how or why we do not know, when all the hardships and heartaches of the depression will be forgotten, the obvious lessons as well, only to go through precisely the same ordeal when the next collapse occurs. This is sheer stupidity. It is just as stupid as though the cylinder head of an engine were to blow off periodically, and each time it is put back exactly as it was before without attempting to find out the cause, whether more bolts were required or different material or a better method of combustion, or different fuel, or perhaps the whole engine needed redesigning.

The condition in which the world finds itself to-day requires more than the some sort of blind faith that has served in the past. Our industrialists have failed us; our bankers and banking system have proved woefully inadequate; our statesmen and politicians have failed utterly, if they have not indeed wilfully underestimated the magnitude of the disaster. In the face of one of the most serious economic breakdowns the world has ever known, prohibition is the greatest concern of our two major political parties. It would be amusing were it not so tragic. Even our profit system, that much-vaunted motivating force, the alleged life blood of the capitalistic system, has failed to prevent this calamity. No subtle operation of "economic laws" is going to evolve order out of the chaos in which we to-day find ourselves. Much less can we expect them to effect any modification in the underlying causes of our present condition. Whatever is done must be done by deliberate thinking and planning for a more rational, equitable and secure ordering of society. And to whom shall we look for guidance? Ordinary prudence would say most certainly not to the same sources, industrialists, capitalists or statesmen who have so clearly demonstrated their ineffectiveness. Neither can we expect our scientific men, acting as individuals, uncritically accepting the present order as finality, to be of much assistance. Nor is it very likely that a Moses or a Messiah will suddenly arise in our midst. It is rather a method than a superman that is required. As previously stated, that method is the scientific method, used with such remarkable success in the laboratory, which must somehow be applied to economics, government, international relations and human affairs in general. And it is to our leading scientific men in all branches, including the social sciences, working cooperatively, that we must look for the application of that method.

To summarize briefly the points which I have attempted to make:

(1) The extreme specialization required in order to make any contribution to a particular science has resulted in a lack of coordination between scientific discoveries and their social uses.

(2) The accumulation of scientific information is so vast that it is impossible for a single individual to encompass any one science *in toto*.

(3) Reliance upon the findings of prior workers in a particular field is essential to progress. Even the work of an Einstein can not be considered individualistic, since it rests upon the discoveries of many past or contemporaneous scientists.

(4) It is recognized in some fields, particularly in medical research and in certain industries, that many problems require the cooperative effort of workers in several branches of science for their ultimate solution.

(5) The scientific method which has resulted in such strides in all branches of science and which promises so much more when used cooperatively, should be applied to human relations, national and international.

(6) In our present social order, the greatest progress has been made in materialistic development through technological applications of scientific data, but in human relations there has not been the slightest employment of the scientific method. Instead there has been stubborn resistance to change which is thoroughly unscientific.

(7) The scientific man, best fitted by training and experience, should lead the way in the extension of the scientific method to human relations and help direct the cooperative effort for the solution of the problems involved. Preconceived ideas and prejudices must be discarded. Human relations must be studied in the same manner as physical problems. Openmindedness must prevail. In the light of the findings, a better order of living than obtains to-day will result.

# THE AGE OF METEOR CRATER

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THE noted astronomer, Arrhenius, is said to have declared that Meteor Crater is the most interesting spot on earth. Although others may not concur in that opinion, it is certainly a fact that Meteor Crater[1] has aroused the wonder and interest of the many who have visited it, and has already called forth more than thirty-five papers describing its peculiarities and explaining its origin. Having spent a few days examining the crater in the spring of 1930, I venture

[1] Situated on the plateau of northern Arizona, about 20 miles west of Winslow. Also called Coon Butte.

to set forth some facts and opinions which seem to bear particularly upon the age and evolution of the crater as it now exists.

For the benefit of those readers who may not be familiar with the previous reports, it may be explained that Meteor Crater is an elliptical pit, about three quarters of a mile long and some 600 feet deep, in the surface of the Arizona plateau between Flagstaff and Winslow. It is surrounded by a circular ridge or parapet that rises about 130 feet above the plateau. From its crest this slopes gently outward but steeply inward to the crater. The latter penetrates the full thickness of the Kaibab (Permian) limestone and is bottomed in the massive gray Coconino sandstone, both of which are nearly horizontal throughout the district. Although Gilbert,[2] followed by Darton and others, surmised that the crater may have been produced by an explosion of steam from a buried volcanic intrusion, it is now the consensus of opinion, which the writer believes to be amply justified, that it was made by a meteoric projectile, or bolide, striking the earth from outside at high velocity and producing an appropriate explosion beneath the surface. This view is confirmed by many remarkable and almost unique facts, which have been fully set forth by Barringer[3] and others.

By sinking shafts and drilling holes, explorers of the crater, led by D. M. Barringer,[4] have shown that the original hole is now partly filled with débris. Some of this is talus-stuff which has rolled down from the surrounding cliffs and alluvial fan material washed in from the same source. In the bottom there is also a considerable thickness (about 90 feet) of evenly stratified lake deposits, indicating the former presence of a perennial body of water. This rests upon a chaotic mass of rock flour and debris, the exact origin of which is uncertain. The total filling is apparently about 700 feet deep in the center, but of course it thins out on the surrounding slopes so that in the adit on the south side the talus is only 60 feet thick.

The rock strata encircling the crater, although gently bent upward, are not, so far as observed by the writer, unusually crushed or fractured, and hence we do not appear to see in them the effects of the actual impact. The distribution of large blocks of the Kaibab limestone in all directions around the crater to distances of one mile or more from the brink is consistent with this view. In that case one may infer that finer material in large quantity was carried much farther before it settled out of the air.

Like most of the surface of the Colorado plateau, the vicinity of Meteor Crater is a region of erosion rather than of deposition. Aside from some thin and discontinuous drifts of windblown sand, there are in fact practically no sedimentary deposits in the vicinity. Erosion is carried on chiefly by the wind but partly by temporary streams of water. The process of solution assists to a slight extent.

Deflation is favored by the open and exposed situation of the crater on a nearly treeless plain, by the generally dry condition of the porous soil and by the friability of the red sandstone (Moencopie formation) which immediately overlies the Kaibab limestone. Near the crater the sandstone has been largely worn away. The work of deflation is indicated by the intricately etched forms of the sandstone outcrops, by the bodies of reddish sand in hollows here and there and by the presence of a deflation armor on the crater rim itself, as will be described later. A view of the locality from an airplane shows also that the surface is largely of the sort left by deflation, but with minor ravines eroded by streams.

The work of water rills is more clearly indicated, because streams work along lines and therefore make distinct ravines or gullies. In general, the porosity of the surface material and the aridity of the region are unfavorable to the development of streams. However, in the occasional sudden downpours of rain, which in this region come only a few times in a decade, much erosion may be done in a few hours. In the intervening times, when streams are inactive, the wind tends to fill the erosion channels with drifted sands. The inner slope of the parapet, being steep, is well furrowed with short shallow ravines, but the gentle outer slope is much less marred in this way. In view of the readiness with which rain is absorbed by the porous material instead of running off over the surface, the general flatness of the plateau is a hindrance to rapid stream erosion.

As it exists to-day the crater rim is only the remnant of the original cone of explosion after the erosive processes have removed what they could. A casual examination of the surface of the parapet gives the misleading impression that it is composed largely of blocks and finer débris of the Kaibab limestone and pieces of sandstone. Pits, trenches and shafts that have been dug, especially on the south and southeast sides, show on the contrary that it consists very largely of a white flour-like material which resembles the purest volcanic ash in general appearance, but is in fact pulverized quartz. As shown by Barringer[5] and

[2] G. K. Gilbert, "The Origin of Hypotheses, Illustrated by the Discussion of a Topographic Problem," SCIENCE, n. s., Vol. 3 (1906), pp. 1–13.

[3] D. M. Barringer, "Coon Mountain and its Crater," *Acad. Nat. Sci. Phila. Pr.*, Vol. 57 (1905), pp. 861–886.

[4] D. M. Barringer, "The Geology of Coon Butte," SCIENCE, n. s., Vol. 24 (1906), pp. 370–371.

[5] D. M. Barringer, "Further notes on Meteor Crater, Arizona," *Acad. Nat. Sci. Phila. Pr.*, Vol. 66 (1915), pp. 556–565.

others, this quartz powder was derived from the pulverizing of the Coconino sandstone at the time of the impact. However, it is now everywhere concealed by a thin layer of heterogeneous débris consisting largely of blocks of limestone ranging from small fragments up to masses weighing 4,000 tons or more. It seems highly improbable that at the time of the explosion the expelled material would settle in this arrangement. On the contrary, the large heavy pieces would tend to come to rest sooner, and much of the fine dust floating in the air would have settled more slowly and would thus have formed the bulk of the upper layer. However, if one introduces the factor of deflation, the existing conditions are readily explained, for the wind searchingly removes all fine material that is not protected, and thus the scattered larger fragments of limestone and sandstone gradually become concentrated into a protective layer against which the wind is powerless. This constitutes the familiar deflation armor or desert pavement which is highly characteristic of arid regions the world over.

If this is the correct interpretation of the present structure of the parapet, it indicates that between the date of the explosion and the present time, the wind may have removed a large part of the original accumulation and perhaps more than half of it.[6] It has been calculated by Tilghman[7] that the débris now represented in the parapet would, if replaced in the crater, fall short, by millions of cubic yards, of filling the cavity. The difference may well have been removed by deflation and stream erosion.

The age of the crater has been discussed by previous writers, but the evidence has been considered very scanty. The stories of legends among the Indians regarding a great catastrophe may probably be dismissed as having little weight, for it is improbable that traditions of such matters would last at best more than a few centuries among such primitive tribes. A minimum age of 700 years is indicated by the fact the growth-rings on large cedars, a few of which are scattered about the parapet, show that no important topographic change has taken place in that space of time.

It was supposed by Barringer[8] that the crater was formed not more than 2,000 to 3,000 years ago. On the basis of the effects of erosion Tilghman[9] favored an age of not more than 10,000 years and probably less than 5,000. There are many facts, however, which indicate a much greater age.

The lake deposits in the bottom of the crater, shown by drilling to be 70 to 90 feet thick, comprise stratified sand and quartz flour with many lacustrine gastropod shells and diatom frustules. This is interbedded with platy fresh-water limestone, lignitic beds, diatomite and a single layer of rhyolitic ash $\frac{1}{4}$ to 3 inches thick.[10] The characteristics of the deposit are such as to indicate a body of water of many years' duration, rather than a seasonal pond or playa. This in turn suggests a climate distinctly cooler or more humid than the present one, for there has been no pond in the crater since it first became known to white men. At present the water-table is about 200 feet below the floor of the pit, whereas during the presence of the lake it must have been somewhat above it.

The bed of volcanic ash is plainly the record of an explosive eruption somewhere in the southwestern arid region. No such eruption is known to have occurred since Pleistocene (late glacial) times. If the age of this shower is ever determined it may afford important evidence regarding the age of Meteor Crater. So far as our present knowledge of these lake beds goes, they suggest the last glacial age of the Pleistocene period rather than any more recent time.

Both upon and beneath the lake beds wedge-shaped alluvial deposits were built out by streamlets descending the steep crater slopes. The lower fans are said by Tilghman[11] to extend out under the lake deposits, although not to the center of the crater, as indicated by exploration in shafts and drill holes. The upper fans are still in process of formation. They consist largely of brown sand exactly like the material now being blown over the surface of the plateau. Some of this is trapped in the crater and has been washed down the slopes in times of rain. A layer of brown sand said to be about 10 feet thick has been spread over the lake deposits, probably in this manner. The advance of these fans is appropriate to a drier climate, with occasional sudden rain storms, as at present.

Most of the limestone blocks upon the parapet are deeply cavernous and corroded by the effects of solution. As this process works rather slowly in an arid climate, the advanced stage of solution pitting indicates a long time. On moraines of the last glacial epoch near Provo, Utah, and elsewhere in the Rocky Mountains, the limestone boulders are much less

[6] In this connection Barringer said, "there can be no doubt that enormous quantities of the finely divided rock flour have been blown away from the slopes by the violent winds . . ." D. M. Barringer, "Meteor Crater in Northern Central Arizona." Private Publ., read Nat. Acad. Sci., Nov. 16, 1909, p. 5.

[7] B. C. Tilghman, "Coon Butte, Arizona," *Acad. Nat. Sci. Phila. Pr.*, Vol. 57 (1905), pp. 887–914.

[8] D. M. Barringer, "Coon Mountain and its Crater," *Acad. Nat. Sci. Phila. Pr.*, Vol. 57 (1905), pp. 861–886.

[9] *Op. cit.*

[10] H. L. Fairchild, "Origin of Meteor Crater (Coon Butte), Arizona," *Bull. Geol. Soc. Am.*, Vol. 18 (1907), pp. 493–504.

[11] *Op. cit.*

pitted. Likewise the tufa domes southwest of Searles Lake in California are but slightly affected by solution, although they are believed to be of late Wisconsin age. On the much older and higher terraces of this lake, which the writer correlates with an earlier (Tahoe) glacial epoch,[12] the tufa domes are even more honeycombed by solution than the limestone blocks at Meteor Crater. These facts alone suggest that the latter may belong to the last interglacial age.

A study of the ravines and small graded valleys on the parapet indicates that the latter has suffered more erosion than the latest (Tioga) glacial moraines, but hardly so much as those of an older epoch. It is also significant that one of the graded dry "washes" which runs out from the parapet into the general surface of the plateau shows no change of form or geomorphic age in passing from the débris mass out over the plateau. This indicates that the entire ravine as seen to-day has developed since the débris cone was built upon the plateau. From this one may conclude that the crater is older than the present sub-cycle of erosion of the plateau surface.

As a fifth source of evidence, the present condition of the talus slopes within the crater affords instructive suggestions regarding the physiographic history. A close scrutiny of the talus shows that it is no longer growing but has been extensively eroded into a series of ravines between which a few wedge-shaped remnants of the talus still remain. The talus is therefore the product of an earlier age, long since past. It is a well-known fact that talus formation is particularly favored by the wedge work of ice ("frost action"), and aridity tends to prevent it. In all our deserts to-day talus slopes are, with local exceptions, wasting away. On the lower slopes of Death Valley only a few small remnants of talus now remain as relics of a previous age when climatic conditions were favorable to its growth. If we suppose the crater to be of Pleistocene age, the moist cold climate of the last glacial epoch would have promoted frost action and talus growth, whereas the arid interglacial and Recent epochs would have suppressed such growth and induced the ripping of the talus by sudden torrents ("cloudbursts"). It is these torrents that are now enlarging the alluvial fans which have crept out over the lake beds.

It seems very significant that the evidence along these five independent lines points to a long period of atmospheric action and also rather definitely to climatic changes from warmer and drier to colder and moister and back to dry again. From these considerations the writer is led to suspect that the crater was made during the last interglacial (or post-Tahoe) epoch, perhaps 40,000 to 75,000 years ago. Of course no finality can be claimed for this estimate, but as a counterbalance for the current view that the crater is only a few thousand years old it has considerable value.

[12] Eliot Blackwelder, "Pleistocene Glaciation in the Sierra Nevada and Basin Ranges," *Bull. Geol. Soc. Am.*, Vol. 42 (1931), pp. 865–922.

# SCIENTIFIC EVENTS

## REORGANIZATION OF FEDERAL SCIENTIFIC BUREAUS

A reorganization of the federal executive departments will be effective in February upon executive orders issued under Congressional authority by President Hoover, unless Congress rejects the plans. Science Service summarizes the major changes in the scientific and engineering bureaus of the federal government as follows:

The U. S. Public Health Service, now in the Treasury Department, will be transferred to the Interior Department and made part of the new division of education, health and recreation which will include bureaus with these functions which are largely already in the Interior Department.

A new Division of Public Works is also established in the Department of the Interior in which practically all the non-military engineering activities of the War Department, which include river and harbors, flood control and similar work are incorporated.

The Bureau of Public Roads, now in the Department of Agriculture, is placed in this public works division, thus giving it jurisdiction over the extensive federal aid highway program.

The Treasury's Supervising Architect office is also transferred to the Public Works Division and numerous commissions and offices also dealing with government construction and purchasing are brought together in the same division for more economical administration.

The General Land Office of the Interior Department is given to the Department of Agriculture and grouped with the Forest Service, the Biological Survey and the Bureau of Chemistry and Soils already in the department into a division of land utilization.

The Hydrographic Office of the Navy and the Naval Observatory are incorporated into a new Department of Commerce Merchant Marine Division, and the Hydrographic Office is merged with the Coast and Geodetic Survey. The same subdivision of the Department of Commerce will include the United States Shipping Board Emergency Fleet Corporation.

The Weather Bureau, long in the Department of