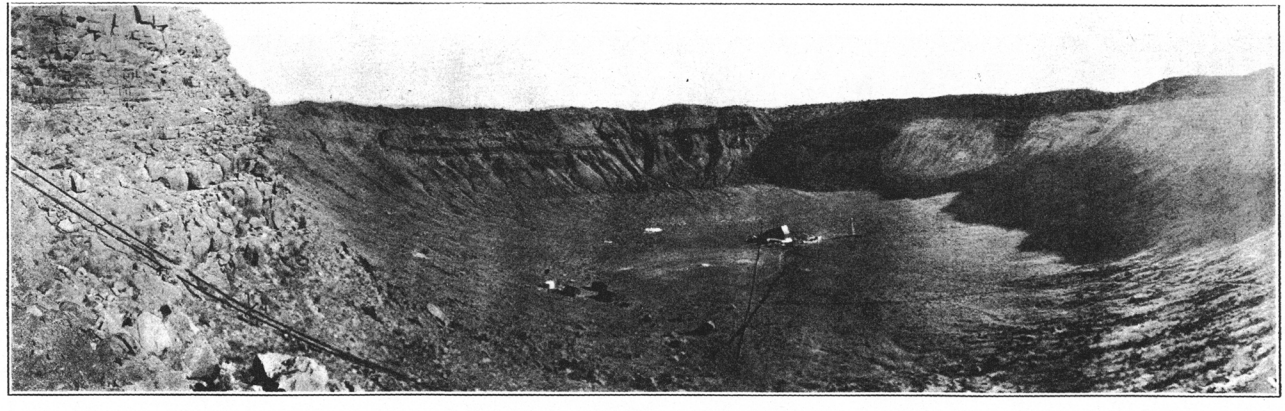

FIGURE 2.—VIEW LOOKING SOUTHEAST

METEOR CRATER, ARIZONA

3. White sandstone with some yellow and pink, about 1,000 feet.

4. Dark red sandstone, thickness unknown.

The uncertainty as to the precise thickness of the limestone is due to the broken and disturbed structure of the uptilted beds in the crater walls. Mr Barringer gives the thickness as 200 to 350 feet. No drilling has been done on the plain outside the crater, where the rocks are undisturbed.

The Crater

Many interesting and important details relating to the crater and the debris will be found in the papers by Messrs Barringer and Tilghman and in the earlier writings by Doctor Gilbert, but only the more important facts will be given here.

The pit or "crater" is circular and bowl-shaped, 4,000 feet in diameter at the top, and toward 600 feet deep, measuring from the rim. The upper part of the walls are steep cliffs (see plate 55) of limestone and sandstone, uptilted so as to have a quaquaversal dip of 30 to 40 degrees, and in places is greatly shattered and crushed. The lower part of the walls is a talus slope produced by many centuries of storm-wash on the broken cliffs. Just previous to the writer's visit to the crater (September, 1906) a heavy storm or "cloudburst," characteristic of the arid region, burst exactly over the crater and illustrated the talus-making process. The northern trail leading down the crater wall was obliterated and

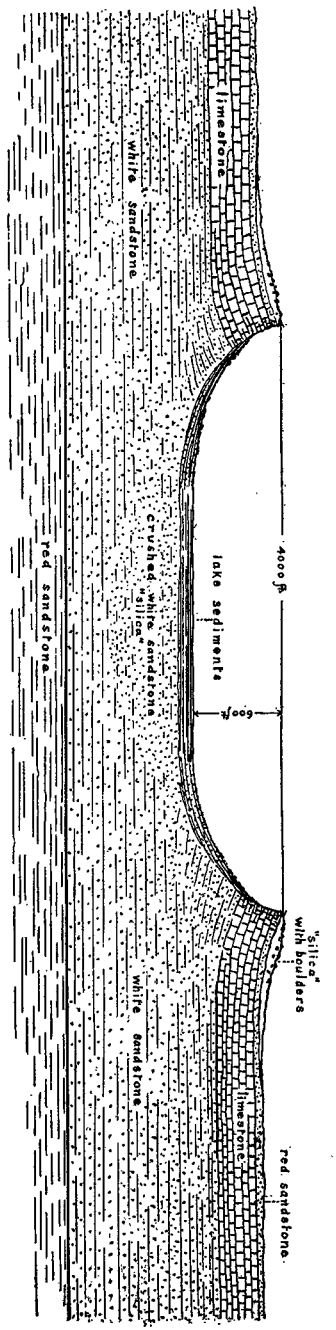

FIGURE 1.—*Vertical Section through Meteor Crater, Arizona.*

Horizontal and vertical scales are equal.

trains of boulders were swept far out on the floor of the crater, while the shaft-house, tool-house, and other buildings in the middle of the pit had their floors buried in mud.

It would appear that the original diameter of the crater must have been appreciably less than now, the walls steeper, and depth of the pit greater. The nearly circular floor of the crater is about 1,800 feet across, with a nearly flat, or gently rolling, surface. The floor consists of aqueous sediments, with intercalating inwashed beds of the talus about the margin. These sediments have been found to average depth of 70 feet, and contain vegetal or peaty layers, beds of diatomaceous material, pond snails, and a stratum of volcanic dust and lapilli from one-fourth of an inch to three inches in thickness; also scattered boulders, which were probably rolled in on the lake ice or rafted in on floating ice cakes. The volcanic debris suggests that the crater antedates the latest volcanic eruptions of the region. At present no water stands in the crater, but it is encountered 200 feet beneath the floor, or over 600 feet below the surface of the plain, which suggests possible climatic change. Mr Holsinger states that cedars growing on the crater rim are over 700 years old.

The bottom of the pit when formed must have been at least 540 feet below the level of the plain and about 750 feet below the rim, the latter now being, after centuries of storm-wash, 130 to 160 feet high above the surrounding plain. This crater rim consists of the uplifted rocks capped by an enormous mass of rocks debris, giving the appearance from a distance of a range of low hills with rough surface (see plate 54).

Volcanic Theory untenable

Beneath the central area of the crater the red standstone (number 4) is found in place beneath the white sandstone (number 3), which shows the absence of any chimney or volcanic pipe of considerable size and positively rules out any explosion from beneath. The conception of a vapor explosion in the thick white sandstone is ruled out by the existing phenomena. Mr Barringer and Mr Tilghman have given the facts bearing on this theory, and in unpublished writing Mr Tilghman has clearly discussed the mechanics and the subsequent effects of a steam explosion. The white sandstone, nearly 1,000 feet thick and underlying all the country, is very porous and would contain a large volume of water. The pressure of any heated water or vapor sufficient to throw the mass of rock out of the pit must have existed through an immense horizontal extent of the strata, and a long time would have been required for entire relief of the pressure through the vent, and with decided hot spring or

fumarolic or solfataric phenomena. With all the careful study, there has not been found the least evidence of any volcanic or igneous activity of any kind. The nearest volcanic phenomena are at the San Francisco mountains, about 15 miles distant. Further, the pulverized character of the rock debris, described below, is not consistent with the idea of an explosion nor with the digestive action of heated waters. The explosive or volcanic theory has not a single fact to stand on. On the other hand, the investigation has developed several remarkable facts which are well explained by the impact theory of the crater genesis.

The powdered Sandstone, "Silica"

It has been found that the greater part of the enormous mass of rock debris or ejectamenta on the outer slopes of the crater rim is a very fine, white, quartz powder; and the same material occupies the pit, beneath the inwashed beds, to the depth of several hundred feet. This "silica" (using the term common on the ground) is certainly only the crushed white sandstone. Much of it is as fine as flour, 50 per cent of it passing through a number 100 sieve, but under the microscope it shows its character as crushed crystalline quartz. Quoting from Mr Tilghman (page 896):

. . . "it is mostly as white as snow and consists of over 99 per cent silica, although here and there small areas or deposits will be of a slightly yellowish color from the yellow limestone and contain a little carbonate of lime (although this has to a great extent been leached out of it), and much more rarely of a reddish color, either stained by or produced from the top stratum of red sandstone. Under the microscope it is seen to consist of minute fragments of clear transparent quartz with edges and points of extreme sharpness, and no signs of any rounding are anywhere visible upon its particles. In some areas the material is composed of this material exclusively. . . . But in other localities it can be found containing a greater or less percentage of broken sand grains among it which have escaped being crushed out of all recognizable shape. A continuous series of material can be found containing more and more broken sand grains . . . on up to the solid sandstone rock. Its general microscopic appearance is identical with that of a handful of glass fragments produced by a blow. It cannot be quite imitated by grinding the sand grains in a mortar, as the edges and points of the powder thus produced are more blunted and rounder and broken than those of the silica. But it is very closely duplicated by the finest powder produced by firing a high-power rifle bullet against a block of the sandstone."

On the surface of the wreckage slopes the silica has been so removed by stormwash and winds that large fragments of the several rocks occupy most of the present surfaces, in size up to thousands of tons (see plate

54); but the silica is everywhere encountered in the pits and trenches. Fragments of the rocks of all sizes are scattered irregularly through the silica, but quite clean sections of the powder are found up to 40 feet deep; and it is the predominating material in contact with the upturned red sandstone. On the south side of the crater rim the silica is exposed in a ravine some 600 feet long and 8 to 10 feet deep. Imbedded in the silica are not only quantities of the limestone and the red sandstone, but also masses of the white sandstone in all stages of the crushing. Some of the blocks preserve the bedding planes and oblique lamination and to the eye appear as firm, unaltered rock, but under a little pressure crumble in the hand into the flour-like silica. By the explorers these have been aptly called the "ghost" sandstone.

Two metamorphic forms of the sandstone are found which are of special significance. One form ("variety A") has a higher density with a slaty structure, the cleavage having no relation to the rock lamination. This form seems to be a direct product of intense compression. It is found in the drill holes to the depth of over 400 feet.

The other peculiar form ("variety B") of the transformed sandstone is a very light, cellular or pumiceous structure, of considerable firmness and rigidity, but so light that it will float on water like a piece of wood. This pumiceous form is rare, but is reported from the drillings to the depth of 160 feet below the sediments. Under the microscope it is found to be mainly composed of amorphous silica, but with scattered particles of crystalline quartz. It would seem to be the natural product of the intense heat of compression on portions of the sandstone which contained sufficient water, perhaps along the joints of the strata, to effect an aqueo-igneous fusion.

These three forms of the crushed sandstone, the powdery, slaty, and cellular, are the products which should be expected from a tremendous crushing blow with resulting heat. They are not the products of an explosion, which would shatter the rocks, but would not reduce them to dust. The first two forms are also entirely opposed to the hypothesis of aqueo-igneous origin of the crater, and the cellular form is probably unknown in hot springs and fumarolic deposits.*

* The mechanics of impact by projectiles, as relating to the origin of the sandstone powder, is well stated by Mr. Tilghman as follows (pages 899-890):

"To account for the presence of this silica powder on the theory that the hole was formed by a great projectile requires a short preliminary study as to the yielding of hard, brittle, and practically incompressible material before a projectile or other blow, or even quiet pressure, for the method is much the same in both cases. Briefly, the way in which substances yield to either pressure or blow in excess of their power of resistance is that a cone of material, with an apex angle of about 90 degrees, is compressed downward into the solid mass of the material from the point of impact. This cone parts from the overlying material, crushes into powder under the force of the pressure or

To summarize: all the phenomena thus far found in the long and careful exploration of the crater, the distribution of the wreckage both inside and outside, and the composition and structure of the materials seem to be fully and satisfactorily explained on the theory of impact by a celestial bolide of high velocity, and do not fit any other theory.

The Nickel-iron Oxides

The association of the Canyon Diablo siderites with the crater needs no discussion here, but it may be said that the distribution of the irons over the crater rim and the surrounding plain has been found much more general and extended than was formerly known; but an important new fact is the general occurrence along with the irons, and also in the wreckage, of iron oxides of meteoric origin. The existence of these oxide masses is not a new discovery, having been noted by Doctor Foote, but their meteoric nature, their abundance and wide dissemination, and their intimate relationship to the phenomena have not been appreciated. Possibly the oxide fragments were confused with the abundant nodules of ordinary limonite derived from the country rocks and scattered over the plain and crater rim.

Many oxide masses, up to large size, have a globular form with more or less concentric structure and lamination, apparently due to weathering and hydration from an original metallic mass. A siderite core is frequently found which appears on cut and etched section much like the Canyon Diablo irons, though the crystalline structure seems somewhat different. Such masses with metallic cores have been found in the silica of the outer slopes to the depth of 27 feet, while multitudes of fragments, evidently derived from disrupted nodules, are found over and in

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blow, and this powder, being still further compressed, transmits the pressure upon it in all directions, somewhat like a fluid, although not equally in all directions. The pressure thus generated in the very substance of the material seeks relief and forces a yielding of the solid material around it, which, of course, occurs along the line of least resistance, and bursts the surface upward and outward into a cone-shaped crater around the point of impact or pressure, the angle of which depends largely upon the nature of the material. . . .

"The bearing of this upon the formation of a rim composed in part of fine powder is as follows: The broken rocks and debris that are expelled from the hole get their velocity imparted to them by the push of an inelastic powder, and not by a compressed elastic gas, and thus, when both rock fragments and powder have progressed far enough to free themselves from the pressure of the penetrating projectile, they fly on together, mixed powder and rocks, at the same velocity. This powder is not dust in the ordinary acceptation of the word, as fine powder mixed with a large quantity of air, which takes a long time to settle out, but is almost unmixed with air in solid masses, particle to particle, like flour in a barrel, so to speak; which masses obey the laws of projectiles and falling bodies, irrespective of the exceedingly minute particles of which they are formed, and are thus deposited in the rim in mixture with and under and over the solid rock masses which accompanied it in its flight, and as quickly."

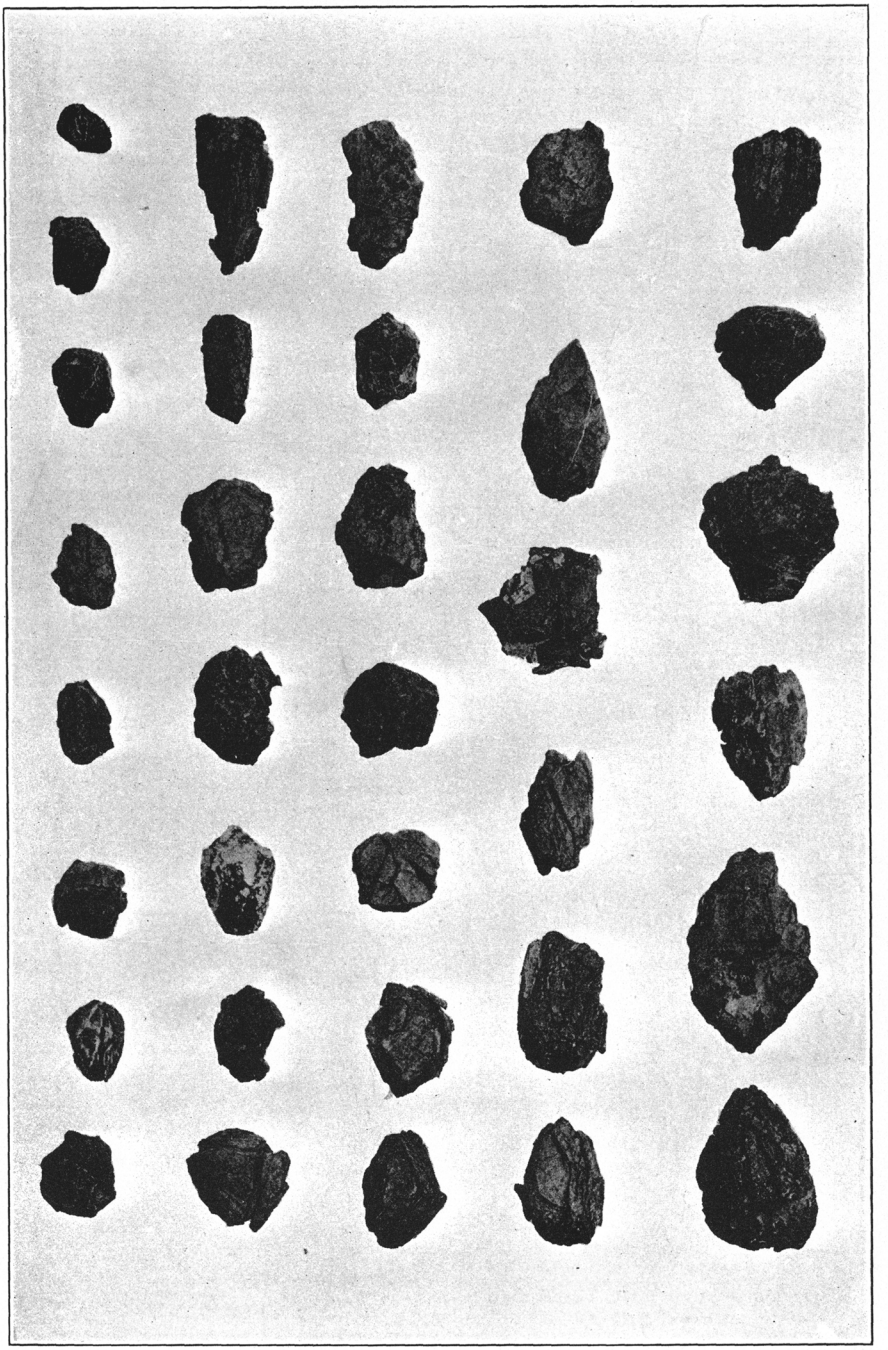
the silica and on the plain. The concentric lamination of the oxides has led the explorers to call the material "iron shale." In the hydration process it is apparent that large quantities of the material have entirely disappeared, but innumerable fragments of dark brown or black color are found which are sufficiently compact to take a polish, and great numbers of small unit masses are found which have a fissured or septarium-like surface apparently due to expansion by hydration (see plate 56).

In color the oxides range from black to yellow, and the decomposing material frequently shows green discoloration due to the nickel. Some fragments are magnetic, but they all are hydrous and seem to be limonite, with perhaps some turgite.

The metallic centers of the "shale balls" polish and etch as readily as the Canyon Diablo irons, but the crystalline structure is not quite the same, and on exposure they behave differently. The Canyon Diablo retain polished surfaces indefinitely, but the core irons rapidly oxidize in the atmosphere of the laboratory and exude drops of iron chloride, soon giving a fresh coating of rust.

It is evident that we have in association with the crater two varieties of siderites, the well-known Canyon Diablo and the chlorine-rich or oxidizing irons. (For brevity the initials C. D. will hereafter be used for the Canyon Diablo irons and C. D. O. for the oxidizing or decomposing irons.) This is a remarkable and critical fact. Do they represent two distinct falls or are they only variations in the decomposition of one huge meteor? It should also be noted in this connection that two forms of the iron oxides may be distinguished, the limonitic and perishable coatings found on the surface of the oxidizing irons, and the firm, compact, and more permanent form, represented by the fissured nodules. Probably these oxides shade into each other, but nevertheless they must indicate variations in the composition of the meteoric material or different circumstances during the hydration process.

Rock fragments are frequently found cemented together or even enclosed by the meteoric iron oxides, some of the dark and lustrous masses of the latter suggesting fusion, though the form is from solution. The explorers have raised the question if some of the oxide material might not represent the superficial burning of the meteor in its heated flight through the atmosphere, subsequently changed by hydration. Theoretically the fused material on the surface of the flying meteorite is swept away as rapidly as formed, but the particles of oxidized metals which formed the incandescent train of the meteor should be found; and the explorers do find a magnetic dust over the plain, over and through the rock debris, and in the crater drillings to the depth of 650 feet below the



METEOR CRATER NICKEL-IRON OXIDES

Specimens of the individual masses of the harder and less decomposable variety. In size they range from half an inch to 2 or 3 inches

floor of the crater. The association of the meteoric dust with the siderites is an interesting but not unexpected fact which indicates no more association with the origin of the crater than do the large masses, but the incorporation of the meteoric material with the wreckage of the crater and deep in the crushed sandstone of the pit is very significant of an association in time.

Disposition of the Meteor

With expert knowledge of projectiles and their effects Mr Tilghman has discussed the problem of the size of the meteorite which could produce the crater (pages 912–913 of his paper). The effect of a projectile is proportionate to weight and velocity, and with the velocity unknown the weight or size is indeterminable.

The original or planetary velocities of meteors may be very large, many miles per second. Small meteors reach the earth's surface with a low terminal velocity, being checked by the resistance of the atmosphere. A very large meteor with high density would traverse the atmosphere with less loss of energy. It is thought that a siderite with a terminal velocity of only a few miles per second would require a diameter of only a few hundred feet in order to produce the Meteor crater.

The amount of Canyon Diablo irons thus far collected is estimated at about 15 tons. The oxides will add only a few tons to this weight. If we double this to allow for fragments yet distributed in the wreckage on the crater rim, it would amount to, say, 60 tons, or about the weight of the largest known meteorites. But this is only a small fraction of the required weight even under an assumed high velocity, and the explorers reasonably are expecting to find the bulk of the meteor in the depths of the crater.

Mr E. E. Howell long ago suggested (see Doctor Gilbert's article) that, as all the Canyon Diablo irons are perfect individuals, none showing either fracture or friction, they originally were imbedded in some easily decomposed or stony material which has disappeared. It is understood that with the low temperature of the celestial visitors even the nickel iron would be as brittle as glass, and the impact would produce subdivision. The explorers have not been unmindful of this suggestion, but thus far their search has not discovered any stony material foreign to the local rocks. Nevertheless this suggestion may give clue to the fate of the bolide.

A very important factor in the problem of the disposition of the meteor is the behavior of the C. D. O. irons. Their decomposition and disap-

pearance is a very pertinent fact, and no limit can be placed on the amount of this material which has been washed away from the slopes of the crater rim. The flour-like silica is quite impervious to the short rains of that arid region, and the stormwash by the infrequent but powerful downpours carries the fine and soluble materials far out on the plain. In a thousand years an enormous amount of the C. D. O. irons might be removed. The fragments now found on the surface are probably only a few of the more resistant fragments or those lately exposed by the erosion of the slopes. If the C. D. O. irons belong to the same fall as the C. D. irons, then the latter probably represent merely a few unoxidizable fragments from the enormous mass of the wrecked meteor, and a part of the wreck may still lie in the crater.

In conversation with the writer many years ago Mr E. E. Howell said that in his opinion the Canyon Diablo siderites were the most interesting of all known meteorites, because of their number, composition and structure, contents and associations. This judgment has been justified. He also believed that the meteor made the crater and might be partly buried in its depths. He seems to have been correct in the view as to the genesis of the crater, and may yet prove so as to the disposition of the meteor.

In a few months we shall probably know more of this matter, as the explorers are imbued with a persistent and commendable scientific curiosity and intend to continue probing the crater until the drill either finds the meteorite or proves its absence in large quantity. It should be said, however, that failure to find vast amount of the meteoric material in the crater will not be conclusive proof against the meteoric or impact theory of the production of the crater.

Name

The earliest mention in print, by Doctor Foote, of the crater was under the name "Coon Mountain," but the term crater was commonly used in his description, and indeed in most of the writings of later authors.

The name used by Doctor Gilbert was "Coon Mountain" or "Coon Butte."

The San Francisco mountain sheet of the U. S. Geological Survey map designates the feature as "Coon Mt."

Mr Barringer used for his article the title "Coon Mountain and its Crater," while Mr Tilghman used the title "Coon Butte."

The name Coon butte has come into general use, perhaps because of its brevity, euphony, and its non-commital character, but it is wholly

inappropriate and should be supplanted. The mound is not a butte in any sense, having no property of form or structure to which the term is correctly applied. The name mountain is also wide of the mark in referring to a height of only 160 feet.

The adjective name "Coon" is meaningless, for no variety of animal (either carnivore or human) ever known by the name is found in the region. Mr Holsinger has sought to find the origin of the name, but has no clue except that stock men say that it was called "Coon Butte" as a landmark to locate a pool of water some miles eastward, known as "Coon Tank."

The important, striking, and positive topographic feature is not the mound or circular rim, but the depression. The name crater is appropriate with reference to the form, and significant and accurate under either hypothesis of origin, as the term crater is generic, being applied to cavities made by projectiles as well as by explosion. The name is euphonic and is in common use in descriptions of the feature.

As a particularizing adjective the term "Meteor" is entirely appropriate, under either theory of crater origin, on account of its association with the most interesting of known siderites. The reasonably certain conclusion that the crater is the effect of impact adds force to the adjective. Moreover, for some time the U. S. Post Office located near Mr Holsinger's camp with the name Meteor, Arizona, gives an official standing to the word.

The name "Canyon Diablo crater" would not be inappropriate, but it has not the brevity nor the euphony of the name proposed.

Appendix (November 10, 1907)

The above paper gives the status of the Meteor Crater problem at the time of its presentation before the Society, December 29, 1906.

During the past summer the drill has been kept busy in the crater, and the results are summarized as follows in a letter from Mr Tilghman, dated November 1, 1907:

"During the season of 1907 sixteen bore holes have been drilled in the eastern portion of the floor of the crater, to an average depth of between 670 and 880 feet. Thirteen of these bore holes have showed undoubted meteoric material at depths of from 400 to 680 feet below the floor of the crater and in a zone from 20 to 100 feet in thickness. This meteoric material consists of (1) silica powder cemented into greenish lumps with a glassy, slag-like material; (2) a black, vitreous material, both of these containing iron and nickel in large quantities; (3) small grains of native metal containing the same ingredients, supposed to be schreibersite.

"This meteoric material is mixed with the usual filling material of the crater, the crushed debris of the strata penetrated, in the proportion of from a trace to 3 per cent.

"Three of the bore holes have been barren of meteoric material.

"Three of the holes have penetrated the underlying red beds at depths respectively of 830, 860, and 870 feet.

"Fourteen of the holes have certainly, and the remaining two probably, penetrated sandstone apparently in place and almost or entirely unaffected by the shock of the impact which produced the crater.

"No evidence of volcanic activity or hot-spring action whatever has been observed in any of the material penetrated by any of the holes.

"All depths as given above are below the floor of the crater, which is itself about 440 feet below the level of the surrounding plain."

The uncrushed sandstone which was pierced by the drilling, as noted above, has been described as follows in a recent letter from Mr Holsinger:

. . . "as we commenced drilling in the flat northeast of the shaft house we encountered sandstone, solid rock, at about 160 to 200 feet. We have from 250 to 400 feet of this, and then break through into finely crushed sandstone mixed with meteoric material. A great slide of rock seems to have fallen back into the hole. . . . I have secured many cores from this slide, showing that it is unaltered sandstone dipping at an angle of about 40 degrees. This slide covers 4 or 5 acres that we have now explored, and possibly much more."

The following articles have been published during the present year.

George P. Merrill: On a peculiar form of metamorphism in siliceous sandstone. Proc. U. S. Nat. Mus., vol. 32, p. 547.

George P. Merrill and Wirt Tassin: Contributions to the study of the Canyon Diablo meteorites. Smith. Misc. Coll., vol. 50, September 12, 1907, pp. 203-214.

F. N. Guild: Coon Mountain crater. Science, vol. 26, July 5, 1907, pp. 24-25.

These papers develop no facts in opposition to the meteoric theory of the crater genesis. The last mentioned article admits the absence of any visible proofs of volcanism, and fails to note the many facts which support the meteoric hypothesis.