Coon Butte.

Dupl.

Coon Mountain and Its Crater.

BY

DANIEL MOREAU BARRINGER.

Coon Butte, Arizona.

BY

BENJAMIN CHEW TILGHMAN.

From the Proceedings of The Academy of Natural Sciences of Philadelphia, December, 1905.

Issued March 1, 1906.

COON MOUNTAIN AND ITS CRATER.

BY DANIEL MOREAU BARRINGER.

FOREWORD.

In October, 1902, I heard for the first time—in casual conversation with Mr. S. J. Holsinger—of Coon Mountain or Coon Butte and its crater, which is located in the northern part of Arizona. He stated to me at the time that he had never seen this remarkable crater, but had heard of it on several occasions, and had heard that quite a large amount of meteoric iron had been found in the immediate vicinity and that some had been found on the inside of the crater, which latter statement was subsequently proved to be incorrect.

I naturally was very incredulous of the theory which, Mr. Holsinger informed me, was held by some of the people living in the neighborhood of Cañon Diablo, namely, that this great hole in the earth's surface had been produced by the impact of an iron body falling out of space, if for no other reason than that I realized that the crater must have been examined by members of the United States Geological Survey while making the topographical maps of this region, and in their report they evidently did not accept this theory.

Nevertheless, the subject continued to interest me so much that upon my return to Philadelphia I determined to speak to my friend, Mr. B. C. Tilghman, in reference to it, because of his general scientific knowledge. This was in the latter part of January, 1903. We decided to write to Mr. Holsinger for further information, and upon receipt of this took the necessary steps to locate the mountain under the United States Mineral Land Laws. Since then, between us, Mr. Tilghman and I have collected an astounding array of evidence in favor of the correctness of the above theory of the causation of this great hole in the earth's surface, and in refutation of the theory adopted by Mr. Gilbert, of the United States Geological Survey, that it was produced by a steam explosion.[1]

[1] See Presidential Address by Grove Karl Gilbert, 1895, before the Geological Society of Washington, published by the Society in March, 1896. Also published in *Science*, N. S., Vol. III, page 1, 1896. Also 13th Ann. U. S. Geol. Sur. Rep., Part I, p. 98, and 14th Ann. U. S. Geol. Sur. Rep., Part I, p. 187. Also Chamberlin and Salisbury's *Geology* (1904), Vol. I, p. 569.

In fact we can now prove that this crater is due to the collision with the earth of an extra-terrestrial body, possibly a small asteroid, which was presumably metallic in nature.

We do not know, and indeed may never know, whether this great meteor was originally an irregularly shaped fragment or whether it was a spheroid, but we have strong reason to believe that the composition of the exterior was that of nickeliferous iron, containing in minute quantity platinum and iridium.

Since acquiring possession of the property, we have learned that this meteoric fall has been the subject of many papers and that the composition of the iron, and the fact that it contains microscopic diamonds, has been well known, upwards of ten tons of iron specimens having been shipped away from this locality; although, singularly enough, the presence of platinum and iridium has not been suspected. The presence of these metals was ascertained for us by Mr. H. H. Alexander, of the Globe Smelter, Denver, by subjecting the iron and the magnetite (the origin of which we shall attempt to explain hereafter) to the fire assay test, samples of each having been sent to him for the purpose. Their presence has been also confirmed by the very high chemical authority, Dr. J. W. Mallet, F.R.S., of the University of Virginia, whose letter on the subject is herewith submitted.[2]

---

[2] UNIVERSITY OF VIRGINIA,
CHARLOTTESVILLE, VA.

August 17, 1905.

D. M. BARRINGER, ESQ., Philadelphia.

DEAR MR BARRINGER:

About a fortnight ago I was at last able to undertake the examination you desired of the residue sent me by Mr. Alexander from solution in dilute hydrochloric acid of 25 lbs. of the Cañon Diablo meteoric iron, and I now report results:

I first repeated twice the assay experiments made by Mr. Alexander, and obtained substantially the same results that he did.

It then seemed to me desirable to apply a method which should not involve any addition of foreign metals (though I have full confidence in the purity of Mr. Alexander's lead, gold and silver), and to avoid determination of platinum "by loss."

I therefore boiled the greater part of the residue sent me by him with a mixture of strong hydrochloric and nitric acids as long as there was any action. This was a very tedious affair, the Schreibersite (phosphide of iron and nickel), which formed a large proportion of the residue, being but slowly attacked, and there being a strong tendency to boiling over from sudden, irregular evolution of nitrogen dioxide. The solution obtained was evaporated two or three times with hydrochloric acid, diluted, filtered and treated with a current of sulphuretted hydrogen, first cold and then while heated. This gave a copious precipitate of sulphur (from reduction of ferric to ferrous chloride) colored brownish by the sulphides of the platinum metals.

This precipitate was filtered off, well washed with water, dried and burned. The small residue left was then reconverted into chlorides, and the platinum and iridium separated in the usual way, by partial reduction of the iridium salt and precipitation of that of platinum with ammonium chloride.

It has seemed to Mr. Tilghman and to me to be better for us each to discuss this matter from our separate points of view—he from the point of view of a physicist, chemist and mathematician, and I from the point of view of a geologist.

The number of arguments which between us we have worked out, in support of the theory that this gigantic hole is an impact crater, will be set forth in the two following papers. It must be remembered that while a great deal of the evidence collected by us is positively in favor of the theory, much of it is negatively so; that is to say it disproves the theory that this great hole is the crater of an ancient volcano, or was produced by an explosion of steam, which latter theory seems to have been adopted by Mr. G. K. Gilbert on what seems to be very insufficient evidence. Perhaps it would be more accurate and just to say that he has adopted this theory because of an inadequate examination of the phenomena at Coon Mountain, or, as it is frequently called, Coon Butte; for had he examined the surface carefully, it does not seem possible to me that any experienced geo'ogist could have arrived at such a conclusion.

Coon Mountain and Its Crater.

There is to be found in the almost level plain country, about five miles almost due south of Sunshine Station, on the Atchison, Topeka & Santa

---

The result represented 3.63 grammes platinum and 14.96 grammes iridium per ton (of 2,000 lbs.) of the original meteoric iron, with probably a trace of rhodium. . . . .

I add the following remarks:

1. Mr. Alexander in using his method undoubtedly dissolved out with *aqua regia* from his cupelled button not only gold and platinum but some iridium, so that the loss of weight (after deduction of gold added) represented not merely platinum, as he assumed, but in part iridium also.
2. On the other hand, it is not certain that in my process *all* the iridium is dissolved out from the original material (residue sent me by Mr. Alexander) by *aqua regia* as used.
3. My results as to separation of the two platinoid metals are fairly trustworthy, but would be more so if there had been a larger absolute quantity of material to work on.
4. It is of course possible that these platinoid metals are not uniformly distributed in the original meteoric iron.

Believe me,

Sincerely yours,

(Signed) J. W. Mallet.

From the specimen of Cañon Diablo iron you left for me, with drill holes in it and a memorandum as to drills being blunted and spoiled, I have obtained five excellent microscopic diamonds—quite like those of South Africa in appearance and markings.

J. W. M.

Fé Ry., in Coconino county, Arizona, a very remarkable and almost perfectly round crater, differing in many respects, as will be hereafter seen, from any crater on the earth's surface with which I, at least, am familiar. The rocks exposed in this region, and for many miles around in every direction, belong to the Aubrey formation of the Upper Carboniferous series. These beds are perfectly horizontal, never having been disturbed since they were laid down except by volcanic tremors, which were probably the cause of several small but deep cracks in the vicinity of Cañon Diablo gorge and running parallel with it. Erosion has removed the upper strata which overlie these beds elsewhere in the region, so that now the uppermost stratum which is found is red sandstone, and this exists only as isolated and quite widely separated flat-topped buttes. It is not likely that this stratum was ever of great thickness. The portions of it which are left vary from a few feet to less than fifty feet in thickness. At the place now occupied by Coon Mountain and its crater (for it should be stated that this crater is within a rather low long mountain rising out of the level plain to a height of from 120 to 160 feet, the irregular top of the mountain forming the rim of the bowl-shaped crater) this sandstone stratum, at the time the crater was made, probably existed here as a flat-topped butte of considerable area, not over thirty feet in height above the surrounding limestone plain. The exact locality now occupied by the mountain and the crater was no doubt very similar to portions of the present surrounding plain before the event which produced them. These isolated buttes of red sandstone, which are dotted over the plain, probably average from fifteen to twenty feet in thickness. Underneath this sandstone there are from 200 to 350 feet of yellowish-gray calcareous sandstone, which when eroded and weathered has the appearance of limestone. In fact, this stratum, which is well shown in the neighboring gorge of Cañon Diablo, is referred to by the United States Geological Survey as the Aubrey limestone. For the sake of clearness it will hereafter be referred to as limestone. Underneath this limestone there is a stratum of apparently from 800 to 900 feet in thickness, but probably much less,[3] of very light gray, almost white, fine-grained sandstone; and underneath this stratum there is a thin stratum of yellow sandstone, the thickness of which is not definitely

[3] It is probable that these figures are very excessive and that the true thickness of this sandstone stratum at this point much more nearly approximates the thickness given to it in the record of the Winona well given below. The record of our bore holes and as obtained from the surrounding exposures must of necessity be unreliable, for reasons which will hereafter appear.

known. This seems to be the uppermost member of what are known as the "Red Beds," for underneath this yellow sandstone there is a reddish-brown sandstone, the thickness of which is given by the United States Geological Survey as more than 1,000 feet. The following record of a well driven by the Railroad Company at Winona, less than thirty miles distant in an air line from the crater first mentioned, shows the thickness of these various strata at that point. It is assumed that the Geological Survey obtained these figures from the Railroad Company, since the figures which they give as to the thickness of these strata, at the place where the A., T. & S. F. Ry. crosses the Cañon Diablo gorge, closely approximate the record of the well.[4] There are no eruptive rocks of any sort in this neighborhood, the nearest eruptive rocks to the so-called crater above referred to being a mountain known as Sunset Mountain about twelve miles in a southeast direction, the Black Mesa in a west and southwest direction about twenty miles distant, and the San Francisco Mountains and the flows therefrom about forty-five to fifty miles distant in a northwest direction. The latter, as is well known, are composed of many volcanic craters and the material ejected therefrom. Some of these craters are of comparatively recent origin, geologically considered, but presumably of much greater age than Coon Mountain and the crater it contains. The Black Mesa above referred to is supposed to be a flow from the San Francisco craters. In the San Francisco Mountains there are many volcanic cones containing more or less perfect craters. These are true volcanic craters. Such, for instance, is the well-known "Sunset" crater, a few miles north of the Santa Fé Railroad and easily accessible from Flagstaff. I have no hesitancy in saying that there is absolutely no connection between the first mentioned crater, which I shall hereafter attempt to describe, and these volcanic craters. And more than that, there is not a single point of similarity, excepting perhaps that of the round shape of the interior basin.

As above stated, the crater which is the subject of this paper is to be found in an area composed of level beds of stratified rocks (Carboniferous sandstones, limestones and shales), which extend uninterruptedly,

[4] Record of Winona well: Aubrey limestone, 185 feet; Dakota sandstone, 456 feet; Red sandstone, 16 feet plus.

"Although no direct measurements have been made in that immediate vicinity, the thickness of the Aubrey limestone at Cañon Diablo is probably not far from 300 feet. At Winona, where its surface is considerably eroded, 185 feet remain. The gray sandstone next below is between 400 and 500 feet thick. The Red Beds are about 1,000 feet thick. Next below is the Redwall limestone which is 600 feet or more in thickness." From information furnished by U. S. Geological Survey.

with the exception of the above volcanic areas, for easily seventy miles in every direction. Generally speaking the same rocks are exposed in the Grand Cañon of the Colorado, the cañons of the Little Colorado and of the stream known as Cañon Diablo, which is distant to the southwest and west only two and one-half miles. The cliffs exposed in this cañon are composed entirely of the upper portion of the limestone bed above referred to, as the cañon does not cut down to the underlying light gray sandstone also referred to above, and the overlying thin red sandstone stratum has been eroded off in this locality. In this crater and around it are to be found nothing but stratified sedimentary rocks or the fragments thereof. Viewed from the railroad across the perfectly level plain, Coon Mountain presents a very peculiar appearance to anyone accustomed to study the sky line. Such an observer would see a small mountain or butte, about one and a half miles long, rising out of the level plain, the sky line of which (the rim of the crater) is very irregular, the mountain differing widely in this respect as well as in its light color from other mountains in the region, which show the usual rounded appearance and gentle lines produced by erosion, and the dark color produced by the eruptive rocks of which they are composed.

Coon Mountain or Coon Butte, as it is often called, does not suggest to one viewing it, especially at close range, from any direction, the existence within itself of a large crater, approximately 3,800 feet in diameter (its diameter along a north-and-south line passing through it being 3,654 feet, while its east-and-west diameter is 3,808 feet) and approximately 600 feet deep from the rim of the crater to the surface of the interior central plain. It is a fact worthy of mention, but after all just what one would expect when one realizes the cause of its origin, that this mountain presents very much the same view to an observer stationed several miles distant, whether he stands on the north, south, east or west side of the mountain. This so-called mountain has an extreme elevation of about 160 feet above the level of the plain, and an average elevation of about 130 feet. Upon closer examination it is found to be composed to a great extent on its outside slopes of an enormous quantity of fragmentary material, which is made up as follows: red sandstone fragments, limestone fragments, white sandstone fragments and a few small yellow and brown sandstone fragments; the largest masses probably weighing upwards of 5,000 tons (these are nearly always limestone) down to silica in powder of microscopic fineness (pulverized sand grains) which will be described hereafter. I have made no attempt to compute the amount of this fragmentary

material, but roughly guess it to be in the neighborhood of 200,000,000 tons; perhaps rather less than more. An additional reason for the existence of the elevation known as Coon Butte or Coon Mountain is to be found in the fact that the uppermost strata exposed in the walls of the interior crater dip quaquaversally, or generally speaking in every direction from the exact center of the crater, at an angle usually varying from ten to forty degrees, and in one case from sixty to seventy degrees. It should be stated, however, that in this case it is evident that a great, presumably wedge-shaped, piece of the material of the cliffs which form the sides of the crater and the rim, has nearly been turned out bodily by the force which produced this enormous hole in the earth's surface. The effect of this would be, of course, to turn the strata nearly on edge at this place. Naturally, this wedge-shaped piece—an expression which is used for want of a better one—lies between two faults, on the other side of each of which the strata dip at a much lower angle, not to exceed perhaps twenty degrees in the one case, that is to the north, and not to exceed five or ten degrees in the other, that is to the southwest. On the west side of the crater the strata are upturned so that they dip at about forty-five degrees west. It is an interesting fact that many large fragments of limestone, which have been hurled out of the crater, are to be found at least a mile from it; and if I am not mistaken there are several large fragments, weighing perhaps fifty tons each, which are more than a mile distant from the center of the crater. These fragments, great and small, are distributed concentrically around the crater, being more abundant near the rim than distant from it. It is worthy of note, however, that the greater number of the larger fragments of the limestone stratum, some of them weighing probably over 5,000 tons, are to be found on the slopes of the mountain outside of the crater, on an east-and-west line passing through the center of the crater. That is to say, there are two places on the rim where these large fragments are most abundant; one almost directly east of the center and the other almost directly west of the center. It is also interesting to see how shattered and cracked many of the exposed limestone fragments are, showing probably that they have been subjected to the concussion from a great blow. These great and small angular blocks of limestone lie in every conceivable position on the slopes of the mountain, many of them standing on end so to speak, that is with the lines of stratification showing a vertical or nearly vertical dip.

I have made more than ten trips to this locality and have examined almost every foot of the ground around it most carefully, and have

failed to find a single piece of eruptive or metamorphosed rock, or any rock indicative of solfateric activity, which has not in all probability been brought to the locality by Indians or the prehistoric inhabitants of this region.

The sharp edges of the angular fragments of rock, which have certainly been expelled out of this crater with great force, are indicative of the recent origin of the crater. In fact, I am ready to believe that it is not more than 2,000 or 3,000 years old, and perhaps much younger. Cedars have been found growing on the rim which are upwards of 700 years old. Were it not for this fact the evidence afforded by the fractured surfaces of the rocks would indicate even a more recent origin.[5]

The interior of the crater can best be likened to a great bowl, excepting that there is an almost vertical escarpment running around the upper portion of the basin, formed of cliffs composed of limestone and the overlying red sandstone. From the bottom of the limestone stratum, or where the more or less shattered and disintegrated white sandstone begins to be seen underneath the limestone cliffs, a great interior fringe of talus commences, which is composed of angular fragments of red sandstone, limestone and gray or white sandstone. This talus slopes at a very low and, for talus representing the effect of weathering, an unusual, or as I think an impossible, angle toward the interior of the plain; but before it reaches the center it disappears underneath stratified sedimentary material which was undoubtedly deposited while the interior of the crater was a lake bottom. There are about seventy feet, and perhaps somewhat more in places, of this material, as has been proved by the shafts and drill holes which have penetrated it. It is composed very largely of wind- and water-borne silica or pulverized sand grains, in which are found numerous fresh-water shells. There are some layers composed almost entirely of microscopic shells, and in some of these sediments there are to be found great numbers of miscroscopic organisms which have silicious skeletons. There has been no opportunity to submit these fresh-water shells and organisms for examination, but it is intended to have this done at an early date. Underneath this sedimentary material there is to be found a more or less compact and unknown quantity of pulverized sandstone (silica), containing here and there angular rock fragments or so-called boulders. The upper portion of this sedimentary material forms, with the over-

[5] It is possible that the cause of this crater may possess considerable historical interest, as explaining the hitherto unexplained fact that throughout this portion of Arizona there are indisputable evidences that the prehistoric civilization ceased abruptly several thousand years ago, according to the necessarily rough estimates of the time which has elapsed.

lying accumulations of soil and wind-blown material and a certain amount of talus which for the greater part has been distributed by torrential action, an almost level central plain in the present visible bottom of the crater. Just how far these lacustrine deposits extend toward the cliffs and underneath the talus, which has been brought to its present position by torrential action, has not yet been determined, but enough is known to state quite positively that they cover the greater portion of the surface of the ancient visible bottom of the crater. As above stated, underneath this sedimentary material there is to be found an incredibly large amount of what has been locally termed silica, and which certainly is due to the pulverization of the sandstone strata and the sand grains composing them. This so-called silica (this name will hereafter be used in referring to this material) is almost free from impurities; several analyses having shown it to contain upwards of 98 and even 99 per cent. SiO_2. To be properly understood this silica should be examined under a microscope. When so examined it is found to be composed of broken sand grains; some of the minute fragments being as large as the half of a sand grain, but the vast majority are very much smaller, and many of the fragments are so small as to be invisible under an ordinary lens. Under a strong glass or microscope they have the general appearance of broken pieces of ice, being of every conceivable shape and almost invariably having very sharp edges, and of course being translucent. Much of this so-called silica is so finely pulverized that no grit can be noticed when it is placed between the teeth, and in fact can be truthfully described as being an impalpable powder. At many places this silica is less finely subdivided than has been described above and is distinctly gritty when placed between the teeth; but at no place has there been found any particle of it which is larger than one of the small sand grains which go to make up the strata in which the crater is found. Without further explanation it can be stated definitely that this silica is nothing more or less than pulverized sandstone. How many million tons of this material there are it would be impossible to estimate. It composes a great part of the enormous rim, over three miles in length measured around the base of the mountain, in which the crater is situated. The amount of it within the crater is absolutely unknown; for it has been found by means of drill holes to a depth of more than 850 feet. At places both on the exterior of the rim and in the interior of the crater, underneath the sedimentary deposits, it is found admixed with a small percentage of lime carbonate, which admixture can of course be readily understood when it is remembered that there is shown in the walls of the crater a calcare-

ous sandstone (herein referred to as limestone for the sake of convenience) which has a thickness of some 250 to 350 feet. If one digs down through the surface soil a foot or more, almost anywhere on the outside of the rim, among the angular fragments which have been thrown out of the hole he will come into this silica, and a great number of trenches and several shafts have shown it to continue downward certainly to the solid or rather more or less shattered rock upon which all of the fragmentary material forming the rim rests. One of these shafts, almost at the base of the mountain and near the surrounding plain, is forty-eight feet in depth. However there are, especially on the southern side of the mountain, several dry washes, where this almost snow-white silica has been exposed for hundreds of feet in length and in places to a depth of upwards of ten feet. It is difficult to understand how this exposure could escape the eye of any careful geologist making a circuit of the crater. If noticed by him it would certainly seem that he would have examined it and ascertained its nature. Having done this, it would seem that he would have been impelled to make a few shallow trenches at different places around the crater, in order to determine how much of this material there was. Having then proved it to exist on all sides of the crater in enormous quantities, it would seem to me that he could not have explained its presence in any other way than that which we have adopted; especially in view of the fact of there being so much corroborative evidence of even a more convincing character. Briefly, it seems to me impossible that this silica could be produced by volcanic action, or by a steam explosion, and I assume that it could be produced only by the pulverizing effect of an almost inconceivably great blow. It should be stated that the silica on the outside of the rim, and to a less extent underneath the sedimentary material in the bottom of the crater, is plentifully admixed with broken fragments of red sandstone, limestone and white sandstone of all sizes within the limits mentioned and sharply angular shapes. It also should be mentioned that the many cuts and shafts (over fifty in all) which we have caused to be made on the outside of the crater, have shown that the silica carrying with it these broken fragments, especially those of smaller size, has evidently welled out of the crater almost like liquid mud, or perhaps, more accurately, like flour when it is poured out of a barrel. It is an interesting fact that it often contains innumerable angular fragments of sandstone in which the grains of sand (some pulverized into silica, some whole and unbroken) are no longer coherent, an effect which we have assumed has been produced by tremendous concussion. It would seem that

these fragments, before they disintegrated entirely, were caught in the flow of silica and carried gently outward and deposited where they are found at present, surrounded by the almost snow-white silica. As the sandstone is itself often very white, the outline of these fragments is not readily distinguished in the sides of the open cuts, until they have been exposed for some time to the weather. However, it is to be remembered that there are in the silica, as far as we have explored it with trenches and shafts, great numbers of perfectly solid coherent sharply angular pieces of sandstone and limestone, as well as of the incoherent fragments. So far as it can be observed the white sandstone stratum, where it is exposed beneath the limestone cliffs inside the crater, is in this same incoherent condition. It is as if it had received a tremendous blow, the concussion from which caused the solid sandstone to disintegrate and become almost like compacted sand, since it can in many instances be dug out and crumbled by the fingers. The effect of this has been of course to cause the sandstone stratum at this point to occupy more space than it previously occupied. The result of this has undoubtedly been the raising of the superimposed limestone and red sandstone strata, causing them to show, when viewed from the interior of the crater, several anticlinal and synclinal folds, and to dip outwardly from the center of the crater, and in this way assisting in forming the elevation locally known as Coon Mountain, which has already been described.

No order is to be observed in the distribution of the angular fragments either within or without the crater, excepting that which I have already referred to, that the greatest amount of large limestone fragments, which it should be remembered is the most coherent rock of the series and the one which has most successfully resisted disintegration, is to be found almost due east and due west of the center of the crater; and also excepting that at certain places there are to be seen spurts of one kind of solid fragments, for example white sandstone, aggregating in amount thousands of tons, and extending from the rim of the crater almost down to its base.

These tongues of fragmentary material, which seem to have been spurted out of the crater with such force as to displace everything which they met, are very interesting; especially those of the white sandstone, some of the fragments of which exhibit very beautiful examples of cross-bedding. The lowest members of the series which was ejected are the red sandstone and the overlying yellow sandstone, small pieces of which are to be found in relatively small quantities on the surface of the southern and southeastern portion of the rim. These are almost

certainly from the upper portion of the Red Beds already referred to.

This brings me to describe more particularly the rim itself. On first examination it would seem that the fragmentary material and silica are almost equally distributed on all sides of the crater. Upon closer examination, however, it is found that there is vastly more of it to the southwest, south and southeast than to the northeast, north and northwest. It also will be observed that the fragmentary material is much more comminuted to the southwest, south and southeast than it is on the opposite sides of the crater. It will also be observed that the limestone cliffs on the interior of the crater are much more shattered to the southwest and south than anywhere else, and the limestone bed itself is raised higher, and to the southeast is to be found the great wedge-shaped piece of the material forming the cliffs and rim, which was turned over and seems to have been near to going out bodily. It will also be observed that the lowest point on the crater is on the north rim, somewhat to the west of a north-and-south line passing through it; and finally the ejected fragments, of ten tons or more in weight, are found distributed over the plain at a greater distance south and southeast of the crater than anywhere else. From all of these facts, the inference is unavoidable that the cause which produced the crater acted with somewhat more violence in a southwest, south and southeast direction than in the opposite direction.

It would be possible to extend this description of the crater to a much greater length; but I hope that in the above I have stated most of the salient facts which would impress the careful observer. Now, there are only three conceivable causes for such a tremendous disturbance of the horizontal strata at this point, and I will take them up separately.

I. *An extremely violently acting volcano.* This can be set aside as being impossible inasmuch—

First: No lava is to be found, or any other volcanic rock, for many miles in any direction. Nor is there to be seen any sulphur, which is found in most volcanic craters of recent origin.

Second: I assume that huge fragments of rock, weighing perhaps upwards of fifty tons, could not have been expelled from the crater and deposited a mile or more distant from its center by volcanic action, in the absence of other numerous and indisputable facts to show that a volcano existed at this place. Moreover, any stone which has been hurled from a volcanic crater through the agency of steam is usually of igneous origin.

Third: We know absolutely the series of rocks at this point, and this

series has been described in the first part of this paper. We also know that only the uppermost strata have been hurled out of this hole by some terrific force. Briefly, it would seem to me to be impossible that any geologist carefully examining the region could reach the conclusion that this is a volcanic crater, or in any way produced by volcanic agencies.

II. *A steam explosion.* This is the theory which seems to have been adopted by the United States Geological Survey to account for this remarkable crater, on the report of one of its members, Mr. Grove Karl Gilbert, and his associates.[6] To me it seems incredible that they could have adopted this explanation of the crater and its surrounding phenomena, if they had carefully examined the surface as above described, for the following reasons:

First: Such a violent paroxysmal outburst of steam as they assume in order to account for Coon Mountain and its crater is, to the best of my knowledge, unrecorded, unless perhaps in connection with some great volcano, and even there its force, I assume, has been, with few exceptions, less than the force expended here; and in such volcanic manifestations there were a number of such explosions, not merely one.

Second: The vast amount of steam required to do the amount of work accomplished at this place could only be stored up in regions of present or recent volcanic activity. There is no evidence that this has ever been such a region.

Third: As suggested above, it is inconceivable to me that there could have been, even in such a region, much less in a region of undisturbed stratified rocks, such a *single* great steam explosion, before which and after which all was quiet.

Fourth: I assume that such an explosion would not have produced the beautifully round crater which we have here; and, moreover, it seems certain that the country round about would be seamed for miles with cracks and fissures, perhaps more or less radial, through which in all probability steam would have ascended for many centuries. Nothing of the sort has been found here. It is certain that the crater was made in an instant of time, after which all was as quiet as before. Any one visiting the locality is impressed by the many evidences of this fact. It is also certain that the crater is very recent, comparatively little or no erosion having taken place since it was made. The evidences of this are to be found on every side. If there had been

[6] See Thirteenth Ann. Rep. U. S. Geol. Sur., Part I, p. 98, and Fourteenth Ann. Rep. U. S. Geol. Sur., Part I, p. 187. Also *Science*, N. S., Vol. III, p. 1, and Chamberlin and Salisbury's *Geology* (1904), Vol. I, p. 569.

much erosion, such as must have taken place in order to account for the great amount of talus which is to be observed on the inside of the crater, supposing it to have accumulated in the usual way, the crater would certainly not be as round as it is. If originally round, it would certainly have been greatly deformed by the process. It could not weather round. It is perfectly clear that this is contrary to any known mode of action of erosion. Therefore it is certain that the talus did not accumulate in the usual way, and that its presence and distribution must be explained on some other theory than that of weathering. This view receives further support from the fact that the very low angle (about twenty degrees from horizontal) which the upper portion of the talus on the interior of the crater makes in its descent from the base of the almost perpendicular cliffs, is a very unusual one.

Fifth: Granting that such a single violent steam explosion is not an absurb hypothesis, it would seem that on this hypothesis there would be abundant evidences of solfateric activity within and without the crater, especially in the immediate vicinity; such as redeposited or secondary silica, carbonate of lime and other minerals which are usually deposited by hot spring action. These minerals would certainly be found within the crater and in the cracks which, under this hypothesis, it would seem should be found traversing the horizontal stratified rocks forming the plain on the outside of the crater. Neither the cracks nor the minerals are to be found. In short, there is no evidence of any sort at or near this spot of solfateric action.

Sixth: If a steam explosion had formed this crater, it is inconceivable to me that it would not have thrown up rocks from a greater depth than that represented by the three uppermost strata, together with a very small portion of the upper part of the Red Beds which underlie them. Nothing would seem to be more certain than that the greater portion of these Red Beds and the great Carboniferous series of strata extending thousands of feet under them, as exposed by the Grand Cañon of the Colorado, only seventy miles distant, are undisturbed In other words, the series of strata at Coon Mountain have not been disturbed, at least to the extent of being thrown out, for a greater depth than the upper portion of the Red Beds, geologically speaking, or about 1,200 feet more or less—perhaps as much as 1,300 feet—below the present surface of the plain.

Seventh: A steam explosion I assume could not have pulverized the individual sand grains, as they have been pulverized here, and produced as a result the millions of tons of "silica" which exists on the inside of the crater and on the outside of the rim as already described. It is not

conceivable to me, as I have already stated, that this material could have been produced in the quantities in which we find it in any other way than by a heavy blow.

III. *The impact of an extra-terrestrial body.*

I shall attempt now to describe briefly such facts as are evident to any geologist making an examination of the region which furnish strong affirmative evidence that this crater could have been made *only* by an extra-terrestrial body falling out of space and moving at great speed. Something between ten and fifteen tons of meteoric iron have been shipped away from this locality, most of it going to the various museums of the world. It is a fact, so far as I know, that none of the "iron shale" or magnetic iron oxide, which will be described hereafter, is to be found in any of these museums; why I cannot understand, for the scientific interest which attaches to it is very great. It is probably not generally known that by far the greater portion of the meteoric iron which has been shipped from this locality has been found lying on the plain immediately surrounding the crater, and much of it has been found on the rim itself. At Cañon Diablo a merchant, Mr. F. W. Volz, tells me he has shipped nearly ten tons of this iron, and he also tells me that before he came to the country a merchant from Winslow shipped perhaps half as much. Both of these merchants hired Mexicans to look for iron specimens in the neighborhood of the crater. These men discovered several pieces weighing from 600 to over 1,000 pounds.

Since we have come into possession of the property we have found several thousand pieces, in all something over a ton, of various sized fragments of meteoric iron, the largest weighing as I remember 225 pounds, down to pieces weighing much less than an ounce or only a few grains. These meteoric iron specimens (known to the scientific world as the Cañon Diablo siderites) are so well known that I shall not attempt to describe them. The following analysis by Messrs. Booth, Garrett and Blair, of Philadelphia, may be taken as representing the general composition of these irons: Si 0.047; S 0.004; P 0.179; C 0.417; Ni 7.940; Fe 91.396; total 99.983. In the present discussion it is far more interesting to state that they have been found more or less concentrically distributed around the crater and to an extreme distance, so far as we know, of two and one-half miles from it, a few small specimens having been found in Cañon Diablo gorge. It is a remarkable fact that these so-called "irons" (to distinguish them from the so-called "iron shale") are very angular in shape, indicating by their fracture that they may have been violently torn off or burned from similar ma-

terial. Some of them contain holes or cavities which were probably once occupied by nodules of troilite (sulphide of iron). Such nodules are beautifully shown by sawing through some of the larger specimens in the Ward and other collections. When exposed to the action of the atmosphere these have oxidized, leaving the cavities they had occupied. Occasionally some of the specimens have a noticeable amount of iron oxide or shale adhering to them, but as a rule they are very free from this. They are usually covered, however, with a very thin film of iron oxide, which may be easily rubbed off with a wire brush if the specimen has been previously heated. When this is done their appearance would indicate that they may have been torn or burned from presumably similar material.

It is a fact worthy of note that so far none of these specimens of meteoric iron have been found at any depth beneath the surface. They are usually lying on the surface or partially or wholly covered by the merely superficial soil, and are distributed, as already stated, more or less concentrically around the crater, most of the small specimens being found, however, to the north and northeast. That there are great numbers of them contained in the thin soil overlying the solid limestone composing the level plain on all sides of the mountain is proven by the fact that we have found several specimens, from seven pounds to twenty-seven pounds in weight, so imbedded in digging a trench for a pipe line from Cañon Diablo gorge to the crater. They have not been found in the numerous cuts or shafts which have been made in the silica. Four of them, weighing three or four pounds each, have been found on the interior of the crater, and, so far as I know, these are the only iron specimens which have been found inside of the crater. These were found above the cliffs already described. Considerable "iron shale" has also been found inside the crater, among the talus at the base of the cliffs. I shall propose hereafter a possible explanation of the fact why these irons are found only on the surface. It is also worthy of note, as already stated, that we have found more of the smaller irons, on or in the surface soil, on the north and northeastern portion of the rim than in other places.

Now there have been found abundantly distributed around the rim, and especially on and in its northern portion, and nearby on the plain, very large quantities, probably aggregating a ton or more in weight, of magnetic oxide of iron. This is so abundantly distributed over the northern surface of the rim and over the surrounding plain, and is so apparent to the casual observer, that it seems wonderful to me that Mr. Gilbert and his associates did not make any reference

to it in their report. It is certainly different from any substance in nature with which I am familiar, and had they taken the trouble to have it analyzed they would have found that the large pieces almost invariably contain nickel (certainly in all the specimens examined) to the same extent, proportionately speaking, as it is found in the Cañon Diablo meteoric iron, from which this magnetic iron oxide was no doubt produced. However, if they had merely broken open some of the larger pieces of this magnetic iron oxide, which it seems to me they could not have failed to see, they would have observed in some of the specimens the characteristic green hydroxide of nickel. The iron oxide was produced, as I assume, by the heat generated from friction while the great iron meteor passed through the earth's atmosphere. As above stated, it has been determined for us that the larger pieces of this so-called "iron shale" contain invariably iron, nickel, iridium and platinum in the same relative proportion (remembering that two are in the form of oxide while the others are in the metallic state) as they are found in the iron from which this material was separated. In the very minute pieces of shale the nickel has been leached out to a greater or less extent. For the sake of clearness and because of the peculiar laminated structure, I shall hereafter refer to this magnetic oxide of iron as "iron shale," adopting the local name by which it is known. This iron shale is very much more magnetic than the original metallic meteoric iron, which in some specimens is only feebly so.

It should be stated in this connection that the surface of the surrounding country for perhaps several miles, concentrically around the crater, contains minute particles of this iron shale, either in the shape of fragments or as spherules. It is found everywhere in the vicinity of the crater, on the rim and on the outside plain. We have assumed that these small particles once constituted a portion of the great luminous tail of the meteoric body which, in our belief, by its collision with the earth made the crater.

Having observed all these things, containing as they do many arguments in favor of the theory that this great hole in the plain was produced by the impact of a body falling out of space, and against the theory that it was produced by either volcanic action or by a steam explosion, it naturally suggested itself to us to endeavor to prove *absolute* synchronism of the two events, namely, the falling of a very great meteor on this particular spot and the formation of this crater. The easiest method of doing this, which at once suggested itself to us, was to have a number of open cuts made through the silica and rock

fragments on the outside of the rim, and to sink a number of shallow shafts through this material, in order to find if possible pieces of the meteor *overlaid by and thoroughly admixed with* the rock fragments and silica which certainly came from great depths in the adjacent hole. Numbers of these cuts were made before finding the objects of our search, but at last we began to find them and now we have found nearly one hundred pieces of meteoric material, some of them as much as fifty pounds in weight, a number of feet beneath the surface in the silica, overlaid and underlaid in no particular order by the various kinds of rock fragments described above, namely, white sandstone, limestone and red sandstone. In one case that I remember we found a large piece of meteoric oxidized material or "iron shale" about six feet beneath the surface in the silica, directly underneath an angular fragment, several feet in diameter, of red sandstone. On the top of this red sandstone was a piece of limestone, and on top of the limestone was a still larger piece of white sandstone. I merely mention this case as it is interesting to reflect that the white sandstone comes from a depth of at least about 400 feet below the surface, and yet it is found on top of the red sandstone fragment (the surface rock) and the limestone fragment which, when the geological order of the rocks is considered, lie above it. However, the most interesting piece of work in this connection which we have done is to be found in one of the shafts on the rim, which shaft is forty-eight feet deep. In this shaft we found vertically one above the other no less than seven quite large specimens of meteoric material or iron shale; the first one being found twelve feet beneath the surface, and the last one being found twenty-seven feet beneath the surface, underneath a large fragment of red sandstone. These pieces were from a pound to probably thirty pounds in weight. On top of the uppermost specimen, and at varying distances between it and the other specimens found in this shaft, there was the usual admixture of silica, white sandstone fragments, limestone and red sandstone fragments. On no conceivable theory other than the one which we have adopted can the facts above described be explained.[7]

I have used the words "meteoric material" because this material is somewhat unlike any which up to that time had been found on the surface. Such material has, however, since been found on the surface,

[7] Since the above was written Mr. Tilghman has informed me that he has by means of a small magnetic separator found distributed through samples of silica, taken from deposits on the slopes of the rim, an appreciable amount of metallic iron in the form of very minute particles and scales which are covered by magnetic oxide of iron. These of necessity are meteoric in nature. They have been found by him in silica which was taken from several feet beneath the surface.

several large specimens, one weighing over 200 pounds and others over 100 pounds, having been found nearly a mile west of the crater, and many small ones distributed around it, generally to the northeast, north and northwest. This material is usually roughly globular or oval in shape, the outside having been converted into hydrated oxide of iron, while the interior is usually magnetic oxide of iron, showing when broken open in nearly every instance the green hydroxide of nickel. In a number of instances, however, these so-called "shale balls" (I again adopt the local name) are found to contain *a solid iron center*. We have some specimens where these iron centers probably weigh as much as twenty to thirty pounds, the total weight of the shale ball being considerably more than this. The magnetic oxide which surrounds the iron center usually presents a more or less laminated appearance, and I assume therefore that much of the so-called iron shale found on the surface, as small flat or slightly curved pieces or thick scale, from an inch to six inches in length and from one-sixteenth inch to several inches in thickness, has resulted from the alteration of shale balls, the iron in the great majority of the cases where these were small or were detached from the meteor in the upper atmosphere having had time to be entirely converted into magnetic oxide. There is such a great similarity of appearance that this inference is to me unavoidable, and I have recently noticed that the pieces of laminated magnetic iron oxide are often grouped, especially where they have been found on the outside plain some distance away from the crater, as if a shale ball, or a piece of metallic iron which was once covered by magnetic oxide of iron, had fallen on this spot and the magnetic oxide of iron had been disintegrated, either by the force of the fall or afterwards by ordinary atmospheric agencies.[8] It is worthy of note that the flat or slightly curved pieces of iron shale are found, like the iron specimens, only on the surface or in the surface soil, and to date at least have not been found admixed with the silica and rock fragments on the outside of the rim, as the shale balls are frequently found.

This brings me to attempt an explanation of the fact that these so-called shale balls are to be found beneath the surface on the outside of the rim, and admixed with the fragmentary material which was certainly expelled from the crater, to a proven depth of twenty-seven feet, and that the angular pieces of meteoric iron have been found up to date *only* on the surface or in the shallow soil which overlies the rock

[8] It may easily be, however, that pieces of metallic iron were found at some of these spots and taken away by the merchants who made a business of collecting these specimens for sale to museums, etc. See footnote 9.

fragments and the silica, which forms part of the rim, or on the surrounding limestone plain.

On April 11, 1904, it was my good fortune to observe, while at Pearce, Arizona, between five and six o'clock in the afternoon, a very brilliant meteor. This same meteor was observed at Tucson, Arizona, by Mr. Holsinger, who had been in charge of our exploratory work for some time previous to this. He was at the time over seventy miles distant from Pearce in an air line. It is a source of much regret that the sun was shining at the time, for otherwise the spectacle would have been a most brilliant and instructive one. As it was, however, the meteor was so large and so brilliant that the following facts could be most clearly determined: The head of the meteor was blue-white in color; from this head there seemed to dart from time to time, and almost from the moment the meteor became visible, many jets of bluish-colored light. Behind the meteor was a glorious comet-like tail, the color of which was generally yellow. From behind the meteor and out of this tail there appeared from time to time, and after the meteor had been visible for an appreciable length of time, great flaming drops, not unlike drops of burning tar. These rapidly fell behind the meteor, being distanced by it. In shape they were, generally speaking, somewhat like a gourd, with the small ends, which as I remember seemed to bend slightly downward, pointing toward the rapidly receding meteor. I counted as many as five of these drops. Mr. Holsinger thought he saw more than five.

Bearing in mind what I have related above, I shall now offer an explanation of the difference in distribution of the pieces of metallic meteoric iron and the so-called shale balls, realizing fully, however, that in the first place not enough work has been done to state with positiveness that no large pieces of iron are to be found in the fragmentary material forming in great part the slopes of the mountain, and in the second place that the explanation which I offer may be proved to be an erroneous one. I am inclined to believe that many of the thousands of pieces of metallic meteoric iron which have been found distributed around Coon Mountain, and which are generally known by the name of the Cañon Diablo siderites, were pieces that were torn loose from the surface of the meteor when it entered the earth's atmosphere by the violent expansion strains set up because of the intense coldness of the main body of the meteor, which of course was cooled to the temperature of outer space, and the intense heat immediately generated upon the entrace of the meteor into the earth's atmosphere. This would explain the darts of light which Mr. Holsinger and I saw going out of

the front of the meteor above referred to, from almost the instant the meteor became visible.[9] These fragments would naturally soon fall behind the meteor, and in the case which is the subject of this paper probably reached the earth after the collision had taken place and all of the material had been thrown out from the crater produced by the impact. The same would be true of the first "shale balls" to be detached, the origin of which, it seems to me, can be explained as follows. As the front surface became more heated it is possible that fewer of these irons would be thrown off, and almost certain that some of the iron would be melted and would naturally run back to the sides or to the rear surface of the meteor, from which from time to time it would be detached. This burning iron would then drop behind, as in the case of the meteor observed by Mr. Holsinger and myself, and form the shale balls above referred to. On this theory the laminated structure which I have spoken of is possibly due to the fact that the melted iron ran back over the meteor to its rear surface, or at least to its sides, and was detached therefrom in a pasty condition. This would seem to offer an explanation of the five flaming drops which I saw falling behind the meteor in April, 1904, and why they were not seen until the meteor had been visible for an appreciable length of time.

These shale balls probably continued to drop off from the great Cañon Diablo meteor, referred to in this paper, until the very moment

[9] Since writing the above it has occurred to the author that the pieces of metallic iron, and the pittings known as "thumb marks" which they show, are due to the very high temperature developed by friction against compressed air in passing through the earth's atmosphere. Dr. Mallet has confirmed this, and points out that in the case of iron meteorites this temperature would of course be still further raised by burning. He has also told me that this is a commonly accepted theory of the cause of these characteristic pittings. The effect of this furious burning, produced by the friction against the compressed air ahead of the flying iron meteor, would probably be to make great irregular cavities or furrows on its surface, as in the case of the 14-ton Willamette meteorite described by Mr. Henry A. Ward in the *Proceedings of the Rochester Academy of Science*, Vol. 4, pp. 137-149, plates 13-18. Whether the spaces represented by such cavities or furrows were once partly filled with nodules of troilite is not of importance in this connection. Having this action in mind it can readily be seen how these furrows or cavities in meeting might cause unconsumed pieces of metallic iron to be liberated, which would then fall behind the main body of the meteor and still burning reach the earth after the collision. Not only "thumb marks" but so-called "ring" meteorites are perfectly explainable on this theory. It receives very strong support from certain iron specimens which have recently been found by us (and since this paper was written) in the trench for the pipe line between Cañon Diablo gorge and the crater. To these specimens when found a large amount of magnetic oxide of iron or iron shale was still firmly attached, and occupied the "thumb mark" pittings on the specimens as well as being adherent to the more or less flat surfaces. When it is found in the pittings, generally referred to by the term of "thumb marks," it is distinctly shaly in character and is seen to curve upward from the bottom of the cavity. There is much to recommend this theory, but may there not be truth in both this theory and in the one just mentioned?

of collision. It is very natural, therefore, to conclude that some of them must have been caught before they reached the surface of the earth by the outgoing rock fragments and silica which poured out of the hole at the moment of collision. They were doubtless all burning fiercely at this moment, and would have continued to burn, like those which were detached in the upper atmosphere, until all of the iron was converted into magnetic iron oxide, had enough oxygen been present to produce this result. However, some of them seem to have been smothered out when covered up by the silica and the rock fragments included in it. This would perfectly explain why some of them have iron centers and some of them do not possess this peculiar feature, and why the pieces of iron shale continued to rain down for some moments after the collision. An interesting fact which is perhaps worthy of note is, that these iron centers nearly always show a peculiar exudation of drops of moisture, often colored green, partly perhaps from the presence of nickel. This exudation, Dr. Mallet explains to me, is due to the presence of chloride of iron. It is singular, however, that only one of the pieces of meteoric iron which we have, one of those which was found in the trench for the pipe line and is referred to in footnote 9, exhibits this peculiarity, it being confined to the so-called iron centers, which have only been found in the shale balls which were entirely covered and surrounded by silica and rock fragments.

During the many visits which I have paid to this remarkable spot, I have made a most thorough search for any other stone than the sandstone and limestone fragments above described. I have found a number of pieces of flint and some pieces of eruptive rock, but in every case there was every reason to believe they had been brought there by Indians who visited this locality, as many of them were pieces of "matates," in which the Indians and prehistoric inhabitants of this country ground their corn; and especially because most of them were found in the near neighborhood of the Indian "hogans" or camps. I had another object, however, than that of trying to find pieces of igneous or eruptive rock, which was to find if possible some pieces of meteoric stone, on the theory that perhaps the great meteor, which by this time I had become firmly convinced produced this crater, was partly metallic and partly stony in composition; in other words, a siderolite. A most careful search of the country for miles around failed to reveal the slightest evidence in favor of this theory. None of the pieces of iron, and by this time several thousands of such pieces have been found on all sides of the crater, have attached to them any particle of stone; except indeed where some pieces of iron

shale have been found adhering to small fragments of limestone and sandstone, or in one small specimen which I found including them, showing conclusively that this iron oxide was in a liquid or fused state when it fell to the earth. In this specimen there are sealed together, as sealing wax would hold them, three small angular fragments of sandstone, and another piece of iron shale which I have is firmly adherent to a piece of limestone, upon which it evidently fell when in a melted condition. The latter specimen shows the green hydroxide of nickel. The result of my careful search has been the conclusion that there is not the slightest evidence in favor of the meteor having been part iron and part stone.

It is only fair to state, however, that upon one of my recent visits to the crater, or accurately on June 24, 1905, I found on the surface of the plain, about a mile and a half west of the mountain, a very remarkable aerolite or meteoric stone. This is as different from all the other meteoric specimens which we have examined, which have come from this locality, as one specimen can be from another. It is subangular in shape, having on one side a rather sharply pointed protuberance, with a generally round and smooth surface which is covered by quite a heavy film of oxide of iron. Two corners were broken off when I found it. The fracture exhibited was very fresh, in fact almost as fresh as the fracture produced by me when knocking off a piece of it for analysis, which was made by Mr. H. H. Alexander and is as follows: SiO_2 37.32%; Fe 22.30%; Ni 1.65%; Al_2O_3 2.53%; CaO 2.96%; MgO 23.02%; S 2.34%. See also description and analysis of the stone which will be hereafter published by Dr. Mallet.

It has some curious markings, looking as if it possibly had received a blow before it entered the earth's atmosphere, these markings being covered with the same film of oxide of iron which cover the rest of the aerolite. A comparison of this analysis with the analysis of the Cañon Diablo meteoric iron shows the wide difference between the two, and the fact that it does not contain a trace of platinum or iridium and relatively small percentages of iron and nickel, while every specimen which has been examined of the meteoric iron or iron shale found in this locality contains the first mentioned metals, is very significant and is in favor of the theory that the aerolite or meteoric stone specimen is not in any way connected with the others.

Now comes a story which is at least very interesting, for as a coincidence, if such it is, it is very remarkable. Two years ago, about January 15, 1904, while two of our employees at Coon Mountain were watching the camp—we had suspended operations during the winter—

they were awakened, so they told us, by a loud hissing noise, and looking northward saw that the heavens were brilliantly lighted, and while rushing out of their tent saw a meteor fall somewhere northwest of the mountain, between them and the railroad. We paid no especial attention to their story, and supposed that although they might have seen a meteor fall, it had come to the earth, if it came to the earth at all, many miles distant. However, if we have been able to fix the dates correctly, on the same evening, at the same moment, a few minutes before nine o'clock, the hour being fixed by the train schedule, Dr. A. Rounsville, of Williams, and Dr. G. F. Manning, of Flagstaff, Arizona, were travelling to Cañon Diablo station, where Dr. Manning had been called to visit a patient. Just before the train stopped Dr. Rounsville saw from one of the windows, on the south side of the train, a blazing meteor fall in the direction of Coon Mountain. According to Dr. Rounsville's statement Dr. Manning did not see the meteor fall, but only saw the very brilliant light produced by it. It is very probable that this was the same meteor that was seen by our employees at Coon Mountain. If so it would appear that our two employees saw it from one side, while Drs. Rounsville and Manning saw it from the other, the observers being about 12 miles apart. As accurately as I can determine, it was very near a spot at the intersection of the two lines of sight, a spot which of course they could not locate exactly, that I found the above described meteoric stone—the only one, so Mr. Volz, of Cañon Diablo, tells me, that has ever been found in this locality, and his intimate knowledge of the locality extends for a period of over fifteen years. That a small stony meteorite should have fallen on almost exactly the same spot on the earth's surface as the great Cañon Diablo iron meteorite fell many centuries ago, is certainly a most remarkable coincidence. I have stated the facts as accurately as possible, and I have no opinion to offer as to whether or not these involve anything more than a coincidence.

I have endeavored to describe in this paper as briefly as possible only such matters as would appeal to a geologist and which have come within my personal observation. Such as they are, after a very careful study of this locality, they do not leave in my mind a scintilla of doubt that this mountain and its crater were produced by the impact of a huge meteorite or small asteroid, and that this fell upon the earth almost vertically, with probably a slight inclination toward the north. As is explained above, the greatest effort seems to have been expended on the southern side of the crater, as evidenced by the walls of the crater itself and by the great amount of material thrown out on the

southern rim, and by the fact that this material is much more comminuted than similar material elsewhere on the rim, and by the further fact that on this portion of the rim alone do we find fragments of the yellow and red sandstone, which we know to be from the deepest strata of which fragments have been expelled from the crater. This theory is still further borne out by the fact that most of the shale balls and smaller meteoric iron specimens have been found on the northern rim, which position they would occupy if they fell slightly behind the meteor itself, and yielded more than it did to the retarding effect of the earth's atmosphere and to the force of gravity.

In using the words "northern" and "southern" in the above connection, I mean by "northern" any direction between northwest and northeast; and by "southern" any direction between southeast and southwest. However, the direction from which the meteor came is a matter which is not as yet susceptible of positive proof and is of probably small importance at this time.

To summarize, we believe we have proved the following facts:

First. That a great meteor, the whole or at least the outside of which was metallic in nature, did fall to the earth at this locality, and that it was so large that portions of it became fused and were detached.

Second. That this great hole in the upper strata of the Aubrey formation was made at the instant of time when this meteor fell upon this exact spot. Having proved these facts, the conclusion is unavoidable that this hole, which as we have seen cannot have been produced by a volcano or by a steam explosion, was produced by the impact of the meteor, which, even admitting that it retained some large proportion of its planetary speed, must have been of great size.

Having proved these facts, and having been prevented by wet silica, a material very difficult to penetrate with a shaft, from sinking with a horse-whim to a depth of more than 200 feet, we put down a number of drill holes in the hope of finding evidence of the meteor beneath the central plain in the crater, using the ordinary type of rotary well-boring machinery. Several of these drill holes encountered obstructions, at least one (and probably more) of which would seem to be meteoric, inasmuch as a magnet put down at the time was strongly attracted to the obstructing object and brought up from it material which assayed four-tenths of one per cent. of nickel. We were unable to force the drill past this obstruction. In another hole the extreme depth of 1,020 feet was reached. In this, however, over 100 feet of red sandstone (the Red Beds above referred to) was penetrated. This seemed to be in place and to form the floor of what,

judging by the results of artillery experiments, we have termed the inner or interior crater, somewhere in which we suppose the wreck of the meteoric body to lie. In *all* of the holes the material (silica, broken and whole sand grains and some pieces of dense layers of cemented material composed largely of carbonate of lime) brought up by the drill from underneath the lacustrine sedimentary formations shows when concentrated many minute fragments of iron shale or minute shale balls which contain an appreciable percentage of nickel, and are therefore doubtless meteoric in nature. It seems certain that much of the nickel has been leached from these fine particles of meteoric material, but notwithstanding this fact they invariably have been found to contain a small fraction of one per cent. of this element, and in other respects are generally similar to the fine particles of iron shale which we have found on the outside of the crater. This evidence, to say the least, is strongly corroborative of, if not absolute proof of, the above theory. To test it still further, however, we are now proceeding to sink with a steam hoist a double compartment shaft in the exact center of the crater. Unless we should be prevented by difficulties which we cannot overcome, this will be sunk to such depths as will demonstrate the existence, as we suppose in a fragmentary condition and several hundred feet below the central plain, or the non-existence of the extra-terrestrial body which, in my best judgment, produced when it collided with the earth the crater which I have endeavored to describe.[10]

[10] It should be borne in mind that this paper treats only of such facts as are of interest to the scientific world, and has no reference whatever to the commercial value of the discovery.

COON BUTTE, ARIZONA.

BY BENJAMIN CHEW TILGHMAN.

In Central Arizona, situated at approximately longitude 111° 1′ west and latitude 36° 2′ north, about five miles almost due south of Sunshine Station on the line of the Atchison, Topeka & Santa Fé Railroad, is situated the very remarkable eminence known locally by the names of Coon Butte, Coon Mountain and Crater Mountain.

This so-called mountain consists of a circular ridge from 130 to 160 feet in height, surrounding an almost circular cup-shaped depression in the earth about 400 feet deep and varying from 3,600 to 3,800 feet in diameter. Viewed from the inside, the crest of the ridge is elevated from 530 to 560 feet above the level of the flat interior plain.

The strata penetrated by this hole are, first, from twenty to forty feet of red sandstone; second, about 250 to 350 feet of a yellowish silicious limestone, or possibly more correctly a very calcareous sandstone; third, an unknown depth of a whitish or light gray sandstone, consisting of rather small water-worn grains but weakly attached to each other; fourth, about 80 to 100 feet of brownish sandstone in which it terminates. The contact between these latter strata is some 880 feet below the floor of the crater, but there is some reason to think it may not be in place but below its original position. These strata are of late Carboniferous formation, and in the surrounding plain lie perfectly level and conformably with each other. The uppermost, the red sandstone, being almost removed by erosion and only showing in spots upon the plain in the form of more or less scattered flat-topped red buttes, although it seems to have been nearly or quite continuous over the area now occupied by the interior edge of the crater.

These same level strata cover the plain in all directions for many miles. They are cut through by Cañon Diablo to a depth of some sixty to seventy feet about two miles to the westward of the crater, and near this gorge are two large earth cracks penetrating the strata to an unknown depth.

Immediately around the crater the strata dip outward in all directions from the center of the crater at an angle of about thirty degrees, and are raised from 140 to 180 feet above the normal position. This is the locality in which the Cañon Diablo meteoric iron has been found to the

amount of some ten to fifteen tons, and the question as to whether or not the hypothetical main body of the meteorite formed the crater in question in its impact with the earth has been the subject of numerous speculations and papers, notably by Professor Gilbert, of the United States Geological Survey, and others. The shape and general appearance of the crater, together with the absolute and entire absence of all evidence of volcanic action in or around it, manifestly inclined these early observers to decide this question, at least tentatively, in the affirmative, and they regarded the matter as worthy of further investigation. In pursuance of this object Professor Gilbert devised what he at the time, regarded as two crucial experiments to determine the presence or absence of a large amount of meteoric iron in the bottom of the crater. These were, first, a topographical survey of the hole and rim by which he made their contents approximately equal, and therefore gave no room for the presence of the bulk of the very considerable body required to produce such a hole by its impact; and secondly, a magnetic survey of the locality, which by its negative results was thought to preclude the possibility of the presence of any considerable mass of metallic iron in the vicinity. By these two experiments the question seemed to be authoritatively decided in the negative and the whole matter has remained in abeyance for many years.

The author of this present paper, having had his attention called to the matter by his friend Mr. D. M. Barringer, has examined the locality with great care, and with Mr. Barringer has done a considerable amount of development work there, and as a result of the facts disclosed thereby is very strongly of the opinion that the hole and its rim were produced in exactly the way at first supposed by the earlier investigators, and wishes here to bring to notice several points in support of the correctness of this theory which have escaped notice, or at least mention, in the papers of the earlier investigators of this most interesting locality.

It is first, however, necessary to criticise the so-called crucial experiments of Professor Gilbert, upon the results of which he definitely abandoned the theory of the meteoric formation of the crater in question, as, if these can be regarded as definitely settling the matter in the negative, there is no use in bringing forward facts looking towards its probability, no matter how plausible they may be. In regard to the first of these crucial experiments, that is, the alleged identical contents of the rim and the hole. In reply to this it can only be said that the author has also made surveys of this locality, and is very sure that the contents of the rim not only does not show the excess over that of the

hole that would allow for a large buried meteorite in the latter, but that it is short by many, at least several million, cubic yards of the quantity necessary to fill the hole at all. This, of course, if correct, and of that the author has no doubt, entirely destroys the weight of Professor Gilbert's reasoning, which was based on the assumed fact that everything ejected from the hole still remained around it. The solution is, of course, that in the time since the impact the rim has been reduced to its present dimensions by erosion, and the reason why it is or was so particularly subject to erosion will be taken up later when the formations of the rim are discussed more in detail.

As to the absence of sufficient magnetic perturbation, this is on its face a much more serious objection, as it undoubtedly proves the absence of any *one* large mass of iron near the locality, whether magnetized itself or only magnetized by the induction of the earth's magnetism, and also the absence of a mass of fragments of a magnetically neutral but magnetically permeable character magnetized by the inductive action of the earth. But it would have no bearing whatever as to the presence or absence of a mass of magnetized fragments each having sufficient coercive force of its own to be independent of the earth's inductive action, to the extent at least of retaining its own proper polarity irrespective of the position in which it is placed in regard to the terrestrial magnetic field. Such a mass of polarized fragments would form a series of closed magnetic circuits with practically no external field whatever. In support of this the following experiment was made. Two little cubes of magnetite about half an inch on one side were taken, which, as nearly as could be observed, had about the same effect on the magnetic needle. The weaker of the two, if there was any difference, was preserved intact, and the stronger was carefully broken up without loss to about the size of coarse sand. These fragments were then packed in a paper case but little larger than the original piece had been. It was found that this had to be approached to within an eighth of an inch of the compass needle to produce the same deflection that the original piece did at eight inches. Not only this, but it was found that one single grain of the sand-like fragments of the pulverized magnetite had more effect upon the compass needle when taken alone than the whole mass of them had when taken together. If the attraction of the mass of fragments of the supposed iron meteorite could be reduced in this proportion to its normal attraction when in a single piece, it might, on Professor Gilbert's own figures, lie within a very short distance of the surface of the present bottom of the hole.

The only remaining questions in regard to this so-called crucial experiment are: First, could the meteorite be reduced to this condition of physical wreck? and second, do the fragments have the necessary inherent magnetism? As to the last requirement, the overwhelming majority of the fragments picked up on the surface, probably ninety-eight per cent., do have this much magnetism, and some much more, and there is no reason to believe that the fragments of the main mass, if there be such, differ much, if any, in this regard from pieces collected on the surface.

Now, as to the probability of the shock of the collision breaking up the body of a solid iron meteorite of considerable size to sufficiently small fragments, it can only be submitted that the velocity and shock were enormous, and that it has been shown that ordinary soft iron at the temperature of liquid air is of about the brittleness of glass under the shock of a blow. Now, as it is practically certain that the body of such a falling mass would be at the actual absolute zero of space beneath its incandescent exterior, it seems much more than probable that the result of such a collision would be to reduce the projectile to an extremely fine state of subdivision in comparison with its original size. If these conditions of subdivision and magnetism are present, and it seems much more than probable that they are, the crux of the second crucial experiment is also escaped and we may proceed to consider the question on its merits, as nothing forbids us from allowing the possibility that the wreck of a great iron meteorite may underlie the bottom of the crater of Coon Butte.

Distribution of Irons around the Hole.

The early accounts of the locations of the finds of irons about this locality the author regards as of very doubtful value, for the reason that the great majority of these finds have been made by persons who were engaged in the occupation of selling them to museums and collectors, and who naturally did not wish to disclose the source of their supply to others. Also, these previous finds have been principally of large size, big enough in fact to enable them to take quite a divergent trajectory from that of the main mass, and too few to enable any reliable generalization to be drawn from their locations, even if the latter could be regarded as thoroughly reliable.

In the last two years the author and men in his and Mr. Barringer's employ have picked up more than 2,000 such irons, ranging in weight from 200 pounds down to a small fraction of an ounce, and have plotted the position of these finds upon a chart which shows plainly that the

principal locality for such finds is in the shape of a crescent surrounding the hole and strictly concentric therewith, and embracing its edges from the northwest to the east and having its line of greatest density about midway between these two points. These directions are taken from the center of the hole. The above distribution is by the number of finds regardless of their weight, as that of the scattering outlying finds is as a rule so much greater than that of the nearer finds as to entirely disturb the symmetry of the distribution. Moreover, the disposition of the smaller irons, which from their irregular forms and light weight could not have been propelled far from the mass from which they separated, is of more importance than that of the larger fragments, which would have more liberty of independent motion.

Distribution of Magnetic Oxide of Iron around the Hole.

In addition to the irons found around the hole there is a very considerable amount of magnetic oxide of iron similarly distributed, the disposition of which does not differ materially from that of the irons themselves. For although it is more generally distributed around the hole and the radius of the area upon which it is found is considerably greater, yet the fragments are arranged in the same general way with the axis of the group, which is also the line of greatest density of their deposition, extending away from the center of the hole in a direction between north and northeast.

Proof of the Meteoric Origin of the Magnetic Oxide of Iron.

The fact that this magnetite is of meteoric origin is proved from the following facts: First—It is found attached to and in some of the cavities of some of the larger irons. Second—Some of the larger pieces, although not the largest, are found to have centers of metallic meteoric iron. Third—The chemical analysis of the iron and the magnetite show a very close agreement between the proportion of metallic iron and the other metals present in the magnetite and in the meteoric iron. These other metals consist of nickel, cobalt, platinum and iridium, and another metal or metals of the platinum group. Fourth—The magnetite is fused and massive and at the same time stratified and laminated, and in general appearance different from any terrestrial magnetite known and closely resembles what would be thought, *à priori*, to be the appearance of such a product of iron melted and burned on the surface of a great meteorite in its passage through the air.

IDENTITY IN POSITION OF THE POINT OF IMPACT OF THE METEORITE WITH THE CENTER OF THE HOLE, AND IDENTITY IN TIME OF THE FORMATION OF THE HOLE WITH THE IMPACT OF THE METEORITE.

We thus have two different meteoric materials distributed over the rim of the hole and the surrounding plain on areas symmetrical about the same line, which is a line drawn in a north-northeasterly direction from the center of the hole. And also each of these areas closely embraces the hole and there terminates. For, with few exceptions, no iron nor magnetite has been found on the surface within the hole, and these exceptional pieces were found close to the wall. and may have fallen in by ordinary weathering action from the cliffs along with outside surface material. This brings these meteoric materials into close relation with the hole, which cannot be accidental, as if the shower of meteoric iron and magnetite fell after the formation of the hole, by other agencies, it is inconceivable that the densest portion of the shower of each material should coincide accurately with the northeasterly rim of the hole and yet none fall into it, although scattered individuals of each shower are found around the hole on all sides. Whereas, if the shower occurred before the formation of the hole, it is equally inconceivable that the fallen material could be found most thickly on the surface of the rim, composed of material ejected from the hole. To further assure the absolute identity in point of time of the fall of meteoric material and the formation of the hole, cuts and shafts were made in the débris composing the rim, and up to date over one hundred pieces of meteoric material have been taken from the ground, at distances varying from six inches to twenty-seven feet below the surface, mixed with the rim material and under large imbedded rocks. In many places it was absolutely impossible, from the slope of the ground and other circumstances, that they could have gotten where found except by simultaneous deposition with the broken material forming the rim. In one shaft seven pieces were found with fifteen feet of vertical depth between the highest and the lowest, which was twenty-seven feet below the surface of the ejected material.

THE RIM.

This consists, as has been briefly stated before, of a circular ridge of from 130 to 160 feet high closely surrounding the hole. A generalized description of its profile would be somewhat as follows: Beginning at a point on the inside of the hole on a level with the surrounding plain, the surface of the rim consists of the edges of the strata which should

normally be lying level some 150 feet below the surface. These strata themselves dip downward and outward from the center of the hole at an angle of, on the average, about thirty degrees, although this varies in places from more than vertical or inclining backward to about ten degrees. The strata themselves are crushed and shattered to an extraordinary degree, and the surface of the rim slopes upward and outward from the center of the hole at an angle of from fifty to eighty degrees; possibly sixty degrees would describe the general shape better than any other slope. Considering the shattered and disintegrated material of which these cliffs are composed, it is remarkable how little talus has fallen from them. This slope continues up almost to the top of the ridge, although here and there are flat benches in it both at the junction of the yellow limestone and the red sandstone and at partings in the red sandstone itself. From fifteen to forty feet from the top of the ridge on the inside is located the top of the red sandstone, which was the original surface of the plain; at the place of impact and from this point the ridge slopes outward at the ordinary sliding angle of loose materials, somewhat less than forty degrees, to its summit. The summit of the ridge is of necessity a closed ring and is sharply serrated into peaks, and the colls between these serrations do not exceed thirty to forty feet in depth but their slopes are steep, often ten to twenty degrees. There is a marked low place in the rim, extending over nearly one-sixth of its circumference on its northern side. On the outside no description will suffice for all sides. The greatest amount, by far, of the material thrown out of the hole is found in the southern quarter of its circumference, and here the rim is almost flat on top for a number of yards and then slopes outward at an angle of only seven degrees for some 900 feet, where it ends in a sharp slope of some twenty-five feet high at an angle of some twenty degrees. Beyond this is a thin cover of ejected material and detached and partly buried limestone fragments which extend for a considerable distance; some of the latter having been thrown nearly a mile from the edge of the hole. The actual surface of this southern side of the rim consists largely of blown sand, as the winds in the country are strong and storms frequent and their usual direction is from the southwest. On the eastern, northern and western sides the ridge is thin and sharp; in many places not over a yard or so in thickness at the very top and sloping outward very sharply, in places up to thirty degrees, for about half its height, and then more gradually at some five degrees until it joins the plain. The general surface of the outer slope is not at all a smooth cone of the angles above stated, but is cut up into hills and hollows and every

imaginable subfeature to a very great degree. This is almost entirely due to the irregularity of its deposition, slightly modified later by the action of water. The surface material of the outside of the rim, where it is not covered with blown sand, as on the southern side, is composed of the broken débris of the three strata through which the hole penetrates, piled together in the utmost confusion and disorder, pieces from all the three strata being thrown together in the most intimate mixture with a slight tendency towards inversion in the order of their deposition. That is, there is rather more of the red sandstone in the deeper portions of the rim than on the surface, while on the surface the limestone and white sandstone predominate, with here and there large areas of unmixed white sandstone lying on the surface. In size these fragments vary from huge rocks forty to fifty feet in length and weighing thousands of tons down to impalpable powder and all intermediate sizes, and many of the rocks are so crushed and broken that they barely hold together. And imbedded in the deposits of impalpable powder are many pieces still retaining the form of rocks, still showing the stratification and bedding planes distinctly, but so crushed as to have lost all solidity. These crushed rocks in many cases have been subjected to such pressure that not only is their consistency as rocks destroyed, but even a certain proportion of the sand grains composing them have been utterly destroyed and they can be rubbed between the fingers to a fine powder, the grains of which will average much less than that of the sand grains originally composing the stone.

This powder forms a very considerable proportion of the substance of the rim. It is not merely a filling material occupying the interstices between the rocks, as might be a rock pile with fine material water-washed or wind-blown into it until all the crevices were filled up solid. But it occurs in distinct deposits, sometimes alone and entirely free from rock fragments and sometimes mixed with a larger or smaller proportion of rock fragments. When this mixture occurs, the rock fragments are usually so far apart that each rock is entirely surrounded and supported by the powder. Such deposits of powdered rock are often overlaid by a cover of broken rock many feet thick, the individual rocks in places weighing a hundred tons or more. In fact, as far as at present developed, it seems to be a very general feature of the structure of the rim that the lowest material, that lying upon the top of the original surface, is a greater or less depth of this powdered rock, sometimes alone and sometimes mixed with rock fragments, and that on this rests and is supported the whole of the detrital cover which constitutes the crest and outer slopes of the rim.

The Interior of the Hole.

From the point on the level with the exterior plain on the inside of the rim the walls of the hole slope downward and inwa d at a constantly diminishing angle for a distance varying from 50 to 150 feet, in the same formation as above described as the base of the inside of the rim. At this point the rock walls begin to be covered with a rocky talus corresponding in all respects with the rocky cover on the exterior of the ridge. For about half the circumference of the hole the yellow limestone extends downward to the talus, and for the remaining half it exposes more or less of the whitish sandstone below. The white sandstone is a much weaker rock than the yellow limestone, and at their contact it is noticed that the former is much crushed and disintegrated by the pressure exerted by it in lifting the limestone. This stratum of crushed sandstone varies in thickness up to some ten or fifteen feet as a maximum, and in some places, usually immediately below the limestone, it is reduced to a bed of sand grains absolutely unconnected with each other, and in places a small proportion of even the sand grains have been crushed and broken to fragments and powder.

The very top of the talus slope is in places at an angle of forty degrees, but usually much flatter down to thirty and twenty-five degrees, this rapidly becoming less and less as it recedes from the cliffs until it is lying at an angle of not more than six degrees at the point where it disappears under the central plain. This central plain is an almost circular area of about 1,800 feet in mean diameter, with a surface generally flat but gently rolling within a limit of fifteen feet, with its lowest point a few feet to the east of the central meridian of the hole and about sixty feet south of the center. Shafts have shown the rocky talus to extend under this central plain at about the same angle that it has above for a distance of at least 400 feet, at which point it is some forty-seven feet below the surface and about twenty feet thick. This talus does not extend entirely across the hole. It is absent at points 50 feet southwest and 200 feet southeast of the center of the hole. Exactly where it terminates is not known.

The Silica.

It is here necessary to describe more minutely the material of the filling of the central plain. This is identical with the impalpably powdered rock referred to briefly above in the description of the rim. This material, of which there are millions of tons in the rim and the bottom of the hole, consists of the rock of the strata concerned reduced

to an extreme state of subdivision. It seems to have been produced principally from the white sandstone, for it is mostly as white as snow and consists of over ninety-nine 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 wearing or rounding are anywhere visible upon its particles. In some areas the material is composed of this material exclusively and it gives no internal evidence of the manner of its production. 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 and less and less silica (as we have gotten to call the impalpable powder, for want of a better short descriptive name), and then more and more *unbroken* sand grains, and then little bunches of sand grains still adhering together, and so 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.

The Interior of the Hole (resumed).

In the central area over which the talus does not extend, the line of the original surface upon which the talus was deposited, and on which the subsequent filling, which now covers this and also a portion of the talus, was deposited, can be very readily recognized. All the material lying above the talus, and above this surface, is horizontally stratified and contains organic remains, such as small shells and no (or but very few and small) rock fragments, while that below this line has no trace of stratification nor of organic remains and contains many rock fragments. In one shaft a beautiful series of rock fragments was observed about twenty feet thick and about twenty feet below the talus, in which the natural order of the rock in place was exactly reversed; that is, the red sandstone was deepest and the yellow limestone and whitish sand-

stone in that order above it. This series naturally suggested the idea that the surface stratum, having received the blow and started on its aerial flight first when the hole was formed, finished its journey first and was consequently deepest imbedded in the silica which was in process of filling the hole made during the flight of these rocks in the air. Almost immediately after the fall of the last of this series—which must have fallen directly in place as found and which is comparatively rare, as the rocks expelled from the hole had usually (apparently) a greater outward radial component in the direction of their flight—came the rush of talus rocks, which fell in masses on the funnel-shaped cliffs surrounding the hole and forming the interior of the rim, and rushing inward covered the surface of the bottom of the hole to a considerable distance from the foot of the cliffs, in fact probably all except a small area of 300 or 400 feet in diameter in the center. Then, during minutes and hours, settled down over everything about the locality the dense cloud of dust to the depth of many feet. This dust, being the finer portions of the silica above described, was then washed into the center of the hole, filling it in some places a hundred feet deep. This was apparently done by successive wet seasons for many years, during which time, at least in the rainy season, a shallow lake occupied the bottom of the hole; over the bottom of which the sediments were distributed in yearly level strata by wave action. The presence of the rare stone fragments in these sediments and the few now on the surface of the interior plain, far beyond any possible place to which they could have rolled if detached and falling from the cliffs, is difficult of explanation unless it be due to a frozen condition of the central lake, on the surface of which these rocks (and they have not been observed of large size) could slide and on which a very slight initial velocity would take them to their present position, to be there deposited upon the melting of the ice. Ten to fourteen inches of ice was formed on the open water in reservoirs in this locality during the last winter.

No very exact estimate of the amount of this silica dust washed down from the sides of the hole can be made, as the shape of the original bottom of the hole is unknown. It is irregular and in places the sediments are 100 feet thick, and it covers an area of about 1,800 feet in diameter. Moreover, it evidently fills the interstices of the talus of unknown thickness extending over a much greater area. It can only be said that it is a very large amount, many million tons. It probably covered all of the exterior of the rim to an equal or greater depth, all of which is gone. In fact it seems extremely probable that the rock cover of the rim, which is now its most prominent feature, on the sur-

face of which both rocks and meteoric material are much more frequent than in the substance of the rim below, is itself a concentration of material like the present rim, below the rock cover, of mixed silica powder and rock, from which the silica powder has been washed away until the accumulated rock cover, and probably the decreasing rainfall of the country, has preserved the rim now remaining beneath this rock cover in its present form. Also, upon the accident as to whether or not there was a strong wind blowing at the time of the formation of the hole would determine whether or not a great portion of the fine powder produced ever settled on or around the rim at all. Hence, in the opinion of the author, the deficiency in the contents of the present rim to fill the existing hole, and this fact is also a valid objection to the use of their comparative bulks as having any bearing whatever upon the probability of the wreck of the great meteorite lying beneath the bottom of the hole.

The Traces of the Luminous Tail of the Great Meteor.

It occurred to the author that if the meteoric theory of the formation of this crater was correct, such a projectile falling through the atmosphere at the requisite speed must have been surrounded by the usual luminous tail always accompanying such objects. And that as no meteoric material except nickel-iron and magnetite containing nickel had been found in the vicinity, it was a fair deduction that the surface of such meteorite, if it ever existed, was of nickel-iron, and that the luminous tail in such case must have consisted of atomized particles of incandescent magnetite. Pursuant to this idea a search for this material was made with magnets about the locality, and it was found that its presence was absolutely universal over the whole locality inside the hole and out for as far as observed, somewhat over two miles from the hole. It consists of a blackish-gray rather fine-grained powder, strongly attractable by the magnet, crystalline in structure, but not at all so in shape, being in small torn irregular masses with generally intensely fine grains of silica powder adhering so firmly to its surface as to suggest adhesion while in a state of fusion. Of very rare occurrence among it are absolutely round balls with a fused polished surface like intensely fine shot. These, it is supposed, have had time to solidify in the vacuum behind the flying meteor free from the fierce rush of air that had solidified the usual grain in any shape whatever, and they were enabled thus to assume the usual shape of liquid drops.

With considerable labor enough of these particles were collected for analysis, and they were found to contain nickel in but little less

proportion to their iron than found in the irons themselves and in the larger pieces of magnetite. This is not a usual substance and, so far as known, is not a constituent of any of the rocks in the neighborhood of the area anywhere adjacent to the same.

On the Fine Silica Powder under the Base of the Rim.

The meteoric theory of the formation of this hole being thought untenable by some previous investigators and the ordinary volcanic action being absent, there has been invoked, to account for its formation, the theory of a single steam explosion, and in fact this theory has been elaborated so far as to try to imagine a state of stress produced by steam which was set off by the blow of a small falling meteorite, much in the same manner that a percussion cap discharges a gun. This was evolved to account for the simultaneous deposition of the meteoric material and the rim. This has been urged in spite of the fact that during the time that the local heat had been increasing in the wet strata there would have inevitably been hot spring action, and that the same thing would have occurred long after the relief of the explosion, and that the traces of this action would have been but little, if any, less evident than those of ordinary volcanic action and are nevertheless totally absent. Yet there is one fact obvious to all observers to-day, to which the author desires to call attention, which makes any such theory of the explosive formation of the hole utterly impossible. This is the fact that the rim is generally founded upon a more or less deep layer of fine silica powder. There is no doubt that the rock fragments forming the rim were all deposited within a few seconds after the hole was made. The great majority were propelled too short a horizontal distance to have had a long trajectory in the air. Now if they had been propelled by a compressed elastic medium, it is evident that on the explosion these compressed gases would have instantly assumed a much higher velocity than the heavy rock particles to which they were imparting velocity and, sweeping by them, would have carried with them every particle of silica powder which had been made by the crushing and yielding of the strata to the strain, and the rocks of the rim would certainly and necessarily have fallen on the bare upturned stratum which had previously formed the surface of the ground around the edge of the hole. 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 such substances yield to either a pressure or blow in excess of their power of resistance is, that a cone of material with an apex angle of about ninety 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 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. With ordinary stone this is usually about thirty degrees, but always must be less than forty-five degrees, which is its limit. This crater-like cone is small at first and remains so for weak impacts or small pressures, but if these are greater the process is continued by the formation of larger cones of compressed powder, deeper in the body of the material, which relieve themselves by bursting up wider craters, until the force of the pressure or impact is no longer able to continue the process and the penetration ceases. Thus the depth of the crater always bears a definite relation to its width, and in large impacts it is found that the crater is always surrounded by a cone of cracked and shattered material, which would have been the next material to be expelled if the energy of the blow had been sufficiently great to accomplish this.

The bearing of this upon the formation of a rim composed in part of fine powder is as follows. The broken rocks and débris that are expelled from the hole get their velocity imparted to them by the push of an inelastic powder behind them 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; and the powder having started under the rock masses, there is a strong tendency for con-

siderable amounts to remain under them on the final deposition of the mixed masses of material in the rim of the hole after their expulsion.

The Crushed Sandstone at Its Upper Contact with the Limestone and the Shattered Cliffs around the Hole.

The author desires particularly to call attention to these features of the walls surrounding the hole. It is very distinctly marked. It is unqestionably due to excessive pressure. If this cone and crater are due to any form of volcanic action, it is difficult to see how this crushing occurred. The sandstone is amply strong to carry its over-burden without crushing; in fact before the general erosion of this country it probably carried many hundreds or thousands feet more without crushing and pressure from above or below as equal in its crushing effects. Then suppose pressure to gradually accumulate and the overlying strata to bulge up into the dome of which the present cone is the base; there could be accumulated but little excess of pressure to crush the sandstone during this rise, as it would be as free to go up under the weight of its overlying strata as it was to support them quiescent, for such motion would be very slow. Then comes the giving way and the explosion, and the result to the remaining rock left around the hole is a relief from pressure and not an increase of it. It is difficult under any of these conditions to imagine any force tending to crush this sandstone and shatter the surrounding walls in the manner that they are shown to-day. It is difficult to discuss the steam explosion theory, for the reason that nobody has ever seen one or known with certainty of any such action, except the blowing off of the tops or sides of ordinary volcanoes in activity in this manner, which is as different as possible in its effects from the so-called maars. There are a lot of holes, not very uniform nor congruous among themselves, which, for want of a better explanation of their formation, have been ascribed to this source, and to which class Coon Butte has been assigned by Prof. Gilbert, as the result of his investigations. This crushing of strata and shattering the walls is, however, the direct and obvious result of the blow of a great projectile. There is almost instantaneously generated an overwhelming pressure deep down in the rocks, tending to lift the surrounding strata at 1,000 or more feet per second. The great weight and inertia of these strata oppose an enormous obstacle to this sudden movement, and the crushing strains developed crush up the weakest rock until the necessary yielding and velocity have been imparted to the overlying strata. The shattered cliffs and upraised rim show the rock started from its position and in partial transition from the hole, from which it would have been

expelled entirely had the blow been a little harder. In this case, however, another rim of crushed and shattered rocks would have been upraised around the enlarged hole.

Comparison of the Crater with those Produced by Lesser Projectiles.

The craters formed by the impact of various small projectiles, mostly of soft materials and at low velocities, have been studied in connection with the formation shown in this locality by others, notably by Professor Gilbert, and the forms shown to bear a rather close resemblance to the crater of Coon Butte and its rim. Continuing these comparisons, however, to more violent impacts of heavier bodies at higher velocities, a still closer parallel is noticed. The material for such comparisons is furnished by the investigations of the several more advanced military nations upon the effects of the impact of round shot on masonry and solid rock. These investigations were undertaken about sixty to seventy years ago, with the object of ascertaining the best effects of the ordnance of that day in the breaching of walls, etc., in bombardments. The general result was to establish the fact that the impact of the projectile produced a comparatively shallow crater of conical form about five times the diameter of the projectile, terminating in an almost cylindrical hole some one and a half to twice the diameter of the projectile within which the projectile or its wreck was deposited. This hole was surrounded by a cone of broken and shattered material which started at or below the bottom of the cylindrical hole and enveloped the actual cavity. The depth in solid limestone and sandstone, at velocities at which the best cast iron shot would break up, and estimated, from the powder charges used, to be somewhere about 1,800 feet per second, was a fraction under two diameters of the projectile used. The depth was observed to increase much more slowly than the velocity of the shot, and more slowly still after the velocities at which the shot would break up had been attained. The author has observed from direct experiment that the crater still retains its round form even when the impact of the projectile is as far removed from the vertical as twenty degrees; the only noticeable effect being the greater shattering of the side of the crater against which the angle of impact causes the projectile to bear with most pressure in its penetration. These experiments were made with a high power, small-bore rifle, having an initial velocity of about 2,300 feet per second.

Confirmatory Evidence Obtained by Deeper Exploration Inside Crater.

As, in the judgment of the author and Mr. Barringer, the outside indications all agreed with the theory that the crater had been produced by the impact of a great meteor, it was determined to explore the interior for additional confirmation of this fact and also to endeavor to reach the main mass of such meteor. In pursuance of this object five small prospecting shafts have been put down of depths varying from 30 to 200 feet, and also five bore holes from 305 to 1,003 feet in depth. Although none of these has struck the main body of the meteor, ample confirmatory evidence of the theory of the meteoric formation of this hole has been obtained.

Rock in place in the bottom of the hole has been struck, in the opinion of the author, in two places. First, in shaft No. 2, 510 feet from the center of the hole, in a direction fifteen degrees north of east from the said center and at a depth of 147 feet; and secondly, in bore hole No. 5, at a distance of 250 feet southeast of said center, at a depth of 890 feet. The shaft penetrated the rock in place fifty-three feet and the bore hole 113 feet. In the shaft the rock, while undoubtedly in place, had been so crushed and disintegrated that its substance was that of a bed of loose sand. But the planes and marks of stratification were complete and unbroken and showed an upturning of the crushed, previously level strata to an angle of about forty-five degrees in a direction away from a point slightly north of the center of the hole. In other words, this rock in place dipped downward and outward, closely corresponding to the rock exposed in the walls of the crater above, but was much more shattered and disintegrated.

The rock in place, penetrated by the drill hole, could be distinguished only by its hardness, and, of course, its condition could not be examined. In both cases the rock was sedimentary sandstone without any sign of heat action whatever, either volcanic or by the action of hot water.

The general description of the filling material in the deeper portions of the hole is as follows: For a distance of 60 to 100 feet from the present bottom of the crater, about its center, the hole is filled with sedimentary material evidently deposited in the bottom of shallow water. It is stratified horizontally, as though the sediments had been washed down from the surrounding walls, either by successive wet seasons or successive violent rain storms, and has been deposited in approximately level sheets by wave action in shallow water. This stratified material is full of small shells of various kinds, and contains

a number of hard level strata a few inches in depth running through it, as though at times the water had disappeared and the sediments had become baked and indurated by exposure to the sun. Around the sides of the crater this sedimentary filling is much shallower, and its bottom is marked by a bed of broken rock talus which extends outward from the edge of the central plain, dipping towards the center at about six or seven degrees. How far this talus extends is unknown, but at 400 feet from the edge of the central plain it is forty-seven feet beneath the surface and about twenty feet thick. In the neighborhood of the center of the hole this sheet of broken rock does not exist over an undetermined area, in which the sedimentary deposit was considerably deeper than around the edges to the depth above noted. Below the sedimentary deposits in this central area, and underneath the talus elsewhere, the crater is filled with powdered rock of an almost impalpable fineness. In some places this is snow-white and contains over 99.5 per cent. silica. Elsewhere it is of a slightly yellowish tinge, and in places is cemented together by redeposited carbonate of lime. Down to 300 feet below the interior plain there is no change in this material. Through it is scattered sparingly fragments, more or less shattered, of the three strata penetrated by the hole, namely, red sandstone, yellow limestone and white sandstone. There is no order of their deposition, but the three materials are mixed indiscriminately. In shaft No. 2, however, at a depth of sixty-seven feet, there is a series of boulders, scattered rather thickly through the powdered silica for about twenty-five feet in depth, in which the natural order of occurrence of the rocks is exactly inverted. That is, fragments of the surface red sandstone are the deepest, above which come fragments of the middle strata of yellow limestone and at the top are situated fragments of the deepest strata of white sandstone. This formation suggests the idea of the surface material, having first received the impact of the meteorite, started first on its aerial flight, followed by the lower materials in turn as they were reached, and retained this order when falling back into the hole as it was being filled up.

In the central portions of the hole, below 300 feet, the proportion of broken and unbroken sand grains among the powdered silica begins to increase perceptibly, and slightly below this point meteoric material, of a character which will be described below, begins to be noticeable. The filling material continues to get coarser and coarser and contains more and more meteoric material with the increasing depth until the 500-foot level is reached. This point is 900 feet below the former level of the rocky plain at this point and about 1,100 feet below the crest of

the rim at its highest point. At the 500-foot level there is but little powdered silica; the material is mostly of broken and unbroken sand grains. Below this point the powdered rock is again met with which is very fine. It is almost, but not quite, as fine as at the surface. This change occurs quite suddenly and is accompanied with a progressive scarcity of meteoric material which is completely absent at 550 feet. From this point down there is again a gradual increase in whole and broken sand grains contained in the material, and at 860 feet it changes color quite suddenly to a reddish-brown sand, which at 890 feet, from the sudden change in hardness and the difficulty of drilling, is almost certainly rock in place. This continues to the fartherest point reached, namely, 1,003 feet below the level of the interior plain.

It is submitted that, regardless of the fact of whether or not the last 100 feet is solid rock or not, that the material penetrated for the last 150 feet must be rock in place; for this reason: The change from white sand to reddish-brown sand is quite marked and sudden, and if this material had been stirred up by the passage of any projectile through it, it would have been so mixed as to be indistinguishable, or at any rate would certainly not have had a definite boundary line between the two materials. For 180 feet below the surface of the plain the filling material is absolutely dry. At this point dampness is perceptible, which increases with the depth until at 200 feet the material is nearly saturated with water; which fact determined the stoppage of the shafts at this point and the use of well-drilling apparatus for the deeper explorations.

Meteoric Material Found in the Lower Portions of the Hole.

The meteoric material found, mixed with filling material, in the hole from the 300- to 500-foot levels is of the following kinds: First, magnetite in the form of scales, closely resembling hammer slag produced by a blacksmith in welding and forging iron. These films occur in varying proportions among the sand. Second, of more sparing occurrence are small particles of brownish magnetite, resembling that picked up on the surface. Third, sand grains wholly or partially coated with magnetite and small bunches of sand grains cemented together with magnetite. The first and third forms have undoubtedly solidified from a state of fusion; the first alone, and the latter when the fused magnetite came in contact with one or more grains of the sand. The appearance of this last form under the microscope is precisely that of broken stone smeared with, and cemented together by, such a fused material as asphalt when prepared for the foundation of an asphalt street. Second,

silicate of iron in forms exactly duplicating the first and third forms of the magnetite above specified; that is, in films and adhering to sand grains. This material was at first thought to be magnetite on account of its exact similarity in appearance, except that it was of rather a darker color. But it was distinguished from magnetite by observing its almost complete indifference to the magnet. Analysis confirms this fact, and these blackish scales leave a snow-white skeleton of gelatinous silica of the shape and size of the original fragment on prolonged boiling in hydrochloric acid.

It is supposed that this material was formed when the fused magnetite and silica from the powdered rock were mixed together at a heat sufficient to cause combination. Both these forms contain but a very small proportion of nickel, and as they both occur below the water level in the silica it is probable that the greater portion of the nickel has been leached out of them, on account of the greater solubility of the nickel oxide and the extreme fineness of subdivision of the material. Third, there has been found among the filling material in a few localities, but much more sparingly than the magnetite or the silicate of iron, small round globules of metallic iron surrounded by an envelope of magnetite. These small globules range from one-twenty-fifth to one-fiftieth of an inch in diameter. While it is conceivable that silicate of iron and magnetite might occur in the wreck of terrestrial strata of the character found in this locality, it is extremely improbable, because there is no trace of any of this material in the unpulverized rock forming the strata in question. But it is absolutely inconceivable that these little metallic spheres with their coating of magnetite could exist in any sedimentary strata, such as alone occur in this locality. Small particles of terrestrial metallic iron have, as is well known, been found in certain localities, but not in rock of this nature. And they could not have resisted complete oxidation if the original rock in which they were found had been weathered away and its material subsequently formed into sandstone. Moreover, if they had resisted such complete oxidation, the coating which would form around them would be ordinary hydrated sesquioxide of iron and could not be magnetite. And also such metallic iron as has been found in terrestrial strata has always been found in strongly basic rocks. Whereas the rocks in this locality are extremely acid, in fact almost pure silica.

Two other remarkable phenomena have been noted in the water pumped from these bore holes. This water is clear and without taste or odor, but it contains a small amount of flocculent gelatinous silica floating in it. Also in several places, and it was noted that these places

were at the levels at which most of the other meteoric material was found, the first water drawn from the hole in the morning, after standing over night, was found to contain a very considerable amount of dingy green protoxide of iron suspended in it, which upon exposure to the air rapidly oxidized and became converted into a reddish-brown hydrated sesquioxide. The only explanation that can be offered for these phenomena is that, probably, the extremely thin films of silicate of iron have had their iron dissolved by long immersion in water containing carbonic acid, leaving their gelatinous silica skeletons suspended in the water, and that the solution of carbonate of iron may later have lost its carbonic acid in some way, possibly by absorption by lime from the limestone strata, and precipitated out of the protoxide of iron which remains in suspension in the water. It has also been noted that from the deeper portions of the hole, below 600 feet, where the meteoric material has not been found, that the sand itself showed a very minute trace of nickel, which has probably come from the leached meteoric material above it.[1]

The Possible Encounter of Larger Meteoric Material.

The small prospecting shafts above referred to were stopped by water at 200 feet before penetrating to levels at which later explorations showed the meteoric material was to be encountered. This stoppage was caused by their small size and their light timbering, which

[1] Since this article was written, the author has discovered the presence of a small amount of very finely divided metallic iron among the silica. This has been found, so far, in every sample examined, from the north and south rims as well as from the filling of the central plain. It varies in amount, but its proportion is extremely small. The largest amount has been found among the silica from the filling of the crater, where it exists to the proportion of nearly a quarter of an ounce to the ton. From the north and south rims the amount is less in the order stated; from the south rim it does not amount to a twentieth as much as from the interior of the crater.

This metallic iron was detected, separated and estimated as follows: The silica was passed through a magnetic separator and a very small amount of magnetic material of a dark color collected and weighed. A weighed portion of this was carefully ground in an agate mortar, wet and the finely powdered material washed away from time to time until the material was reduced to about one-tenth of its original bulk. In this residue, by the use of a glass, could be observed a great number of bright, white, shining metallic scales and spangles. They were strongly influenced by a magnet. A solution of copper sulphate was then poured over this residue and the bright white spangles were observed to turn dull red-copper color at once. The finer portions were then observed to be indifferent to the magnet, although the larger ones were still attracted. On prolonged treatment all became indifferent to the magnet. The residue was then washed and the copper in it determined, there being none in it before treatment. As a check the iron was determined in the copper sulphate solution used and wash waters, the solution being pure. Distinct traces of nickel were also observed in this material.

rendered them unfit to penetrate strata in which pressure tending to crush them would be encountered. The five bore holes were all put down within a very small area. Their object was to find out how far down this hole extends. This object was attained by the fifth alone. Three of the previous holes were stopped by encountering substances which, although not determined with certainty, were in all probability larger fragments of the great meteor. The first was found in bore hole No. 1 under the following circumstances: This hole had been put down about 300 feet, being four inches in diameter, when the piping stuck, and a two and one-half inch pipe was then put down to 420 feet and there stuck. A one and one-fourth inch pipe had been put down 630 feet and withdrawn owing to a change in drillers. The hole thus remained idle for some ten days. On resuming work it was found to be filled up to about 380 feet, that is to about forty feet above the end of the two and one-half inch casing. When the drilling was resumed the small pipe very rapidly cleared out the casing and the hole below until it arrived at 480 feet, where it encountered an obstacle that could not be penetrated, although the hole had previously been 150 feet deeper. Against this obstacle the drill was kept rotating two days. It was so hard that it was penetrated less than two inches and would dull the drills almost immediately. It was while rotating upon this obstacle that brown magnetite, resembling that found upon the surface, was gotten from the hole and also the greater number of little iron spheres with magnetite coverings. The obstacle proved impossible to penetrate, and it was attempted to remove it by jetting large quantities of water and also dropping the bit upon it as hard as could be done with so small and weak a line of pipe as one and one-fourth inch, and by this means it was after a long time forced down nearly a foot, thus proving that it was a comparatively small object. As it was impossible to get through it or around it, this hole was then abandoned. The one solution of this matter can be that the hole passed very close to a small fragment of meteoric iron or magnetite when it was first put down, and that the subsequent washing of water through the hole had loosened up this object, which subsequently, by the caving of the hole, slid across it and effectually stopped further progress. The next hole, No. 2, was stopped in much the same manner by an obstacle of apparently the same character at 300 feet. This hole was, however, using a four-inch pipe, and on this account and its less depth the object was much more accessible. Much less magnetite and other meteoric material was obtained from this obstacle than from that in No. 1. It wore out the tempered steel drills in the same way. A drill with chisel edge was

then put in and the strong and heavy pipe line, weighing about 3,500 pounds, was then dropped on this obstruction a great number of times. It was driven a very small fraction of an inch each time, possibly between two and one-half and three inches in all. The pipe line was dropped about eight feet each time, which was as much as it would stand without collapsing. And each time the drill struck the obstruction it would ring with a clear metallic sound and rebound some eighteen inches to two feet. This was almost certain proof of the metallic nature of the obstacle, as stone would have crushed and given a dead impact without appreciable rebound.

A small magnet of about half pound in weight was then lowered down the hole on the end of a string. This magnet repeatedly attached itself to the sides of the iron casing in going down, so that ample opportunity was offered to feel the pull necessary to detach it from adhering by its own magnetism to a piece of unmagnetized iron. The pipe casing during this trial was lifted some fifteen to twenty feet above the obstruction. When the magnet passed below the end of the pipe casing it descended perfectly free until it reached the bottom, where it attached itself very firmly to whatever object obstructed the hole, and required a pull of several times as much force to detach it as was necessary to detach it from adhering to the pipe casing at nearly the same depth, and consequently with nearly the same weight of line supporting it. This was repeated many times and there was no doubt about the facts as stated. It was then endeavored to get an impression of the bottom of the hole, but suitable material was not at hand and the impression was not very satisfactory, although it seemed to show a flat bottom to the hole with a crack about one and one-fourth inches wide and of unknown depth with roughly parallel edges across the bottom of the hole. This shape was not like anything observed on any of the surface irons, but was less like what might be expected in a rock boulder. This crack caught the drills and made it almost impossible to rotate upon this obstruction. The magnet brought up a small quantity of iron chips, some of which were undoubtedly from the pipe, having been cut from it by the machinery for rotating it, but others seemed of different nature and fracture from either pipe chips or the steel of the drill, which, moreover, had not lost material of this size and shape. They were thought to be meteoric iron. On analysis the mixed metallic iron gave .4 per cent. of nickel. As the greater proportion of this iron was undoubtedly composed of pipe chips, free from nickel, this was thought to be strongly confirmatory of the probability of the fact that the doubtful material was actually meteoric iron.

The pipe was then withdrawn and three sticks of No. 1 dynamite put down into the hole, in contact with this obstruction, and there exploded. This explosion, which would have certainly shattered any boulder small enough to have been driven by the pipe line even in the open air and much more so under 100 feet of water tamping, had no effect whatever upon the obstruction, except to drive it downward about two inches; and when the pipe was put back into the hole and again dropped on the obstruction it still bounced and rang as before. This hole was then abandoned. Hole No. 4 encountered an obstacle of this kind at about 400 feet which threatened to stop the hole. But from the wear of the drills it was suspected that the obstacle did not cut off all of the hole, and it was found that a two and one-half inch pipe would pass this obstruction which had stopped a four-inch pipe, and this hole was continued down to 600 feet where it was lost for other causes. The last hole, No. 5, did not encounter any such obstacle and was the only one which attained the object of all of them, namely, to find if possible the bottom of the hole. This object having been attained and the five prospecting bore holes proving exceedingly tedious and expensive and the results more or less uncertain, it was determined to abandon this method of proceeding and put down a shaft properly equipped for penetrating the wet ground. This has been done to a depth of 180 feet, and further progress now awaits the installation of the machinery.

The author feels that he can announce the following facts as absolutely proved:

First: That at this locality there is a great hole or crater in the earth which corresponds in all respects, except in its gigantic scale, with impact craters formed in rock by projectiles of considerable size moving at considerable velocities.

Second: That in and around this hole and below its bottom to a distance of over 1,400 feet below the present surface of the plain surrounding it, and the original surface of the place where this hole was formed, every indication of either volcanic or hot spring action is positively absent.

Third: That in and about this hole all signs which might be expected of the impact of such a great projectile are present.

Fourth: That upon the surface of the rim and upon the surrounding plain there has been found and still exists a large quantity of meteoric material, and that the distribution of this material is symmetrical with a line passing through the center of this hole.

Fifth: That this meteoric material was deposited at the same instant of time at which the hole was made.

Sixth: That in and around this hole is an enormous quantity of pulverized rock, produced from the strata penetrated by the hole, in a state of subdivision which can be produced by a violent blow, but cannot be produced by forms of natural erosion.

Seventh: That there can have been no form of natural erosion active in this locality which would have produced this material and have collected it and retained it in the position in which found.

Eighth: That meteoric material has been found among the filling material of this hole at a depth of 900 feet below the surface of the original plain, and 500 feet below the present bottom of the crater, and 400 feet below the surface of the material which fell back into the crater at the instant of its formation.

Ninth: That all of the attendant minor phenomena observed can be explained upon the theory of the impact of a great projectile, and none can be satisfactorily explained upon any other theory.

In view of these positively established facts, the author feels that he is justified, under due reserve as to subsequently developed facts, in announcing that the formation at this locality is due to the impact of a meteor of enormous and hitherto unprecedented size.

Date of the Occurrence.

Fortunately there is a means at hand of obtaining a very good idea of the age or rather the extreme recentness of this phenomenon. That is, aside from the evidence of the hole itself and the lack of erosion of the sharp edges of the ejected rocks themselves, and this in a country of desert sand and furious winds, in which all exposed rocks are rounded and sculptured by wind erosion to a marked degree. This evidence comes from a little red sandstone butte some half a mile north of the north edge of the hole. This, as mentioned in the earlier part of this paper, is a portion of what was once the covering rock of this country and which can be seen at a glance to be in process of rapid removal. Now it happens that a jet of the crushed material and broken rock a little more vigorous than most has fallen across this butte, and it can be traced up the near slope and across the top. Then there is an interval of fifty feet or so in the lee of the hill upon which none was deposited owing to its horizontal velocity, and then it begins again on the plain beyond for a few hundred feet until it terminates. Now this deposit up the near or southern side of the butte, in spite of the evidently rapid erosion to which it is subject, lies on the surface right up to the cap, without any red sandstone material having fallen or having been washed down upon it. From its appearance it might have been depos-

ited yesterday. This will give a superior limit of time within which the fall must have occurred from whatever rate may be assigned to the erosion of the red sandstone buttes. The author would name 10,000 years as the utmost possible limit which could be allowed, and feels that this is much too liberal and that something well inside of 5,000 years is much more nearly in accordance with the facts. In fact, so recent is the appearance of everything in this locality that some stunted cedars, growing on the rim and showing year rings of over 700 years of growth, are not without value in placing a minimum limit within which the fall cannot have occurred.

Size of the Meteorite Forming the Hole.

Of this it is extremely difficult to form any idea from data which would stand critical examination. Professor Gilbert put the necessary minimum as the equivalent of a sphere of 750 feet in diameter, and the probable size as equivalent to a sphere of 1,500 feet in diameter. This seems to the author as most excessive. The problem contains too many unknown factors to make calculation much, if any, better than guesswork. The following facts may be considered as having some bearing in assigning a possible maximum size to the projectile. The artillery tables above referred to give a penetration of something less than two diameters in solid limestone rock for shot at about 1,800 feet per second. Now, from the probable absence of meteoric material in the hole below 500 feet, this is assumed as about its limit of penetration. This corresponds to a penetration of about 900 feet of solid rock on the whole considerably softer than limestone, and would therefore correspond to a sphere of considerably less than 450 feet in diameter, if the velocity were not in excess of 1,800 feet per second. Now what this striking velocity was can only be guessed at, although it is absolutely certain that it was in excess of 1,800 feet per second, in all probability many times in excess of this figure; and it must be kept in mind that the energy would increase as the square of the velocity, and that the cubic contents of the hole excavated would vary directly with the energy exerted. Therefore if the velocity was 9,000 feet per second, or five times that quoted above, a sphere of one-twenty-fifth the weight of the above would deliver the same amount of energy and therefore probably make the same sized hole. The original velocity of any such body is reasonably well known from astronomical considerations and it probably struck the atmosphere at between nine and forty-five miles per second, depending upon the direction of its motion in relation to the motion of the earth. We know that this excessive velocity is very soon

dissipated in the smaller meteorites and that they strike the earth with a very moderate velocity; but could such a thin layer as the atmosphere deal in the same manner with a large body? The author is of the opinion that it could not, and that this body probably struck with a large part of its planetary velocity, and that it was extremely small in comparison with anything that would be deduced by assuming for it any such striking velocity as has ever been produced in a terrestrial projectile; but as and for the reason set forth above, he does not feel justified from any known data in naming any definite figure in connection therewith.

The Composition of the Meteorite.

The composition of the outer surface, at least, of this meteorite is fairly well known and appears to have been fairly constant. For the great numbers of specimens picked up around the hole, which must have come indiscriminately from all points of the surface, are of fairly constant composition. That is, metallic iron with very small percentages of carbon, sulphur and phosphorus, with between seven and eight per cent. of nickel and a trace of cobalt. This metallic mass carries about three-fourths of an ounce per ton of platinum and iridium.

As to the interior composition of the meteorite, nothing definite can be known. If the body was a fragment the probability is that it was homogeneous throughout, as there is little or no difference between the fragments from all portions of its surface. If, however, the object was a small spheroid its interior might differ considerably from that of its exterior. It seems improbable that the mass contained any notable proportion of stony material, as nothing of this kind has been observed in the fragments around the rim, nor has prolonged and careful microscopic examination of a very large number of samples of the filling material of the hole from all depths shown anything but the broken débris of the strata penetrated, except the above-mentioned meteoric material, which is all either metallic iron or the direct results of its combustion or union of such products of combustion with the surrounding silica. It is, however, to be noted that a small stone meteorite of several pounds in weight, containing metallic iron sparsely scattered through it, was picked up by Mr. Barringer about two miles from the crater. There is, however, excellent reason for the belief that this object was observed to fall during the winter of 1903. In any event, although the iron contains a proportion of nickel somewhat less than that in the fragments of the great meteorite, yet, after careful and repeated examinations, it has been proved that the metals of the plati-

num group are certainly absent from this material. Now, although it is conceivable that a stony meteorite containing metallic iron might under some circumstances, such as prolonged heating in a reducing atmosphere, acquire a superficial coating of iron, yet it is entirely inconceivable that such a coating, concentrated upon the surface from a stony interior, could contain a definite and constant proportion of metals of the platinum group and yet leave the iron still contained in the mass entirely without any such constituents. Mr. Barringer's account of these unusual formations at Coon Butte immediately precedes this paper.