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Meteorite Impact Suggested by Shatter Cones in Rock

Three cryptoexplosion structures yield new evidence of natural hypervelocity shocks.

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The moon's surface is peppered with with some 30,000 telescopically identifiable craters considered by most scientists to be of meteoritic origin. On the earth, two crater-forming meteorites have struck Siberia in the present century. To go back into the Quaternary, Meteor Crater, Arizona, and more than a dozen other craters in various parts of the world stand as mute evidence that the earth has not been spared from cosmic collisions (*1*). Beals (*2*) has described several impact scars or "fossil craters" in Canada of Paleozoic age and older. Under the uniformitarian principle, it would seem that bedrock-shattering meteorite impacts are a process of some geologic consequence, so that one should find meteorite impact scars or "astroblemes" (a word from Greek roots meaning "star" and "wound from a thrown object such as a javelin or stone") in ancient formations if criteria can be developed for their recognition.

Obviously, this thesis would be most convincing if one could find a large meteoritic mass resting in the middle of a chaotically jumbled area of rock. Few persons would question a direct cause-and-effect relationship. But meteorites have never been found in ancient rock, and this suggests that such fragments as are preserved from volitilization during a hypervelocity impact weather rapidly. In the absence of the meteorite, the formation of a chaotic, circular structure, extensive brecciation, and intense shattering are all suggestive of meteorite impact but are hardly definitive. Structures displaying such characteristics are known, but they are generally correctly and less esoterically explained as resulting from explosions related to volcanism or to other mechanisms.

There is, however, one aspect of a meteorite impact which should serve to differentiate an astrobleme from a structure caused by a volcanic explosion or any other terrestrial phenomenon. A giant meteorite (that is, one which is not appreciably decelerated by passage through the atmosphere) should on the average strike the earth with a velocity of about 15,000 meters per second. A principal effect of this impact is the generation of an intense and high-velocity shock wave which spreads out from the impact point, or "ground zero," and engulfs a great volume of rock before it finally decays into an elastic wave. Volcanic explosions are steam explosions involving pressures of not more than several hundred atmospheres, so it is extremely doubtful that a shock wave can be developed in rock as a part of volcanic phenomena. It appears that a lightning bolt would be a possible means of shocking rock, but such an effect would be extremely localized. Naturally occurring chemical or nuclear explosions can almost certainly be entirely ruled out. It would seem, then, that if one can produce evidence that a large volume of rock has been intensely and naturally shocked, this would constitute definitive evidence of a meteorite impact. Fortunately, at least under favorable conditions, rocks when shocked appear to fracture into a curious pattern, forming shatter cones which are preserved and may be readily identified in the field.

Shatter cones are striated cup-and-cone structures found usually in carbonate rocks, but they also have been noted in shale and chert (Figs. 1–3). Presumably, a fine-grained homogeneous rock like dolomite favors their development, but it is not an absolute requirement. The striated surfaces radiate from small parasitic half-cones on the face of a master cone—a pattern which serves to differentiate these striations from the parallel grooving of slickensided fault planes. The apical angles of the cones are from 75 to nearly 90 degrees. The size of the cone apparently depends upon the thickness of the bed which yields as a unit. Some cones as small as 1 centimeter in height have been collected at the Crooked Creek (Missouri) deformation, while at Kentland (Indiana) cones as long as 2 meters have been seen in limestone and cones longer than 12 meters in shale. This coning is apparently a type of mechanical failure under percussion which causes a stratum to become thinner and slightly more elongate by normal faulting—that is, by downward slipping of the cup relative to the cone.

A pertinent question is: Do shatter cones unquestionably require a shock wave for their formation? This cannot be categorically answered, but it is clear that they are quite distinct and different from two geological structures which they vaguely resemble and with which they might be confused—namely, cone-

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in-cone structures and slickensides. In the United States, shatter cones have been found only very near the center of some of the structures identified in the 1940 edition of the *Structural Map of the United States* as cryptovolcanic structures—that is, deformations formed by a hidden explosion somehow considered to be related to volcanism although no direct evidence of this volcanism, such as volcanic rocks or hydrothermal alteration, is found. Thus, they are uniquely present in structures considered to have been caused by a natural explosion. I prefer the term *cryptoexplosion structures* to *cryptovolcanic structures*, so as not to exclude the possibility of an extraterrestrial origin.

Shatter cones have never been reported from normal geological situations, so it would seem that they are not formed by tectonic stresses or by simple static loading. Nor have they been reported from rocks known to have been engulfed by volcanic explosions. So far as artificial detonations are concerned, low-velocity heaving explosives such as commercial dynamite (detonation wave velocity, about 5000 m/sec), which are almost exclusively used for quarrying and similar operations, commonly produce rude cones, but these lack the surface markings of shatter cones. On the other hand, military explosives of high detonation velocity and high *brisance* or shattering effect, like RDX (detonation wave velocity, 8000 m/sec), form cones with surface markings closely resembling those of shatter cones but not so perfectly formed as shatter cones. By extrapolation, it would seem that even greater *brisance* than that of RDX is needed to produce good shatter cones. Since the mean geocentric velocity of meteorites is about 15,000 meters per second, it is to be expected that extremely intense shattering will result for large bolides not appreciably cushioned by the atmosphere. One may conclude that rare natural conditions are required to produce shatter cones but that such conditions could be provided by a large meteorite impact. (*Note added in proof*: A visit to the site of an underground nuclear bomb test revealed portions of large shatter cones in volcanic tuff like those in Richmond shale at Kentland Quarry. Nearby, indurated clay beds beneath the sites of large test explosions of TNT displayed tent-shaped features very similar to shatter cones. The tent shape presumably resulted from a cylindrically spreading shock wave produced by the cylindrical high-explosive charge.)

Recently, I prepared a paper (*3*) describing the four localities in the world where shatter cones had been discovered—Steinheim Basin, Germany; Wells Creek Basin, Tennessee; Kentland, Indiana; and Crooked Creek, Maryland. In that paper I also cited five additional similar structures in the United States. An invitation from G. Kuiper to study the moon's surface at the MacDonald Observatory afforded me an opportunity to visit one of these structures, at nearby Sierra Madera, Texas. Shatter cones were found to be excellently developed there. With this new stimulus, I quickly visited the four other structures—Serpent Mound, Ohio; Flynn Creek, Tennessee; Jeptha Knob, Kentucky; and Howell, Tennessee. Shatter cones were discovered at the first two sites named. Rock outcrops at the Howell structure are too poorly developed to permit any intensive search there. The search at Jeptha Knob was not exhaustive, but it seemed that this structure is probably not of the same type as the others.

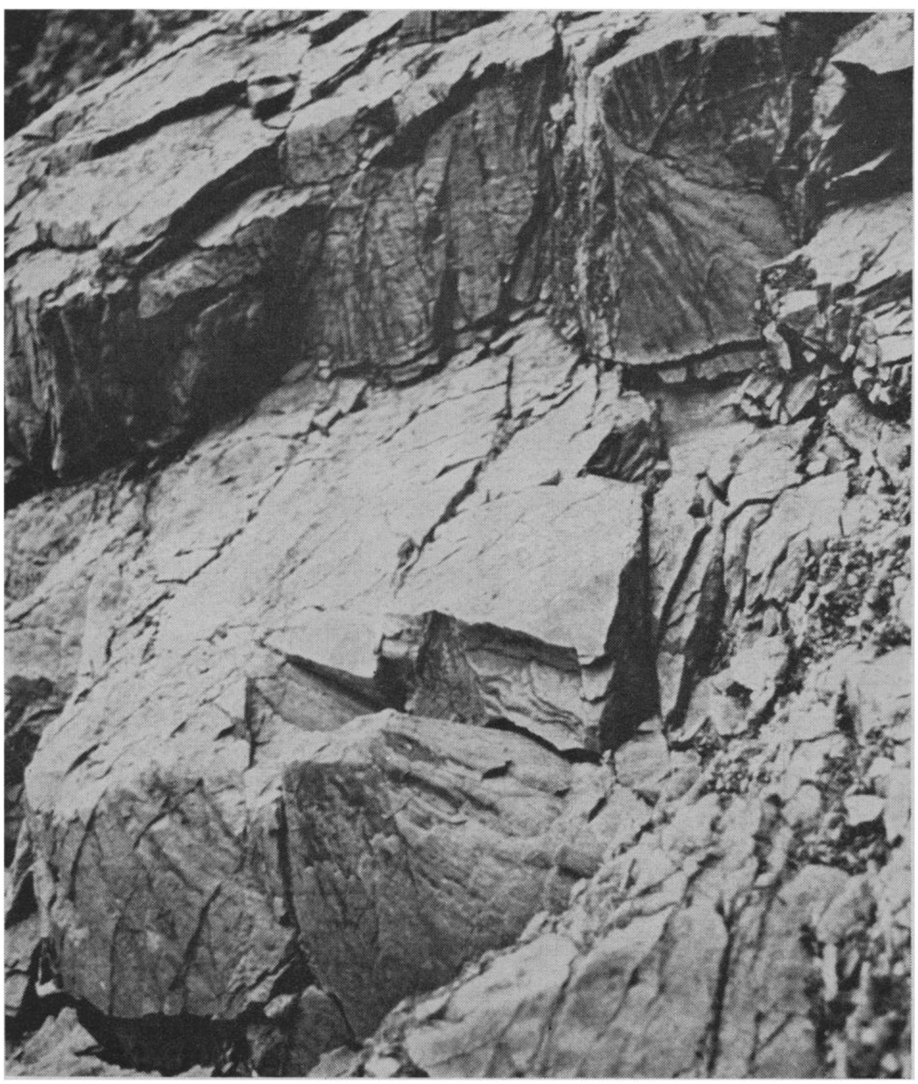

Fig. 1. Shatter cones in Ordovician limestone at Kentland quarry, Indiana. Cones are nearly 1 meter in length and are oriented upward. Such cones are believed to be indicative of a natural shock of high velocity which could only be generated by a meteorite impact.

Sierra Madera Structure

This circular (2-mile diameter) and intensely deranged structure lies 20 miles south of Fort Stockton, Texas, in the vicinity of the Glass Mountains. The geology of this uplift has been described by King (*4*) as an intensely deformed and brecciated area of Permian strata with a central domal uplift surrounded by a ring syncline and possibly a ring fold. Pointing out the damped wave form of this structure, Boon and Albritton (*5*) included it in their list of structures possibly created by meteorite impact. However, Shoemaker (*6*) doubts that detailed mapping will support the conclusion that this is an example of central domal uplift and ring fold form; instead, he believes that the central dome is a mass of megabreccia. Wilson (*7*) reports that two wells drilled to 7000 and 12,000 feet, respectively, revealed no evidence that volcanism played any part in the formation of this structure. A core at 8000 feet revealed only moderate dips, and this suggests that the structure may tend to die out with depth.

A field trip to Sierra Madera in October 1959 revealed the frequent occurrence of shatter cones; thus, this became the fifth locality in the world in which they are known. Although cones in the area are distinctive and numerous, shatter-coning of rock there, as elsewhere, is a subtle characteristic so it is not surprising that others have not previously reported them. The shattering is more extensive at Sierra Madera than at any other locality where shatter cones have been found, although the rocks are not as intensively shattered there as at Wells Creek Basin. The first fragment was discovered in the float of a dry creek on the flank of the structure. Even cone fragments no larger than one's thumb are so distinctive that they are immediately identifiable. During two days of search literally thousands of shatter cones and cone fragments were seen near the center of the structure. Usually these were developed in thin beds lying between more massive strata, but sometimes they were present in the thicker beds as well.

Serpent Mound Structure

I visited this highly deranged structure in November 1959 to search for shatter cones. I examined several peripheral areas, including a quarry which revealed a large mass of what may be explosion breccia, but I found no shatter cones. I then visited the absolute center of this circular deformation and began an intensive search for shatter cones. No outcrops are exposed, so it was necessary to resort to breaking open such residual boulders as could be found. Eventually a boulder was split which clearly revealed these cones. Subsequently, in a period of two days, shatter cones were found in about 20 boulders, or in a ratio of about one in each 25 boulders split open. Boulders containing shatter cones were readily split asunder, while others were difficult to break open. Since cones, as always, were found only in the immediate vicinity of the structure's center, it would seem that the shattering associated with any such cryptoexplosion structure is concentrated near ground zero, although the rocks are heaved up over a much larger area.

Serpent Mound was first mapped and described in 1920 by Bucher (*8*), who considered it to be cryptovolcanic and similar to the Steinheim Basin structure in Germany; however, he was not aware of the presence of shatter cones like those already known then at Steinheim, the type locality for them.

Flynn Creek Structure

This deformation was originally described by Wilson and Born (*9*), who considered that it was created by a cryptovolcanic explosion. Wilson (*10*) now has revised this opinion, attributing the origin of the structure to a meteorite impact. With C. W. Wilson and R. Stearns, I visited the deformation in November 1959. We discovered some shatter cones in a thin bed along a new road cut not far from the structure's center; thus, this became the seventh known locality for shatter cones. Although these shatter cones are poor examples, the identification is unquestionable. Probably a more detailed search would reveal more distinctive beds.

Meteor Crater

The present theory would, of course, be more convincing if shatter cones were found at well-established, modern meteor craters. With this in mind, I examined the rocks at Meteor Crater, Arizona; the search was by no means exhaustive, but no shatter cones were found. If cones are in fact completely absent from the formations exposed at Meteor Crater, this may be due to one of several causes. For example, the rocks immediately beneath ground zero are now covered with lake beds. Another possible explanation lies in the considerable deceleration by the atmosphere of comparatively small crater-forming meteorites. The 300-ton Sikhote Alin meteorite presumably entered the atmosphere at a velocity of about 15,000 meters per second, but it struck

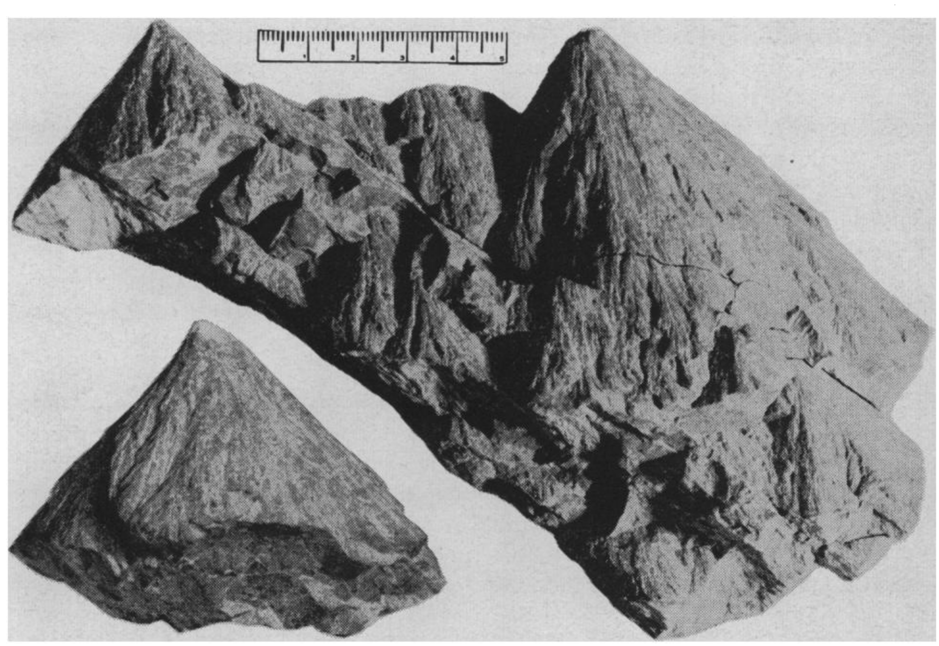

Fig. 2. A group of shatter cones in Knoxville dolomite from the Wells Creek Basin cryptoexplosion structure in Tennessee. The characteristic parasitic coning on the master cone and the common orientation of many interlocking cones is clearly displayed. A single cone is shown below. Scale in centimeters.

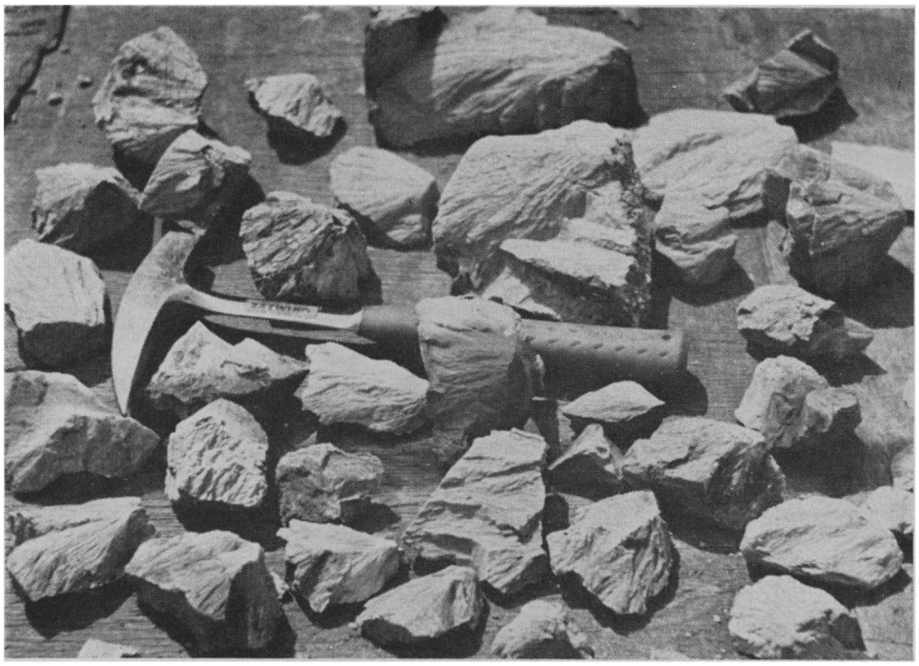

Fig. 3. A collection of shatter cones from the Permian dolomite at the Sierra Madera cryptoexplosion structure in Texas.

the earth at only 500 meters per second —a 97 percent deceleration (*11*). Although much larger, the Meteor Crater bolide, estimated by Shoemaker (*12*) to have weighed 63,000 tons and to have measured 80 feet in diameter, may have been somewhat slowed down. If shock-wave velocities of, say, at least 10,000 meters per second are needed to produce shatter cones, as is suggested by extrapolating from tests with commercial dynamite through high-shattering military explosives, then shatter cones may not have formed at Meteor Crater. Only crater-forming meteorites of somewhat larger size than the Meteor Crater bolide or with a greater geocentric velocity would produce them. However, Shoemaker believes that the impact velocity at Meteor Crater was in excess of 10,000 meters per second.

Orientation of Shatter Cones

The orientation of shatter cones is useful for establishing the impact direction. In most cases the cones point opposite to the direction of shock-wave propagation—in other words, toward the locus of pulse source. It is to be expected that the simple spherical spread of the shock wave from its source will be complicated by reflections from interfaces and by other factors, so that shatter-cone orientation will be somewhat complex.

A visit to Kentland quarry, where there is a great amount of new excavation, confirmed my previous opinion (*13*) that the cones there show a preferred orientation. An examination of several hundred cones exposed in the quarry face shows that roughly 95 percent are oriented normal to the strata and point upward. The remainder of the cones are inverted, as though by a directly reflected wave. The inverted cones are rather difficult to find, since the rock tends to split away more easily around the upright cones where the fracturing is stronger. The term *upward* is used here relative to the presumed original flat position of the beds, since the beds would presumably have been invaded by the shock immediately prior to upheaval.

One rare inverted cone was also found at the Wells Creek Basin structure, although nearly all of the cones there point in the upward direction. At Sierra Madera the cones appear, in general, to point upward, but more work needs to be done to determine which beds, if any, are overturned. At Flynn Creek the orientation is also upward. At the Steinheim Basin structure, an unusual specimen was found showing cones pointing in three directions. The general upward orientation of the cones at all localities where orientation can be determined suggest impact percussion rather than volcanic forces, which would come from below.

Conclusions

Shatter cones probably are a specific criterion for identifying the root structures of large fossil meteorite impacts, so geologists have a useful "index fossil" for astroblemes. These provide a site for the study of effects of hypervelocity impacts which have released energies equivalent to several H-bombs. Astroblemes may also be useful for understanding the origin of lunar craters, which probably are similarly formed. At the very least, all deformations which contain shatter cones must be assigned a single mode of origin (*14*).

Note added in proof: An eighth world locality for shatter cones unquestionably is the rim of the crater occupied by Lake Bosumtwi, Ashanti, Ghana. This crater has been widely reported as of probable meteoritic origin. H. Rohleder (*15*) described and showed percussion cones, termed by him *Drucksuturen* or *Druckfiguren*, along with reconstituted pulverized rock. He states that these cones are apparently of the same origin as the *Strahlenkalk* (the type examples of shatter cones) at the Steinheim Basin structure. He apparently does not use this last term, since the shatter cones are in Precambrian quartzite rather than in limestone.

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