[AMERICAN JOURNAL OF SCIENCE, VOL. 261, SUMMER 1963, P. 650-664]

CRYPTOEXPLOSION STRUCTURES: A DISCUSSION

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ABSTRACT. An attempt is made to reply to and discuss the objections raised by W. H. Bucher in the preceding paper against the concept that cryptoexplosion structures of the Steinheim (Germany) and Wells Creek (Tennessee) type are astroblemes (meteorite impact structures).

The writer considers that the Barringer Crater (Meteor Crater) is unquestionably of meteoritic origin and that criteria for astroblemes may validly be extrapolated from it. The Wells Creek and Steinheim cryptoexplosion structures are not necessarily genetically related to the larger geologic structures around them. The Vredefort Ring may well be really related to the Bushveld complex and the Great Dike of Rhodesia, but an impact rationale can be suggested for the entire group. Perhaps great lopolithic bodies can be created by impact; for example, the Sudbury lopolith. All seem to agree that shatter cones and coesite validly indicate intense shock; the writer believes such shock can only be created by meteoritic impact.

The writer agrees with Bucher that there are many puzzling and unresolved aspects of cryptoexplosion structures and that we are still far from a definitive understanding of their true nature. These fascinating structures, which may be the terrestrial analogs of lunar craters, deserve careful scrutiny.

BACKGROUND

This paper is a reply, made at the kind invitation of Professor Walter H. Bucher, to his paper "Cryptoexplosion Structures Caused from Without or Within the Earth? ("Astroblemes" or "Geoblemes?")". In view of the growing literature on impact structures and the topical interest in lunar craters, it is most welcome and useful that Bucher, who wrote the classical paper on cryptoexplosion structures within the United States (Bucher, 1936), should once again evaluate them. My purpose is not to engage in polemics but rather simply to discuss a few of the many questions raised by Bucher against the interpretation that certain cryptoexplosion structures are ancient meteorite impact scars. As one who has espoused the case for impact structures for nearly two decades, I freely admit that the case is still far from final proof. On the other hand, it has been satisfying to witness the changing view of geologists toward the impact rationale from virtually complete non-acceptance, and even ridicule, to its present position as the favored hypothesis, as Bucher concedes.

Although one hesitates to burden geology with additional terminology I welcome Bucher's acceptance of the neutral and self-explanatory term *cryptoexplosion structure*. I also find useful, and will use here, the term *astrobleme* (star-wound) as meaning a structure which is thought to be the scar, or intense circular deformation, caused by a meteorite or comet-head impact. Similarly, in adhering to general usage, we can define a *cryptovolcanic structure* as a natural explosion structure which is considered to be related to volcanism but without the extrusion of volcanic rock or any marked hydrothermal effects. To be even more specific, we can agree too that the Steinheim Basin structure is the prototype cryptoexplosion structure whereas the Wells Creek Basin structure may be usefully used as the "syntype" for the United States.

* The opinions and assertions contained herein are the private ones of the writer, and are not to be construed as official, or as reflecting the views of the Navy Department or the naval service at large.

As Bucher noted, the 1961 edition of the Tectonic Map of the United States, published by the American Association of Petroleum Geologists displays 14 structures of the cryptoexplosion type. They are labeled as structures that are "intensely disturbed and with localized uplift". This map is a revision of the 1944 edition in which many of these same structures were termed "*cryptovolcanic*". I do not believe that all these structures are astroblemes. Those which I would definitely so include are: the Wells Creek disturbance in Tennessee, the Decaturville disturbance in Missouri, the Kentland disturbance in Indiana, the Crooked Creek disturbance in Missouri (not shown on the map; Hendriks, 1954), the Serpent Mound disturbance in Ohio, and the Sierra Madera disturbance in Texas. Any critical discussion of the astrobleme problem should be directed toward these. Two meteorite craters are shown by this symbol; viz. Meteor Crater in Arizona and Odessa Crater in Texas. Some of the remaining disturbances very likely are astroblemes, especially the Flynn Creek disturbance in Tennessee, the Manson structure in Iowa, and the Glasford in Illinois (not shown on the map; Buschbach and Ryan, 1962). Some of the others show little evidence of shock or explosive origin—e.g., the Glover Bluff uplift in Wisconsin. Upheaval Dome in Utah is probably a salt structure. Beals (1958) has found several examples of probable fossil meteorite craters in the Canadian Shield.

To give the reader a pictorial insight into the question under discussion, Plates 1 and 2 are included, showing an aerial view of the Ashanti Crater, a presumed Quaternary meteorite crater, and the Decaturville structure, a cryptoexplosion structure whose circular pattern shows up from the air. The Ashanti Crater, developed in a Precambrian metasedimentary terrane and without any associated lava, was first described as a meteorite crater by Maclaran (1931), mostly on geomorphic criteria. Rohleder (1936) and Junner (1937) denied Maclaran's contention, preferring a phreatic steam explosion or, in essence, a cryptovolcanic interpretation. Rohleder found shatter cones at Ashanti which he described as similar to those at Steinheim Basin. Junner described a pumiceous volcanic agglomerate from Ashanti. But since its description seemed to me to be that of an impactite, I obtained a sample from D. M. Bates of the Ghana Geological Survey. This was found to contain coesite and otherwise to resemble the suevite from the Ries Basin (Littler and others, 1961). My view is that it is a bona fide meteorite crater and by far the largest known Quaternary example in the world.

BARRINGER CRATER

The case for astroblemes is in considerable part premised upon the authenticity of the Barringer Crater (Meteor Crater) in Arizona as meteoritic. Bucher questions its validity and apparently adheres to Gilbert's (1896) steam explosion or cryptovolcanic explanation. Gilbert compared Barringer Crater with the Mt. Bandai-san explosion in Japan (which incidently did not produce a crater but merely blew down the flank of a mountain without extrusion of lava). He wrote, "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 . . . The little limestone

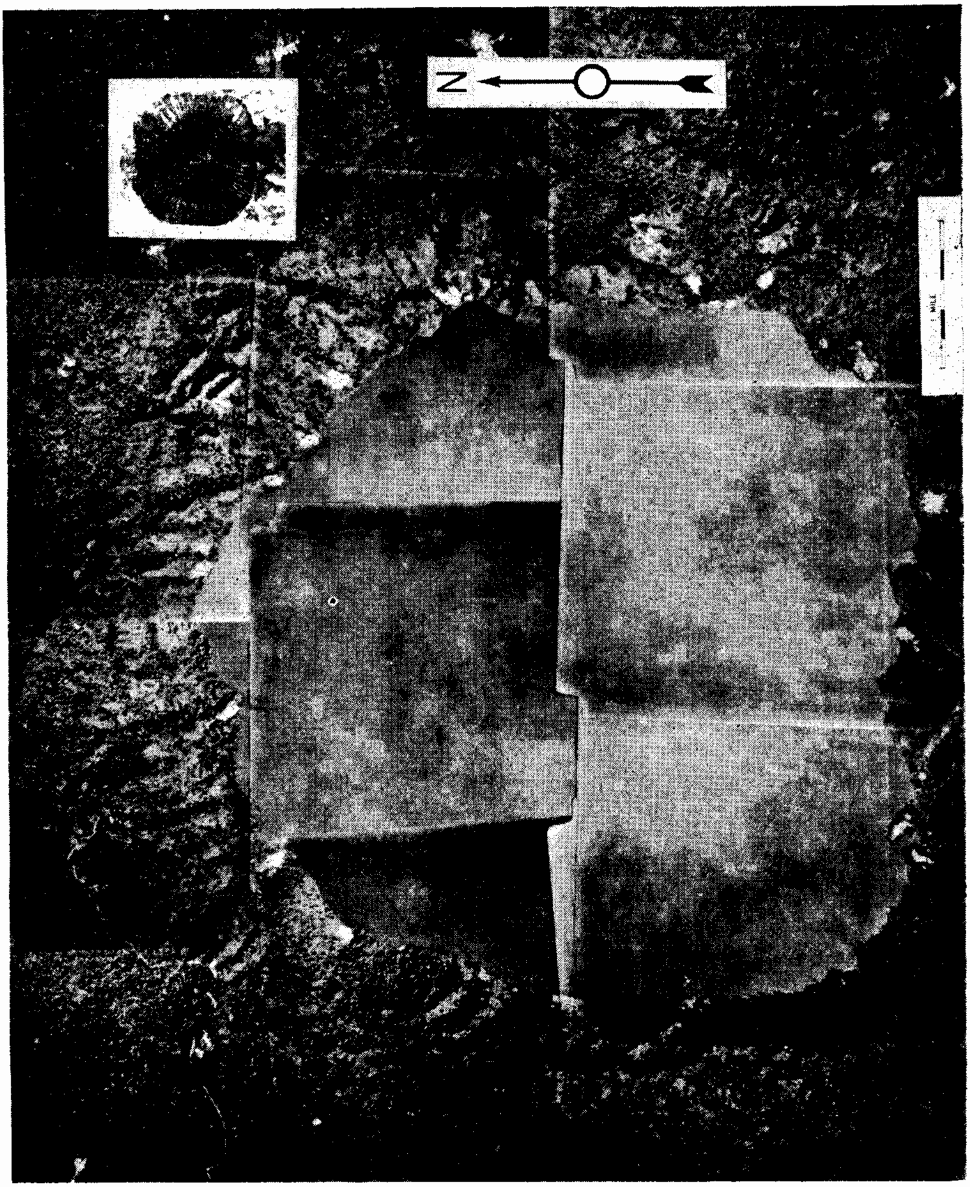

PLATE 1

Ashanti Meteorite Crater in Ghana, Africa, (6°30′ N; 1°25′ W). Interpretation of this crater as meteoritic is based upon shatter cones, coesite-bearing impactite, and geomorphology. Ashanti crater has a rim diameter of 6½ miles and is occupied by Lake Bosumtwi, nearly 5 miles across. The lake is 250 feet deep, above which the crater walls rise 900 to 1200 feet. The outer ramparts rise 300 to 600 feet above the surrounding terrane. A swale or ring syncline (Outer Depression) surrounds the entire crater as an annulus ½ to 2 miles across. These dimensions make Ashanti Crater by far the largest known Quaternary crater in the world. At upper left, an inset of Barringer (Meteor) Crater, Arizona, is shown approximately to scale for sake of comparison. Aerial photographs from Hunting Aerosurveys of Johannesburg. Uncontrolled mosaic prepared by Robert S. Dietz, U. S. Navy Electronics Laboratory, San Diego, California.

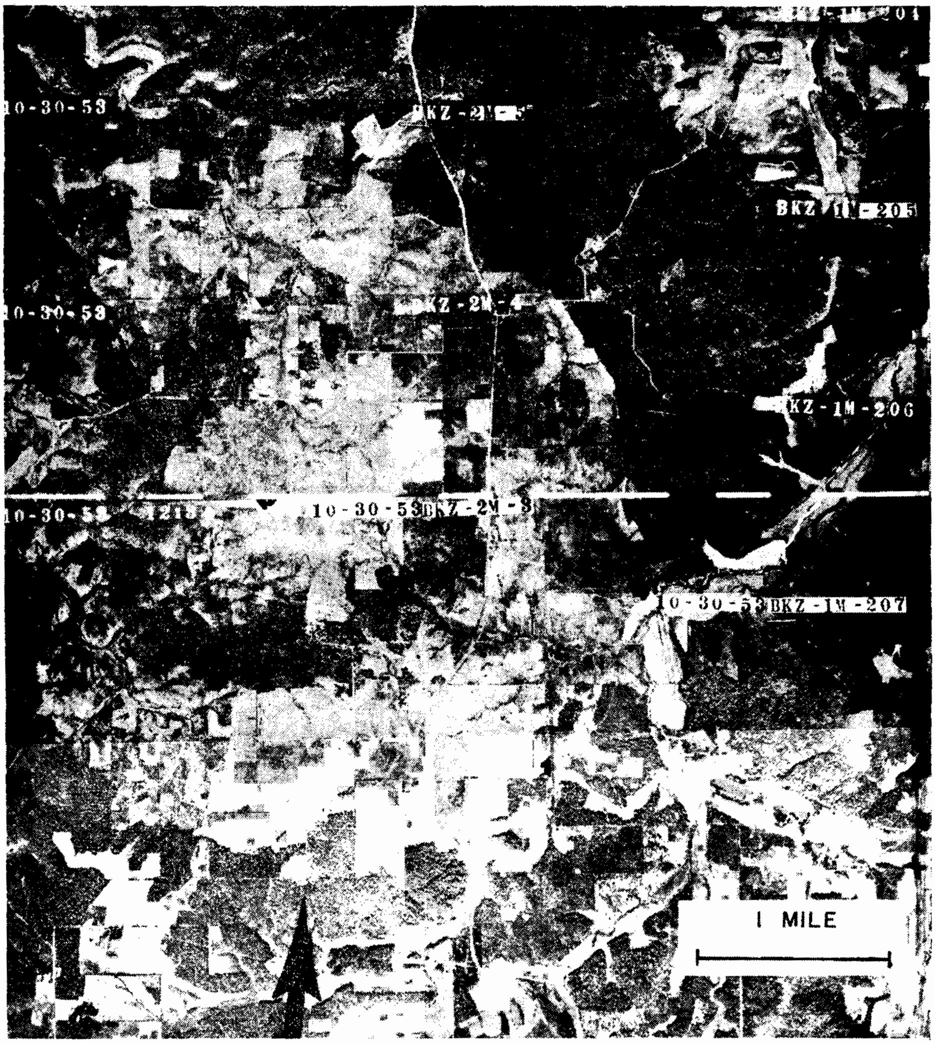

PLATE 2

Decaturville Cryptoexplosion Structure, Camden County, Missouri. Most structures of this type do not stand out on aerial photos but the Decaturville and Crooked Creek disturbances in Missouri are exceptions. A megabreccia is found in the shatter-coned central eye, including a large Precambrian block uplifted from basement normally about 1200 feet deep in this region. The characteristic so-called damped wave structure of cryptoexplosion structures apparently is revealed by the ring syncline (tree-covered) and outer broad ring anticline. As revealed here, the structure is $3\frac{1}{2}$ miles across. This structure is probably an astrobleme (ancient meteorite impact scar), judging in part on the shatter cone evidence for intense shock. U. S. Department of Agriculture photo of Camden County, sheet 4.

crater is in the midst of a great volcanic district. The nearest 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".

All sorts of suggestive volcanic associations can be (and have been) drawn relative to Barringer Crater. Nearby to the northwest are the San Francisco Peaks, whose north flank is pocked with more than 100 parasitic volcanic craters. White Mountain, to the southeast, is similarly peppered with volcanic craterlets. A volcanic collapse feature (?), Stoneman Lake, about the size of Barringer Crater, lies on the south flank of San Francisco Mountain, only 35 miles west-southwest of Barringer Crater. Darton (1905, 1945) drew a comparison with Zuni Salt Lake in New Mexico. A world-famous nest of Pliocene diatremes, the Hopi Buttes, lies to the north-northeast. This activity ceased a few million years ago, while Barringer Crater is about 25,000 years old according to Buddhue (unpublished information). If viewed in the perspective of deep geologic time, this activity would erroneously appear synchronous.

It would be an unwarranted digression to reassess here the validity of Barringer Crater as meteoritic. Suffice it to say, it is virtually universally accepted as such (see, for example, a recent discussion by Shoemaker, 1963). The burden of proof otherwise now lies upon anyone who questions its impact origin. Although there are numerous associations that argue against Barringer Crater's meteoritic origin, it indubitably is meteoritic. Landing amidst this full span of volcanic effects was a most confusing thing for a meteorite to do but, with the perversity of nature, it apparently did so anyway. The argument of geological associations for Barringer Crater being cryptovolcanic can be strongly based, but it fails. Even Hager (1953), who was the last to oppose its meteoritic origin, gave up the cryptoexplosion argument in favor of doming followed by solution collapse.

I would like to correct the impression I apparently made with Professor Bucher in referring to Gilbert's 1896 paper "*On the origin of hypotheses*" as a "philosophical paper" that I was just dismissing it lightly. On the contrary, I was referring to its true philosophic import. It was concerned with the manner in which scientists tested conflicting hypotheses. Gilbert's approach being as he termed it, "reasoning by analogy". He used the Barringer Crater as an example. I *do* believe that Gilbert reached the wrong conclusion in considering it the result of a volcanic steam explosion (cryptovolcanic) rather than a meteorite impact crater. One cannot establish a prototype structure, or the first of anything, through reasoning by analogy since there is no other structure with which to compare. So Gilbert's philosophic rationale failed at Barringer Meteor Crater.

WELLS CREEK CRYPTOEXPLOSION STRUCTURE

As Bucher notes, the Wells Creek disturbance certainly must be of the same origin as the Steinheim prototype, so it makes a useful "syntype" for the United States. Certainly any definitive proof that it is not an astrobleme would discredit the impact hypothesis. Bucher argues that the Wells Creek basin must be terrestrial in origin because of its regional associations. To me, this seems to be only a possibility rather than a probability. It is difficult to lay down any point upon the tectonic map of the United States without finding associated regional trends, etc. If we consider all of the cryptoexplosion structures, they seem to be randomly disposed. What, for example, could be any more lonesome than the Kentland disturbance? There is a great geologic literature about lineaments and trends, but often the points correlated seem as random as the stars in the sky.

RIES-STEINHEIM

Bucher argues that the Urach diatremes must be genetically related to the Ries-Steinheim twin event and, since the Urach diatremes are related to cryptovolcanism, so must be Ries-Steinheim. A similar analysis has been made by Dehm (1962).

There seems little doubt that the Ries and Steinheim structures are genetically related as is virtually agreed by all students of the problem. However, inclusion of the Urach diatremes as also related is questionable. Like the Ries-Steinheim structures, the Urach diatremes formed in the uppermost Miocene but this paleontological dating still could remove Urach diatreme activity 2 to 3 million years away from the Ries-Steinheim event. Accordingly, the Urach diatremes may be removed further away in both time and space than the diatremes of the Hopi Buttes are from Barringer Crater.

Bucher considers the high heat flow at the Ries Basin to be evidence favorable to a cryptovolcanic interpretation and he adds, "The heat effect lingers after more than 10 million years". An apparently more exact timing of the Ries event by potassium-argon dating is 14.8 ± 0.7 million years [uppermost Miocene by Kulp's (1961) table] as found by Gentner and others (ms. 1962). Incidently, they find essentially the same age for the Bohemian tectites (14.7 ± 0.7 million years). The apparent synchroneity of the Bohemian tektite fall with the Ries-Steinheim event is much closer in time than that established for Urach diatreme activity. Certainly it is unthinkable that energies needed to eject the tektites from the Ries and place them in Bohemia could be generated by cryptovolcanism. Several options are open which can relate the tektites to the Ries event, but all involve a cosmic event (Vand, 1962).

It is worth pointing out that an excess heat flow at the Ries Basin is consistent with an impact event as well as with a cryptovolcanic event. A rough geothermal calculation made for me by Richard von Herzen of the Scripps Institution of Oceanography (personal communication) indicated that shock heat trapped at depths between about 5 to 20 km below the Ries Basin by an impact 15 million years ago would just now be escaping at the surface.

If the Urach activity is ever definitely shown to be inextricably associated with the Ries-Steinheim event, a cosmic interpretation is still not wholly destroyed. Could not an impact trigger a type of diatreme activity if conditions were already labile? Little is surmised and even less known about the ultimate cause of diatreme-forming gaseous activity which seems to drill its way upward from deep within the crust or subcrust. An impact might open up fractures allowing the ascent of gaseous magmas: and an impact is highly vectored so that energy might be selectively focused at some deep and distant locus.

VREDEFORT RING

Any discussion of the Vredefort Ring as an impact structure should be divorced from structures like the Steinheim prototype. Whereas I am strongly inclined toward its impact origin, the evidence is of a different sort and on a vastly greater scale. Doubtless many geologists, who are favorably disposed towards interpreting Steinheim-type disturbances as astroblemes, would hesitate and even consider reckless any extrapolation to the Vredefort Ring.

Although I am inclined to question the reality of the structural relationships discussed by Bucher for the cryptoexplosion structures in Europe and the United States, a close relationship between the Vredefort Ring, the Bushveld igneous complex, the Tromsburg anomaly (apparently a buried lopolith), and the Great Dike seems quite possible even though their great antiquity makes synchronous dating uncertain. This is not an absolute necessity as the evidence is merely suggestive, not demanding; thus there is justification for judging the impact origin of the Vredefort Ring without reference to regional geology. But suppose we assume that all these great structures are genetically related; does this destroy the impact concept? Not necessarily, because they might be related directly (Vredefort, Tromsburg, and Bushveld) or indirectly (Great Dike) to a great multiple impact event.

The essence of the Bushveld Complex and the Tromsburg question is, "Can a lopolith (term loosely used) be created by an impact"? This seems to me to be a possibility worth entertaining. I have considered this question elsewhere (Dietz, 1961a,b, 1962, in press,b) so only a brief comment is needed here. We can look at this problem most critically by referring to the best known and most extensively described lopolith in the world and one frequently compared to the Bushveld Complex—namely, the Sudbury structure in Ontario.

An impact rationale is as follows: 1.7 billion years ago, an asteroid, with an impact energy circa 3×10^{29} ergs, struck the Sudbury area (fig. 1). A crater was formed 30 miles across and 3 miles deep. A thick collar of rock was heaved up, forming the crater wall. The collar can still be recognized around the southern periphery, and it can be permissibly assumed in the massive granitic rocks around the northern margin. Shock brecciation (the Sudbury breccia) and shatter coning were extensively developed in the rocks of the crater wall. Because of its great magnitude, the Sudbury impact triggered magmatism by off-loading the lower crust and mantle and by adding shock heat. This resulted in partial fusion of the deep rock which was already critically hot, which rose and was added to impact-melted rock. An *extrusive lopolith,* a saucer-shaped pool of magma, formed and differentiated in the crater bottom. A thick cap of welded tuffs, the Onaping tuffs, were laid down as a capping crust. A body of water then occupied this explosion basin in which the Whitewater sediments were deposited. Rebound, isostasy, tectonics (especially the Grenville orogeny from the south which thrusted the lopolith into an oval shape), and, finally, erosion have modified the structure. The bolide was a copper-rich iron meteorite which smeared itself along the margin of the explosion crater and was injected into radial tensional cracks. Although later converted to sulfides, the Sudbury ores would be of meteoritic parenthood.

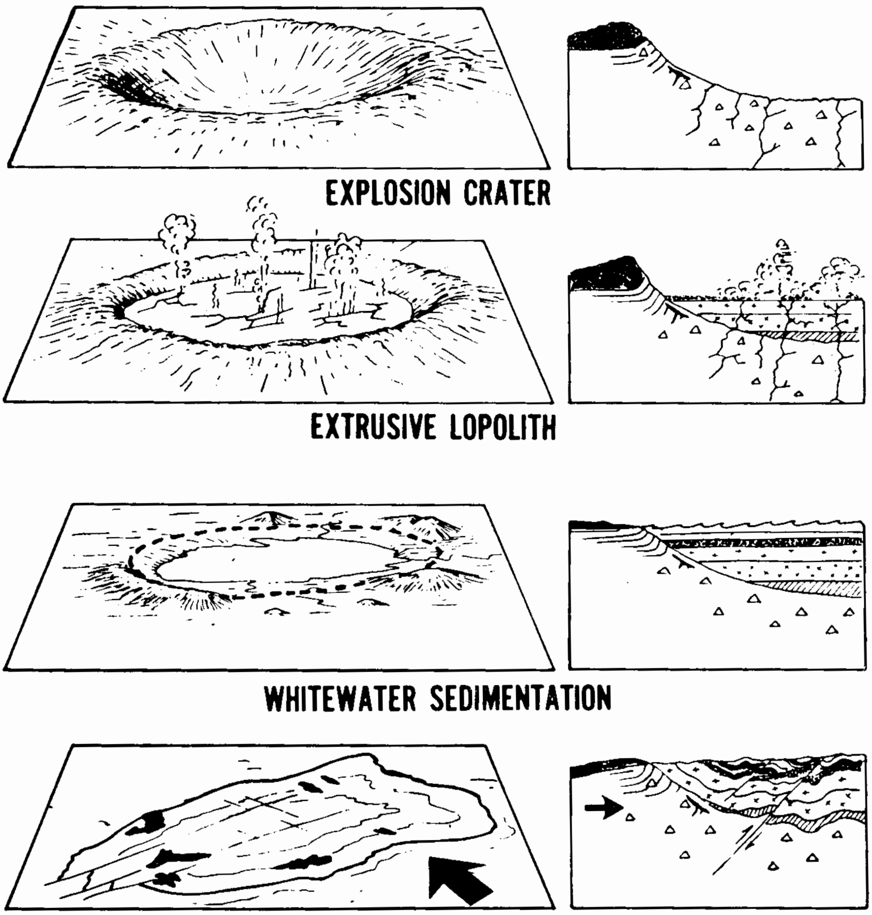

Fig. 1. The development of the Sudbury structure as an intrusive lopolith according to the impact rationale. The suggestion is made that the Bushveld lopolith, a deep layered pool of congealed magma, may also be related in some way to an impact.

In the time-sequence diagram shown, an impact explosion crater is formed. Magma wells up into the crater forming a saucer-shaped pool; it differentiates and a layer of welded tuff crusts over the top. A body of water fills the basin in which sediments are laid down, burying the lopolith. Later thrusting deforms the lopolith into an oval form and finally erosion bevels the structure to its present aspect.

Impact structures must fall into a gradational family of structures since, unlike volcanic and magmatic phenomenon, we can invoke packets of energy of virtually unlimited yield. One can readily imagine a cosmic crash of sufficient energy (10^{38} ergs) to disperse the earth to infinity, but obviously this has never happened. It is also true that an impact from an asteroid the size of Ceres (480 miles in diameter) would create a depression the size of an ocean basin but this seems not to be a geologically permissible explanation for ocean basins. I do feel, however, that impacts can and have occurred that have

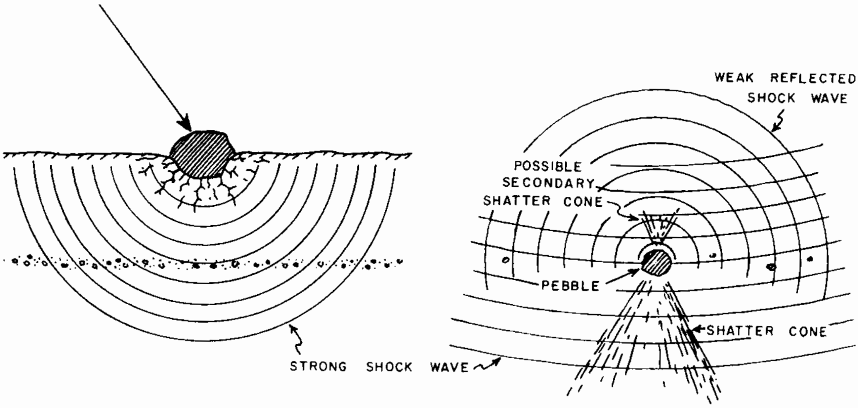

Fig. 2. To show the probable effect of a localized discontinuity, such as a pebble, on the development of a shatter cone. The shock wave from a meteorite passes through homogeneous bedrock; a pebble acts as a secondary source at which another shock wave is generated. Interaction causes rarifaction (and hence tension) along a conical surface, producing a shatter cone. Cone axis points toward the on-coming shock wave; reflection can occasionally produce an inverted cone.

created or triggered magmatism. and it seems to me that we should take a critical look at some lopoliths from this viewpoint. The maria on the moon may be reasonably interpreted as extrusive lopoliths created by great impacts. and lopoliths of the Sudbury type may provide terrestrial anologs. Can the Bushveld Igneous Complex be fitted into this sort of rationale? I think that quite possibly it can.

SHATTER CONES

I am pleased to note that Bucher agrees that shatter cones are a type of shock fracturing and are clearly distinctive from cone-in-cone, slickensides. mullion structure, etc. Coning is. of course. a common type of mechanical failure (e.g. conchoidal fracturing), but shatter coning is distinctive when well developed as at the Steinheim structure (Dietz, 1959, 1960, in press,a). Especially characteristic are the horsetail-like packets (parasitic cones) on the master cone. Where they are poorly developed, the evaluation of conical fractures as shatter cones can easily become subjective.

Regarding the origin and orientation of shatter cones, I do not entirely follow Bucher's reasoning regarding differentiated and undifferentiated surfaces. so that I am not sure I can comment meaningfully. The phenomenon of a meteorite striking the earth can be equally well interpreted as the earth striking the meteorite. In either event a shock wave emanates from the impact point and spreads down through the rock strata. If a quartz pebble or other inhomogeneity is encountered by this transient shock wave. it seems to act as a secondary source from which a new shock wave will spall out, forming a shatter cone. Shatter cones with some type of inhomogeneity in their apex are commonly encountered in the field (fig. 2). Such cones must point toward the oncoming shock wave, and cones found opposing this direction can only be explained by reflection. I cannot agree with Bucher's interpretation that shat-

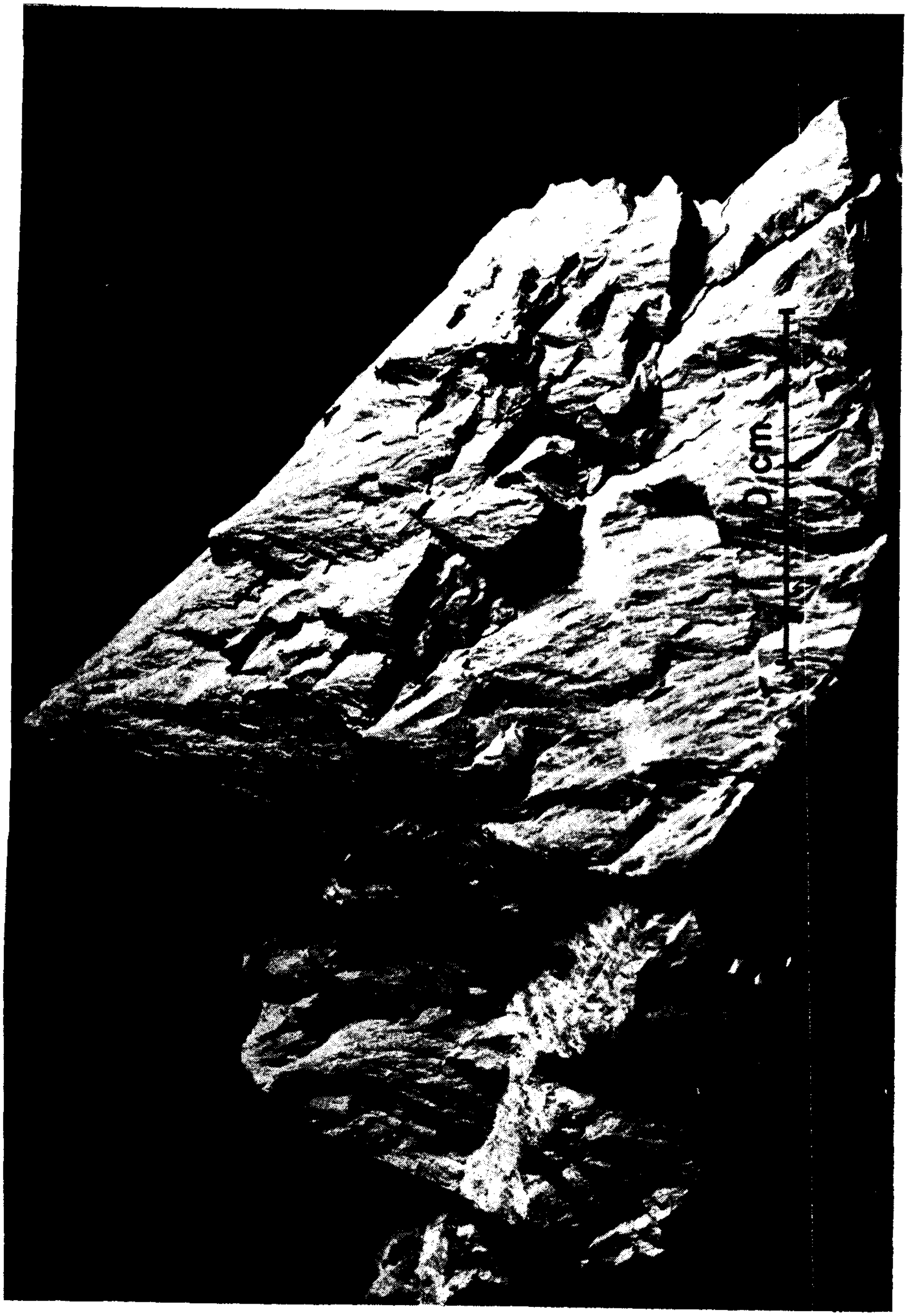

PLATE 3

A shatter-coned block of Knox dolomite from the bull's eye uplift of the Wells Creek Basin cryptoexplosion structure. Note the common orientation of the many interlacing cones. The typical features of shatter coning are well displayed on this specimen. Photo by C. W. Wilson, Jr.

PLATE 4

A shatter-coned outcrop of Permian dolomite at the the Sierra Madera, Texas, cryptoexplosion structure, The cones all show a common orientation which is considered to be the direction from which the shock wave approached this block of megabreccia.

ter cones pointing upward are explainable by a cryptovolcanic pulse coming from below. While Bucher may have produced fracture coning by his thumper experiments. I question that these are in fact shatter cones. His photos of the rude subconical fractures produced by his impact experiments reveal some plumose marking but nothing resembling the horse-tailing of shatter cones. For comparison, good examples of shatter cones are presented (pls. 3 and 4).

Shatter cones are usually limited to the intensely deranged central eye of cryptoexplosion structures. The outer rings show only heaving, suggesting that the shock waves decay rapidly. But considering the great size of the meteorite needed to produce the Vredefort Ring, it is quite expectable to find shatter coning far out into the upthrown collar. We should also expect, as observed by Hargraves (1961), the cones to point inward toward ground zero when the rocks are returned to their pre-event attitude. More recent work by Manton (Hargraves, personal communication) shows the orientation of these cones to be somewhat upward, which fits the impact hypothesis. Manton also has now found shatter cones in the old granite of the Vredefort Ring, thus taking care of this discrepancy remarked upon by Bucher.

I retain the conviction that shatter cones are truly indicative of intense transient shock loading, far in excess of any known volcanic forces. Their concentration in the bulls-eye of cryptoexplosion structures indicates a highly localized ground zero. And when the preferred orientation of the cones can be worked out, the apices *do* point toward the direction of an oncoming shock wave. When definitely recognized, they seem to me a valid criterion for intense shock such as can be derived only from a cosmic impact.

As an explanation of twin cryptoexplosion structures e.g. Ries-Steinheim, Bucher questions the likelihood of multiple impacts. But, for many meteorite craters, the impacts have been multiple; in fact, they seem almost to be the rule. Sikote-Alin, Campo del Cielo, Henbury, Wabar (Al Hadida, Rub-al-Khali), Kaalijarv, and Clearwater Lakes—all involved multiple impact. Even the meteorites from Barringer Crater and the Odessa Crater in Texas are so chemically and petrologically alike that they may have come from a multiple strike (Henderson, personal communication). It is not clear, at least to the writer, if such bodies were mutually rotating in space or were a result of disruption of a single body by the sun's tide, the earth's gravitational field, or the earth's atmosphere. Detailed discussion of such celestial mechanics is given by Baldwin (1963).

COESITE

As Bucher points out, the full geological significance of coesite and stishovite is, of course, far from understood. So far, however, they appear to be a useful and possibly definitive criterion for meteorite craters and astroblemes.

Coesite has been found to date at Barringer Crater (Chao, Shoemaker, and Madsen, 1960) and the Ashanti Crater (Littler and others, 1961), which appear to be Quaternary meteorite craters. It has also been found in Darwin glass (Cohen, personal communication) and in Wabar glass (Chao, Fahey, and Littler, 1961). So far as astroblemes are concerned, it has been found in the Ries structure (Shoemaker and Chao, 1961), at Serpent Mound and Kentland

(Cohen, Bunch, and Read, 1961), and at Holleford (Cohen, personal communication), one of the Canadian "fossil meteorite craters". It has also been found to be produced by the transient shock of an explosion of 0.5 kiloton of TNT in alluvium at the Atomic Energy Commission Nevada Test Site (Milton, and others, 1962).

Several geologists of the U. S. Geological Survey's astrogeology group have searched for coesite to some extent in mylonites and along thrust sheet soles, where high point pressures might have occurred, but with negative results. Coesite has also been searched for in the hyperabyssal and diamondiferous kimberlite pipes, but without success. But, while the lack of any report of coesite in normal volcanic and magmatic geologic structures has not been entirely neglected, one must agree with Bucher that any assessment of the meaning of coesite must be circumspect until much more is known about its overall geologic occurrence.

SOME FURTHER DISCUSSION

Bucher raises a knotty question in pointing out that all cryptoexplosion structures show central uplifts, whereas terrestrial meteorite craters rarely show central peaks. Kaalijarv seems to be one exception. Barringer Crater also may be. D. M. Barringer (B. Barringer, verbal communication) records that the drilling results there reveal a central high of disturbed beds which has been covered over by the fill of lake beds. If we may refer to the moon, the frequency of central peaks in lunar craters attains a maximum at the 60-mile diameter and decreases steadily toward both larger and smaller craters. No peak is known for lunar craters less than about 4 miles in diameter (R. Baldwin, personal communication). Also, terrestrial meteorite craters differ from cryptoexplosion structures in that we see the underlying bedrock exposed only in the latter. Further, the reality of uplift in some cryptoexplosion structures is still definitely unresolved. Eggleton and Shoemaker (1961) mapped the central eye of the Sierra Madera structure as simply a nest of megabreccia. Bucher (1936) did the same for the Serpent Mound disturbance. When mapping a poorly exposed locality, there is a tendency to map on the basis of the oldest rock exposed and to consider it the top of a basement dome when it may be an isolated and floating (rootless) megabreccia block. However, the overall uplift of the central areas seems unquestionably real at some cryptoexplosion structures, e.g., at the Wells Creek disturbance (Wilson, 1953).

Meteorite fragments have yet to be found at cryptoexplosion structures. Perhaps the answer partially lies in "cosmic ice" (solid H_2O, NH_3, CH_4, etc.) which would leave no trace. We have only recently learned about the importance of these volatiles in the makeup of comet heads.

CONCLUSIONS

Regardless of their origin, these intriguing cryptoexplosion structures bear a striking relationship to lunar craters, of which they may be the terrestrial equivalent (Dietz, 1946). Considering the urgency now attached to understanding the moon's surface, it would seem appropriate for the National Aeronautics and Space Administration to support a thorough investigation by surface geology, geophysics, and drilling of these structures. I am sure that Professor Bucher would join me in urging such an undertaking. Very likely it would reap rewards equivalent to the Mohole Project. At a small fraction of the cost of sending a rocket to the moon, a great new insight would be obtained about lunar processes.

I concur with Bucher that traditional thinking should not be overlooked: we should not forgo the mundane in favor of the esoteric. On the other hand, meteoritic impacts must play a geologic role, and the cryptoexplosion structures seem to be examples. On the status of astroblemes I believe we stand today where we stood in 1930 relative to the acceptance of the Barringer Crater as a bona fide meteorite crater, following the writings of Barringer, Rogers, Spencer, and Blackwelder. The case is not yet proven but the scales are tipped in its direction.

Astrogeology is a subject which must concern the earth, as well as the moon.

ACKNOWLEDGMENTS

It is a pleasure to thank the several persons with whom I have enjoyed useful discussion in preparing this reply, viz.: R. B. Baldwin, of Grand Rapids, Michigan: Richard von Herzen, of Scripps Institution of Oceanography, La Jolla, California: Eugene Shoemaker and others of the U. S. Geological Survey's Astrogeologic group at Menlo Park, California. John Holden assisted in the preparation of the figures, and Nathan Ayer has helped in bibliographic and clerical matters.

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