SCIENCE

FRIDAY, JANUARY 3, 1896.

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MSS. intended for publication and books etc., intended for review should be sent to the responsible editor, Prof. J. McKeen Cattell, Garrison-on-Hudson, N. Y.

*THE ORIGIN OF HYPOTHESES, ILLUSTRATED BY THE DISCUSSION OF A TOPOGRAPHIC PROBLEM.**

AN important part—in some respects the most important part—of the work of science is the explanation of the facts of Nature. The process through which natural phenomena are explained is called the 'method of hypotheses,' and though it is familiar to most of my audience I shall nevertheless describe it briefly for the purpose of directing special attention to one of its factors.

The hypothesis has been called a 'scientific guess,' and unless the title 'guess' carries with it something of disrespect it is not inappropriate. When the investigator, having under consideration a fact or group of facts whose origin or cause is unknown, seeks to discover their origin, his first step is to make a guess. In other words, he frames a hypothesis or invents a tentative theory. Then he proceeds to test the hypothesis, and in planning a test he reasons in this way: If the phenomenon was really produced in the hypothetic manner, then it should possess, in addition to the features already observed, certain other specific features, and the discovery of these will serve to verify the hypothesis. Resuming

*Annual Address of the President of the Geological Society of Washington; read December 11, 1895, to the Scientific Societies of Washington. By special arrangement, through the Joint Commission of those societies, this number of SCIENCE is mailed to all members.

its examination, he searches for these particular features. If they are found the theory is supported; and in case the features thus predicted and discovered are numerous and varied, the theory is accepted as satisfactory. But if the reëxamination reveals features inconsistent with the tentative theory, the theory is thereby discredited, and the investigator proceeds to frame and test a new one. Thus, by a series of trials, inadequate explanations are one by one set aside, and eventually an explanation is discovered which satisfies all requirements.

When the subject of study is one of wide interest it usually happens that several investigators coöperate in the invention and testing of hypotheses. Often each investigator will originate a hypothesis, and a series of rigorous tests will be applied through the endeavor of each one to establish his own by overthrowing all others. The different theories are rivals competing for ascendancy, and their authors are also rivals, ambitious for the credit of discovery. The personal factor thus introduced tends to bias the judgment and is to that extent unfavorable to the progress of science; but the conflict of theories, leading, as it eventually must, to the survival of the fittest, is advantageous. Fortunately there is a mode of using hypotheses which regulates the personal factor without restricting the competition of theories, and this has found favor with the greatest investigators. It has recently been formulated and ably advocated by our fellow-member, Prof. T. C. Chamberlin, who calls it the 'method of multiple hypotheses.'*

In the application of this method the student of a group of phenomena, instead of inventing and testing hypotheses one at a time, devises at an early stage as many as possible, and then, treating them as rival claimants, assigns to himself the rôle of judge. Returning to the study of nature, he seeks for special features which cannot consist with all the hypotheses, and may therefore serve to discriminate among them. Thus by a series of crucial tests he eliminates one after another of the tentative theories until but a single one remains, and he then proceeds to apply such tests as he may to the survivor.

In these methods of work, whether theories are examined successively or simultaneously, there are two steps involving the initiative of the investigator; he invents hypotheses and he invents tests for them. It is to the intellectual character of these inventions that your attention is invited.

The mental process by which hypotheses are suggested is obscure. Ordinarily they flash into consciousness without premonition, and it would be easy to ascribe them to a mysterious intuition or creative faculty; but this would contravene one of the broadest generalizations of modern psychology. Just as in the domain of matter nothing is created from nothing, just as in the domain of life there is no spontaneous generation, so in the domain of mind there are no ideas which do not owe their existence to antecedent ideas which stand in the relation of parent to child. It is only because our mental processes are largely conducted outside the field of consciousness that the lineage of ideas is difficult to trace.

To explain the origin of hypotheses I have a hypothesis to present,—not, indeed, as original, for it has been at least tacitly assumed by various writers on scientific method, but rather as worthy of more general attention and recognition. It is that hypotheses are always suggested through analogy. The unexplained phenomenon on which the student fixes his attention resembles in some of its features another phenomenon of which the explanation is known. Analogic reasoning suggests that the desired explanation is similar in char-

*The Method of Multiple Working Hypotheses, SCIENCE (1st series), Vol. XV. (1890) pp. 92–96.

acter to the known, and this suggestion constitutes the production of a hypothesis.

To test this hypothesis of hypotheses I have for some years endeavored to analyze the methods employed by myself and some of my associates in geologic research, and this study has proved so interesting in connection with the investigation of a peculiar crater in Arizona, that I shall devote the remainder of my hour to an outline of that investigation.

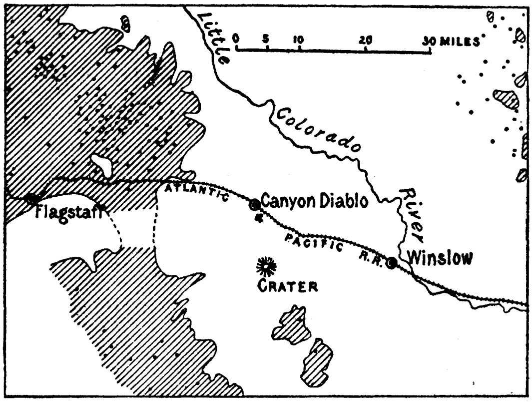

FIG. 1.—Map of part of northern Arizona. The shaded areas are covered by volcanic rocks. Dots mark ancient volcanic vents.

In northeastern Arizona there is an arid plain beneath whose scanty soil are level beds of limestone. At one point the plain is interrupted by a bowl-shaped or saucer-shaped hollow, a few thousand feet broad and a few hundred feet deep; and about this hollow is an approximately circular rim rising one or two hundred feet above the surface of the plain (Plate 1, Figs. 2 and 3). In other words, there is a crater; but the crater differs from the ordinary volcanic structure of that name in that it contains no volcanic rock. The circling sides of the bowl show limestone and sandstone, and the rim is wholly composed of these materials. On the slopes of this crater and on the plain round about many pieces of iron have been found, not iron ore, but the metal itself, and this substance is foreign to the limestone of the plain and to all other formations of the region.* The features of the locality thus include three things of unusual character and requiring explanation: First, the crater composed of non-volcanic rock; second, the scattered iron masses; third, the association of crater and iron. To account for these phenomena a number of theories have been suggested.

In the year 1886 a company of shepherds encamped on the slopes of the crater and pastured their sheep on the surrounding plain. Mathias Armijo, one of their number, found a piece of iron, and, deceived by its lustrous surface, supposed it to be silver. The mistake was quickly corrected by his fellows, but his discovery excited their interest, and other pieces of iron were soon found. The curiosity of the shepherds was aroused also by the crater, and they invented a theory which is admirable for its simplicity: The crater was produced by an explosion, the material of the rim being thrown out from the central cavity, and the iron was thrown out from the same cavity at the same time. You will observe that this theory is comprehensive. It accounts for the crater, the iron, and the association of the two. As I have never met these first students of the phenomena I have had no opportunity to make inquiry as to the origin of their theory; but its close relation to the theories of geologic disturbance which are current in mining districts suggests that it also sprung from the familiar process of blasting. As the firing of a blast opens a cavity and heaps dislocated rock masses in an irregular way, the unlearned miner finds in natural blasting an easy explanation of hollows and uplifts.

Four years later a man by the name of Craft saw in the iron a possibility of profit. Setting up a heap of stone to mark the spot,

* The crater is locally known as Coon Mountain, or Coon Butte. The iron is known to literature as the Canyon Diablo fall of meteorites.

he located a mining claim; and going to the city of Albuquerque, he announced that he had a vein of pure iron 40 yards wide and two miles long, and offered to sell his property to a railway company. The samples he submitted were examined by an assayer, and the officers of the company gave consideration to his proposal, agreeing to send a representative to examine the property. The negotiation was not concluded, because Mr. Craft, having borrowed money on the strength of his great expectations, mysteriously disappeared, but the incident served to give information of the locality to a scientific observer. The assayer forwarded a piece of the iron to the late Dr. A. E. Foote, the mineralogist, who visited the place, collected a quantity of the iron and examined the crater. In the summer of 1891 he communicated his observations to the American Association for the Advancement of Science,* which that year was the guest of the scientific societies of Washington, and his paper aroused much interest. For the crater of non-volcanic rock he offered no explanation, but the iron he pronounced of celestial origin—a shower of fallen meteors. It has long been known that many of the bodies which reach the earth from outer space are composed of iron, and that such iron is of peculiar character, having a certain crystalline structure, being alloyed with nickel, and including nodules of certain substances which are not found in any other association. So Doctor Foote, in characterizing the iron as meteoric, merely referred it to a well-established class. His explanation was not tentative, but final, and has not been called in question by any subsequent investigator.

In the discussion following the reading of his paper a new hypothesis was proposed, and as this was offered by myself I can trace its origin with comparative confidence. The crust of the earth is not equally dense at all points, but some parts are heavier than others. Not only are there variations from hill to hill and from formation to formation, but the continents are in general composed of lighter materials than the ocean beds, and one side of the sphere is so much heavier than the other that its attraction pulls most of the water away from the other side. Among the various theories that have been proposed for the origin of the planet there is one which ascribes it to the falling together under mutual attraction of many smaller celestial bodies, and it has been suggested that the variations in the crust may represent original differences of the concurrent masses. Speculating on such lines I had asked myself what would result if another small star should now be added to the earth, and one of the consequences which had occurred to me was the formation of a crater, the suggestion springing from the many familiar instances of craters formed by collision. A raindrop falling on soft ooze produces a miniature crater; so does a pebble thrown into a pool of pasty mud. A larger crater is made when a steel projectile is fired against steel armor plate; and analogy easily bridged the interval from the cannon ball to the asteroid. So when Dr. Foote described a limestone crater in association with iron masses from outer space, it at once occurred to me that the theme of my speculation might here find its realization. The suggested explanation assumes that the shower of falling iron masses included one larger than the rest, and that this greater mass, by the violence of its collision, produced the crater. Here again you will observe that a single theory explains the crater, the iron and their association.

The thought of examining the scar produced on the earth by the collision of a star

* A new locality for meteoric iron with a preliminary notice of the discovery of diamonds in the iron. Proc. Am. Ass. Adv. Science, Vol. 40, pp. 279–283.

was so attractive that I desired to visit the crater, but as that was not immediately practicable I arranged to have it visited by one of my colleagues. A few months later Mr. Willard D. Johnson spent several days at the locality, making a sketch map and describing the various features. When he reached the rim of the crater he found it to consist chiefly of limestone strata inclined outward, and his first thought was that the rim might be the remnant of the dome of strata over a laccolite. The laccolite is a peculiar volcanic product. The molten lavas which make volcanoes rise from deep sources through cracks or passages among the rocks and flow out over the surface of the land; but sometimes rising lavas fail to reach the surface, and accumulate at lower levels, opening for themselves bubble-shaped chambers over which the strata are arched. In the dome-like structures thus produced the rocks dip outward in all directions from a central region, and this outward dip was the feature which, through analogy, suggested to Mr. Johnson a laccolitic origin. His first idea, however, was not long retained, for examining the walls and bottom of the crater he found no trace of the igneous rocks of which laccolites are composed, and the theory afforded no aid in accounting for the hollow. He therefore dismissed it and sought another. He may have considered several others, but the only one placed on record is an explosion theory. In some way, probably by volcanic heat, a body of steam was produced at a depth of some hundreds or thousands of feet, and the explosion of this steam produced the crater. The fall of iron was independent, and the association of the two occurrences in the same locality is accidental.* As Mr. Johnson is at once a civil engineer and a student of geology and geography, he had at command as basis for analogic reasoning the explosive phenomena associated with the arts and also those which belong to the history of volcanoes, and we may assume that these suggested his theory.

* Mr. Johnson's discussion of the problem was communicated to me in a personal letter. G. K. G.

Mr. Johnson's account of the crater was much fuller than Dr. Foote's, but instead of satisfying my curiosity tended rather to whet it, and I availed myself of the first opportunity to make a personal visit. Four hypotheses had now been made, but only two survived. The theory of the shepherds, deriving the iron from the cavity of the crater, was disproved by Dr. Foote's determination of the meteoric character of the iron. The laccolitic theory had been promptly set aside by Mr. Johnson. There remained the theory of a star's collision and the theory of a steam explosion. If my visit was to aid in the determination of the problem of cause it must gather the data which would discriminate between these two theories, and an attempt was accordingly made to devise crucial tests. If the crater was produced by the collision and penetration of a stellar body that body now lay beneath the bowl, but not so if the crater resulted from explosion. Any observation which would determine the presence or absence of a buried star might therefore serve as a crucial test. Direct exploration by means of a shaft or drill hole could not be undertaken on account of the expense, but two indirect methods seemed feasible.

If the crater were produced by explosion the material contained in the rim, being identical with that removed from the hollow, is of equal amount; but if a star entered the hole the hole was partly filled thereby, and the remaining hollow must be less in volume than the rim. The presence or absence of the star might therefore be tested by measuring the cubic contents of the hollow and of the rim and comparing the two. Of the intellectual origin of this test perhaps the most that can be said is that it is a test by quantities, and that the experienced investigator, having previously found relations of quantity the most satisfactory criteria, habitually employs them whenever the circumstances permit.

Again it occurred to me that the stellar body would presumptively be composed, like the smaller masses round about, of iron, and that its presence or absence might, therefore, be determined by means of the magnetic needle. If it were absent the compass would point in the same direction, whatever its position with reference to the crater, whether within or without, on one side or the other, near by or miles away; but if a mass of iron large enough to produce the crater lay beneath it its attraction would pull the needle one way or the other, producing local variations. Doubtless the suggestion of this test came from knowledge of the methods employed in searching for magnetic iron ore in northern Michigan, where the prospector carries the dip needle to and fro through the forest, and by means of its changes of direction determines the position and extent of bodies of ore.

As an equipment for these measurements I provided myself with the instruments necessary to make an accurate topographic map, and obtained, through the courtesy of the Coast and Geodetic Survey, a full set of instruments for the observation of terrestrial magnetism. I was so fortunate, also, as to secure the coöperation of an expert magnetic observer, Mr. Marcus Baker, of the Geological Survey, and together we set out for Arizona.

At this time it seemed to me that the presumption was in favor of the theory ascribing the crater to a falling star, because that theory explained, while its rival did not, the close association of the crater with the shower of celestial iron. So far as we know, a falling meteor is just as likely to reach any one spot on the earth's surface as any other, and it is, therefore, entirely possible that the coincidence of the meteoric locality with the locality of the crater has no special significance; but if the two phenomena are not connected by a causal relation, it is no more probable that the crater should coincide in place with one of the 165 meteoric falls recorded within the bounds of the United States than that it should occupy any other spot of our broad domain. A rough estimate shows the probability of non-coincidence to be at least 800 times as great as the probability of coincidence. This by no means warrants the conclusion that an explanation ascribing a causal relation is 800 times as probable as one ascribing fortuitous coincidence, but it legitimately inclines the mind toward causality in the absence of more direct and authoritative evidence.

This point is illustrated by the investigation of the peculiar sky colors observed twelve years ago. Considering the phenomenon of coloration in its entirety—character, distribution and duration—it was not merely rare, it was unique. In the same year a tremendous volcanic explosion occurred in the Straits of Sunda, and that also was unique in intensity. The coincidence of the two, which in this case was a matter of time rather than place, led to the belief that the one was caused by the other, and this belief was held by many men of science before an adequate explanation of the mode of causation had been suggested.

So when Mr. Baker and I started for the crater it seemed rather probable than otherwise that we should find a local deflection of the magnetic needle, and that we should find the material of the rim more than sufficient to fill the hollow it surrounds.

Before our journey was ended another explanation suggested itself. Mr. Johnson had described the crater as not truly circular but somewhat oval, the longer diameter lying east and west. He noted also that

ILLUSTRATIONS TO ARTICLE BY G. K. GILBERT ON HYPOTHESES.

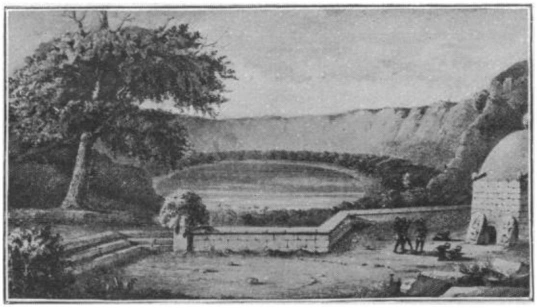

FIG. 1.—Lonar Lake, India, occupying an explosion crater. From Newbold's *Summary of the Geology of Southern India*, Jour. Roy. Asiatic Soc., vol. 9, p. 40. London, 1848.

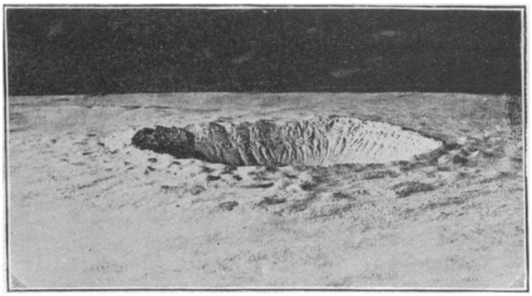

FIG. 2.—The limestone crater of Arizona, Coon Butte, as seen from the south. Photograph of a model by Mr. Victor Mindeleff.

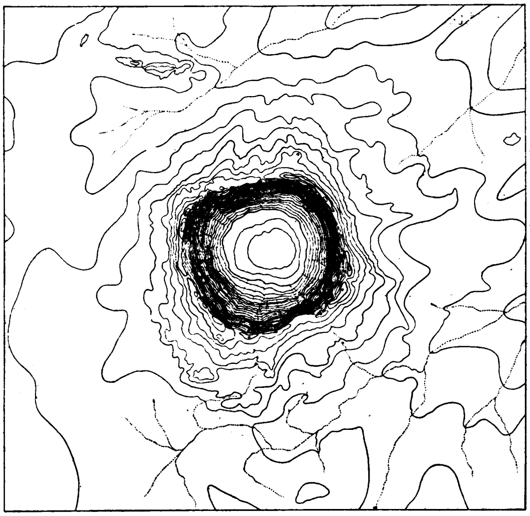

FIG. 3.—Contour map of Coon Butte. The vertical distance from contour to contour is ten feet. Lines of drainage are dotted.

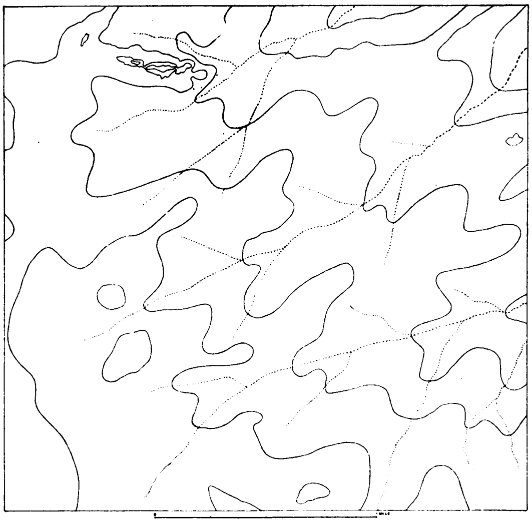

FIG. 4.—Restoration of the site of Coon Butte before the formation of the crater. Contour interval, ten feet; lines of drainage dotted. Compare with Fig. 3.

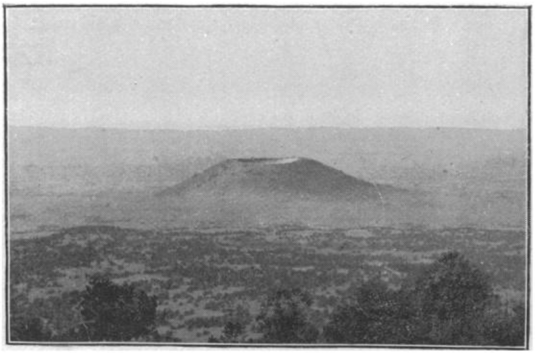

FIG. 5.—Volcanic cinder-cone, with crater, north of San Francisco Mountain, Arizona. The position of the crater, at top of the hill, is characteristic of most volcanoes. Compare Fig, 2, where the crater lies chiefly below the level of the plain.

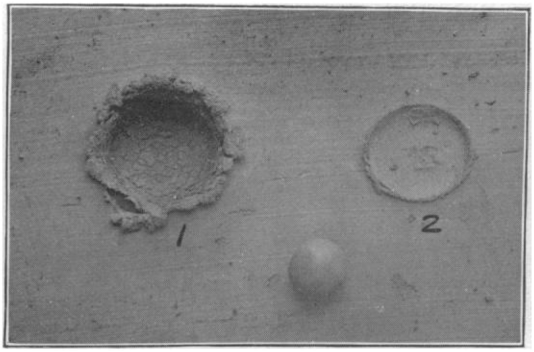

FIG. 6.—Craters made by throwing clay balls at a clay target. A ball of the same size is shown. 1 shows the effect of high velocity, 2 of low.

ILLUSTRATIONS TO ARTICLE BY G. K. GILBERT ON HYPOTHESES.

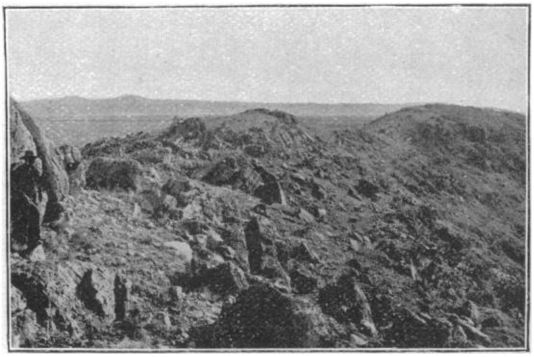

FIG. 1.—Rim of Coon Butte, with part of inner face.

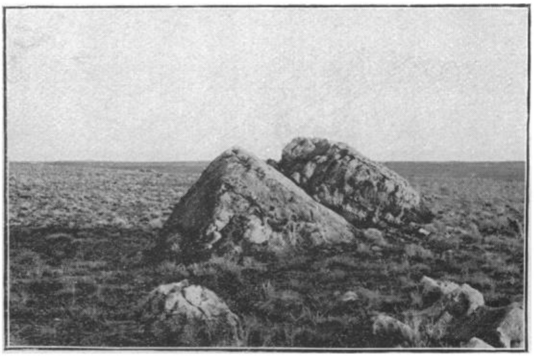

FIG. 2.—Block of limestone on outer slope of Coon Butte, one-half mile from rim.

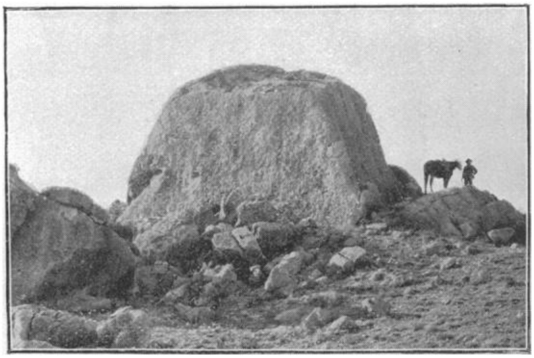

FIG. 3.—Largest block of limestone on rim of Coon Butte. Diameter, 60 feet.

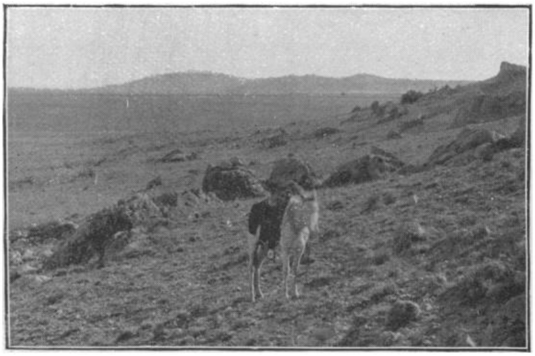

FIG. 4.—Outer slope of Coon Butte.

FIG. 5.—Interior of Coon Butte, as seen from the talus on one side. The cliff below the rim is of limestone.

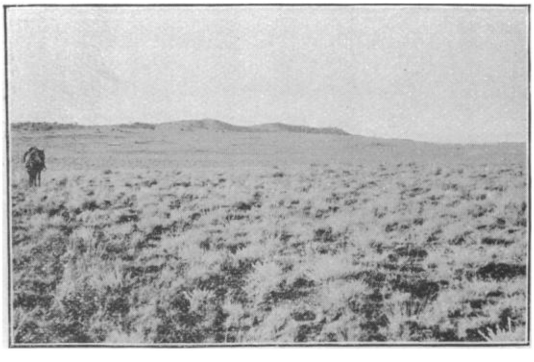

FIG. 6.—Exterior of Coon Butte, as seen from the surrounding plain.

the rim was bulkier on the east side than on the west, and that nearly all the iron had been found east of the crater. The new explanation was that a star, falling obliquely from the western sky, struck the earth and bounded off, finally coming to rest at some point farther east. The idea was of course derived from the ricochet of projectiles; I had seen the mark left by a rifle ball where it rebounded from a plowed field. This explanation could be tested by a simple examination of the topographic form; and it may be as well to anticipate here the order of the narrative, and say that the form of the crater was found to be quite inconsistent with the ricochet hypothesis. The difference of the two diameters is quite small; the eastern rim is but little more massive than the western; and the dislocation of the rocks in the western rim is of such character that it could not have been produced by a body descending obliquely toward the east.

Arriving at the crater we spent two weeks in topographic and magnetic surveys and the study of local details. The diameter of the bowl, measured from rim to rim, is about three-fourths of a mile. Its depth below the rim is from 550 to 600 feet; below the plain, 400 feet, the rim being 150 to 200 feet high. The rim is in part composed of limestone strata like those which underlie the plain, but turned up, so as to incline steeply away from the hollow on all sides. On the inclined strata rests a mantle of loose fragments which are in part of limestone and in part of sandstone. The limestone masses are fragments of the formation occurring just beneath, and the sandstone masses are fragments of a formation which underlies the limestone formation. Most of the masses are of moderate size, but others are large, the limestone reaching a diameter of 60 feet, and the sandstone about 100 feet. (Plate 2. Figs. 1–4.). They are irregularly mingled, one material predominating in one tract and the other in another. The limestone is the more conspicuous because withstanding better the attacks of the weather. In fact the larger blocks of sandstone have been so far washed away that they do not project above the surface. From the crest of the rim outward this loose material occupies the surface for an average distance of half a mile, being characterized by rolling or hummocky topography. At greater distances it is thinly spread and the constituent blocks are small. At one mile it is represented only by scattered fragments, but these continue with diminishing frequency to a distance of three and a half miles.

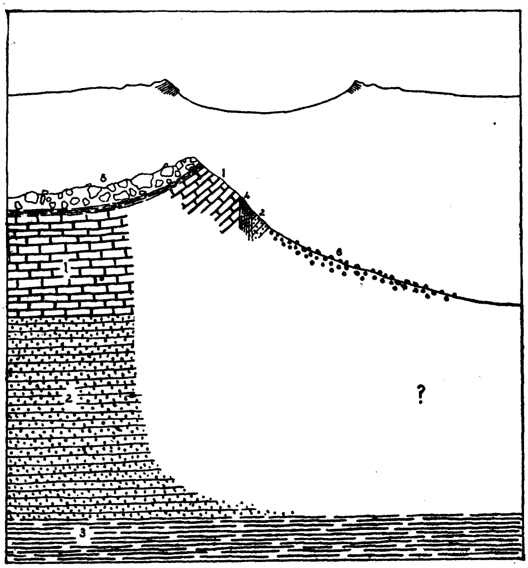

FIG. 2.—The upper diagram is profile across the crater; the lower, a cross-section of the rim. 1, limestone. 2, sandstone. 3, red shale. 4, crushed rock. 5, loose blocks of limestone and sandstone. 6, talus of debris fallen from 1 and 2 above.

Inside the rim the edges of limestone strata occupy the slope for a space of 150 to 250 feet. They are succeeded in several places by sandstone strata, but the sandstone does not hold its original relation to the limestone; it is separated by a vertical zone of crushed rock, and there is other evidence that it has been faulted upward.

The lower slopes are occupied by fragments of limestone and sandstone with an arrangement showing that they have fallen from the cliff above so as to constitute a talus of the ordinary type, and the central tract is composed of fine material of the same kind. Whatever may have been the original shape of the pit, its present form has resulted from subsequent modification under the action of rain and frost.

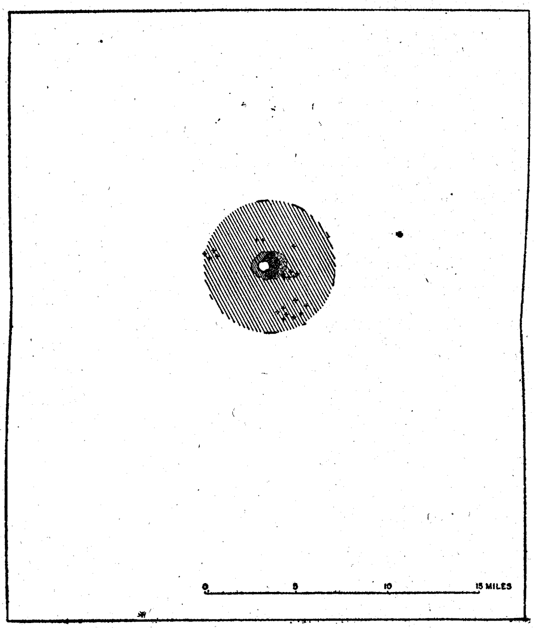

FIG. 3.—Distribution Chart. The inner line is the rim of crater. In the inner shaded area the loose debris has a depth of more than one foot. In the outer shaded area are scattered blocks; where the area is bounded by a line its limit was surveyed. The chief district of small iron masses is shown by dots. Large iron masses are indicated by crosses. The distribution of the iron is chiefly on the authority of Mr. F. W. Volz, of Canyon Diablo, A. T.

No iron has been found within the crater, but a great number of fragments were obtained from the outer slopes where they rested on the mantle of loose blocks. Many others were obtained from the plain within the region of scattered debris, and others, though a smaller number, from the outer plain. One large piece was discovered eight miles east of the crater, or almost twice as distant as any fragments of the ejected limestone. Another was long ago discovered twenty miles to the southward, but what became of it is not known, and it has not been definitely identified as a member of the same meteoric shower. Most of the masses are small. There have been found more than one thousand, possibly more than two thousand, pieces weighing less than an ounce; others weigh a few ounces or a few pounds; forty or fifty exceed one hundred pounds, and two exceed one thousand pounds. The total weight of all finds is probably ten tons. At the time of my visit I was told that all had been discovered east of a north and south line passing through the middle of the crater, but this may have been an accident of the method of search, for more recently six large ones have been reported from points west of that line.

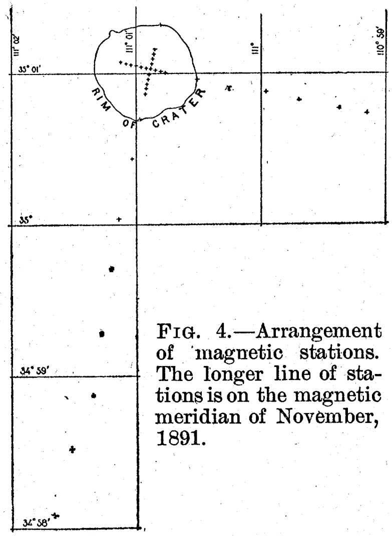

FIG. 4.—Arrangement of magnetic stations. The longer line of stations is on the magnetic meridian of November, 1891.

The magnetic survey by Mr. Baker included the selection and mapping of a system of stations, and the observation at each of the three magnetic elements: the horizontal component of direction, or the compass bearing; the vertical component of direction, or the inclination of the dip needle; and the intensity of the magnetic force. Two lines of stations, at right angles to each other, were carried across the crater, and one of these lines was extended to a distance of three and a half miles on the plain. When the results were tabulated and compared, the magnetism was found to be constant in direction and intensity at all the stations, the deviations from uniformity being not greater than the unavoidable errors of observation. So if the crater contains a mass of iron its attraction is too feeble to be detected by the instruments employed. That we might learn the precise meaning of this result, the delicacy of the instruments was afterward tested at the Washington Navy Yard, by observing their behavior when placed in certain definite relations to a group of iron cannon whose weight was known, and the following conclusions were reached: If a mass of iron equivalent to a sphere 1500 feet in diameter is buried beneath the crater it must lie at least 50 miles below the surface; if a mass 500 feet in diameter lies there its depth is not less than 10 miles. So the theory of a great iron meteor is negatived by the magnetic results, unless we may suppose either that the meteor was quite small as compared to the diameter of the crater, or that it penetrated to a very great depth.

The topographic survey was executed with such detail as to warrant the drawing of contour lines for each ten feet of height. (Plate 1, Fig. 3.) During its progress the configuration of the surrounding country was carefully studied, and its general plan was found to be so simple and regular that the original contours before the creation of the crater could be restored without great liability of error. (Plate 1, Fig. 4.) Such restoration was made, and with its aid two quantities were afterwards computed: first, the cubic contents of the rim so far as it projects above the ancient surface; second, the cubic contents of the hollow so far as it lies below the ancient surface. The two volumes were compared with each other and also with the volume of a spherical projectile estimated as competent to produce the crater. From experiments with balls of clay fired against a target of the same material it seems probable that a crater 4,000 feet in diameter might be produced by a swift-moving meteor with a diameter of 1,500 feet. (Plate 1, Fig. 6.) It seems possible, though not probable, that it could be made by a mass 750 feet in diameter. The volume of the greater assumed projectile is 60 million cubic yards; the volume of the lesser, 7½ million yards. The magnitude of the hollow was found to be 82 million yards, and the magnitude of the rim was also found to be 82 million yards. It, therefore, appears that if the rim were to be dug away down to the level of the ancient plain, and the material tightly packed within the hollow of the crater, it would suffice to precisely fill that hollow and restore the ancient plain. The excess of matter required by the theory of a buried star was not found.

Thus each of the two experiments whose testimony had been invoked declared against the theory of a colliding meteor; and the expectation founded on the high improbability of fortuitous coincidence nevertheless failed of realization.

Attention being now directed to the only surviving theory, that of steam explosion, all the various features discovered in the local study were considered with reference to it. To describe and discuss them on this occasion would lead too far from our subject, and they may be passed by with the remark that, while not all are as yet fully understood, they seem not to oppose the theory.

For the sake of applying another quantitative test, an attempt was made to ascertain whether the energy which could be developed by heating the water contained in the sandstone formation would be sufficient, when the overlying strata gave way, to hurl their fragments out upon the sursounding plain. As the data were quite indefinite the computation could result only in a rough approximation, and there is no need to weary you with its details, but it served to show that the assumed cause was of the same order of magnitude as the result accomplished. The idea of applying such a test needs no specific explanation, because quantitative tests of this particular type are among the most familiar resources of investigation. Whenever a tentative theory involves the application of force or the expenditure of energy the investigator (or his critic) habitually asks whether the assumed cause affords a sufficient amount of force or of energy.

Practically the same conclusion was reached in a more satisfactory way by studying the accounts of other natural explosions where steam was the agent. At several epochs in its history the top of Mount Vesuvius has been torn away by a sudden convulsion. In Java the summit of Mount Tomboro was blown away, with the production of a great crater which now contains a lake, and a similar catastrope occurred on the slope of Mount Pepandaján. The great explosion of Krakatoa, in 1883, demolished several volcanic islands and created others, reconstructing the topography of a district in the Straits of Sunda. On July 15, 1888, a great opening was torn in the Japanese mountain Kobandai, the summit and part of one side being removed. The last mentioned instance is the most available for comparison because the agency of steam distinctly appeared, and because the history of the event has been admirably reported by two Japanese geologists, Profs. Sekiya and Kikuchi, of Tokio. *

* The Eruption of Bandai-san. Trans. Seismological Soc. of Japan, Vol. XIII., (1890), pp. 139-222. 9 plates.

There were in this case about twenty explosions, all occurring within the space of one or two minutes. A cloud of rock fragments ascended to a height of 4,000 feet. The greater number, moving obliquely away from the mountain side, fell upon its lower slope, down which they rolled as an avalanche for a distance of five miles, overwhelming several villages and transforming a fertile plain into a rocky desert. In other directions fell showers of stones, and a cloud of dust descending more slowly. The resulting crater, less regular in form than the subject of our study, was nineteen times as capacious, and from its bottom fierce jets of steam issued for weeks and even months. Kobandai is a volcanic peak, and although it had been quiescent for ten centuries there can be little doubt that the steam it evolved was generated by volcanic heat.

The competency of volcanic steam for the production of a crater is thus shown by a parallel instance, and the only conspicuous difference between the Japanese case and the Arizonian lies in the fact that in the one the disrupted rock was volcanic and in the other it was not. This difference seems unessential, for in neither case was there an eruption of liquid rock; the ancient lavas of Kobandai had been cold for ages, and their relation to the catastrophe was wholly passive. Moreover, the manifestation of volcanic energy is no more exceptional on the Arizona plateau than in the Bandai district. The little limestone crater is in the midst of a great volcanic district. (Fig. 1, Page 3, and Plate 1, Fig. 5.) The nearest volcanic crater is but ten miles distant, and within a radius of fifty miles are hundreds of vents from which lava has issued during the later geologic periods.

In following this line of thought I have but reversed the logical route by which Mr. Johnson probably reached his theory, verifying the theory by recomparison with its source.

Yet other verification was afterwards found through the published accounts of certain small craters in Germany, France and India. In the valley of the Rhine are a number of circular basins, for the most part containing lakes and hence called *maars*. They are depressed below the level of the surrounding plain, and some of them are surrounded by raised rims. The descriptions are somewhat conflicting, but it is clear that some of the basins are hollowed chiefly from non-volcanic rocks, limestone, sandstone and slate, and that their rims are composed in part of fragments of similar rocks.* The Indian crater (Plate 1, Fig. 1), which also contains a lake, is hollowed from a volcanic rock, the Deccan trap, and shows no other material; but in other features it parallels so closely the Arizona crater that I quote from Doctor Blanford's description:

"The surrounding country for hundreds of miles consists entirely of Deccan trap; in this rock, at Lonar, there is a nearly circular hollow about 300 to 400 feet deep, and rather more than a mile in diameter, containing at the bottom a shallow lake of salt water without any outlet. * * * * The sides of the hollow to the north and northeast are absolutely level with the surrounding country, whilst in all other directions there is a raised rim, never exceeding 100 feet in height, and frequently only 40 or 50, composed of blocks of basalt, irregularly piled, and precisely similar to the rock exposed on the sides of the hollow. The dip of the surrounding traps is away from the hollow, but very low.

"It is impossible to ascribe this hollow to any other cause than volcanic explosion."†

* Volcanos. By G. Poulett Scrope. London, 1872. Pp. 369-384. Die Vulkane der Eifel, in ihrer Bildungsweise erlautert. By Dr. Herman Vogelsang. Naturkundige verhandelingen von der hollandische Maalschappij der Wetenschappen te Haarlem. Vol. 21, Part 1. Pp. 41-76.

†A Manual of the Geology of India, by H. B. Medlicott and W. T. Blanford. Part I., pp. 379-380 8vo. Calcutta, 1879.

For the sake of completeness, mention should be made of two other hypotheses, which resemble the laccolitic suggestion in that each was based on a single feature of the crater but failed to find verification in any other feature. The fact that the pit occurs in limestone suggested that it might be what is called a *limestone sink*, a cavern having been made by the solution of the rock and the roof having afterwards fallen in.* The fact that the loose debris of the rim lies in hummocks with intervening hollows, and thus resembles in its topographic character the terminal moraine of a glacier, suggested that ice was concerned in its distribution.

Yet another hypothesis, and the last that need be mentioned, was made by welding together two which had preceded. It is a general fact that causes are complex, and as the explanations which first suggest themselves are apt to be simple, it often occurs that the theory finally adopted combines elements of two or more of the theories tentatively proposed. The expert constructor of theories is therefore prone to suspect that rival explanations embody half truths, and to seek for methods of combination. The combination proposed in this case utilizes the theory of meteoric impact and the theory of volcanic explosion, and its author is Mr. Warren Upham. His suggestion is that, by some volcanic process, heat had been engendered among the rocks of the locality, so that the conditions were ripe for an explosion, and that the mine was actually fired by a falling star, whose collision ruptured a barrier between water and hot rock, or in some other way touched the volcanic button.† It will be noted that this explanation demands a coincidence of what may be called the second order, for the colliding star is supposed not only to have chanced upon the prepared

* This suggestion was made by a correspondent.

† American Geologist, Vol. 13, (1894), p. 116; also a personal letter.

locality, but to have arrived opportunely at the critical epoch.

Still another contribution to the subject, while it does not increase the number of hypotheses, is nevertheless important in that it tends to diminish the weight of the magnetic evidence and thus to reopen the question which Mr. Baker and I supposed we had settled. Our fellow-member, Mr. Edwin E. Howell, through whose hands much of the meteoric iron has passed,

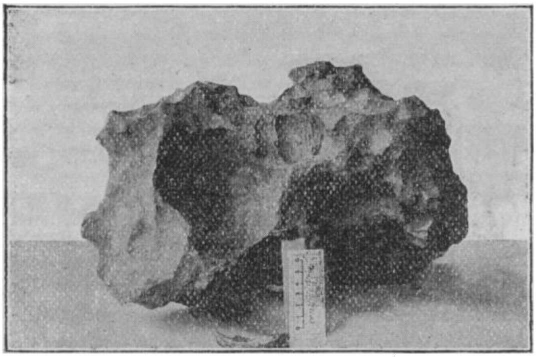

Fig. 5.—Iron meteorite found near the crater. Weighs 161½ pounds. Property of Mr. Edwin E. Howell, of Washington, D. C.

points out that each of the iron masses, great and small, is in itself a complete individual. They have none of the characters that would be found if they had been broken one from another, and yet, as they are all of one type and all reached the earth within a small district, it must be supposed that they were originally connected in some way. Reasoning by analogy from the characters of other meteoric bodies, he infers that the irons were all included in a large mass of some different material, either crystalline rock, such as constitutes the class of meteorites called 'stony,' or else a compound of iron and sulphur, similar to certain nodules discovered inside the iron masses when sawn in two. Neither of these materials is so enduring as the iron, and the fact that they are not now found on the plain does not prove their original absence. Moreover, the plain is strewn in the vicinity of the crater with bits of limonite, a mineral frequently produced by the action of air and water on iron sulphide, and this material is much more abundant than the iron. If it be true that the iron masses were thus imbedded, like plums, in an astral pudding, the hypothetic buried star might have great size and yet only small power to attract the magnetic needle. Mr. Howell also proposes a qualification of the test by volumes, suggesting that some of the rocks beneath the buried star might have been condensed by the shock so as to occupy less space.* These considerations are eminently pertinent to the study of the crater and will find appropriate place in any comprehensive discussion of its origin ; but the fact which is peculiarly worthy of note at the present time is their ability to unsettle a conclusion that was beginning to feel itself secure. This illustrates the tentative nature, not only of the hypotheses of Science, but of what Science calls its results. The method of hypotheses, and that method is the method of Science, founds its explanations of Nature wholly on observed facts, and its results are ever subject to the limitations imposed by imperfect observation. However grand, however widely accepted, however useful its conclusion, none is so sure that it can not be called in question by a newly discovered fact. In the domain of the world's knowledge there is no infallibility.

And now let us return for a moment from the illustrative investigation to the hypothesis of hypotheses. If my idea is correct —if it be true that tentative explanations are always founded on accepted explanations of similar phenomena—then fertility of invention implies a wide and varied knowledge of the causes of things, and the

* Mr. Howell's suggestions were communicated orally and are here published by permission.

understanding of Nature in many of her varied aspects is an essential part of the intellectual equipment of the investigator. Moreover, mankind, collectively, through the agency of its men of science and inventors, is an investigator, slowly unravelling the complex of Nature and weaving from the disentangled thread the fabric of civilization. Its material, social and intellectual condition advances with the progress of its knowledge of natural laws and is wholly dependent thereon. As an investigator it makes each new conquest by the aid of possessions earlier acquired, and the breadth of its domain each day is the foundation and measure of its daily progress. Knowledge of Nature is an account at bank, where each dividend is added to the principal and the interest is ever compounded; and hence it is that human progress, founded on natural knowledge, advances with ever increasing speed.

G. K. GILBERT.

SOME FUNDAMENTALS OF NOMENCLATURE.

THE following paragraphs are a brief abstract of two consecutive papers read before the Biological Society, of Washington, on November 16 and 30, 1895. And, though averse to attempting the condensation of so much matter into small space, the attempt is made in deference to the expressed wishes of several who are interested in the questions discussed in the original papers.

It is certainly time that inquiry should be made into the remotest history of the evolution of the binary nomenclature in use by botanists and zoölogists; for it is only by the way of the history of any system that we may easily arrive at an understanding of its fundamental principles. Within the last thirty years there has been much legislation attempted respecting nomenclature. There is talk of further legislation in the future, and certainly much need of it, if by it we may hope to establish a rational and acceptable system. Yet very few of those who enter the arena of nomenclatorial discussion seem disposed to acquire anything more than a superficial knowledge of the origin and development of the binary system; they have never looked carefully to see whether priority, or fitness in names, or the mere convenience of the biological public at a given period, or prevailing usage, is the fundamental principle which has brought the system to its present state; or whether the combined force of all these and some other possible principles have given us such a system—or such a set of systems—as we have, and are more or less content, or discontented.

No subject is well understood, now-a-days, it is everywhere conceded, until it has been viewed from the evolutionary standpoint. But research into the history and evolution of our nomenclature is still neglected; and some are, I think vainly, hoping to resolve all difficulties even by burying still more deeply in oblivion the early history of nomenclature. This is really a curious point in the present status of things. But the present need of historical research is clearly evinced by the absurdities which legislative bodies have already given expression to when endeavoring to state fundamentals.

In attempting to set forth what it calls 'Leading Principles' even the celebrated 'Paris Code' is more remarkable for cheap platitudes and skillful evasions than for any distinct pronouncements regarding principles. Botanists of that period were beginning to awaken to a sense of the importance of priority, but were not yet ready to accord it a place among what were designated as the Leading Principles, yet placing it first among accessory, or secondary, elements of nomenclature.

The body of American botanists who, in 1892, promulgated what is known as the