shows the means of these scores for each group, at each level of illumination, in the task of equating sound with light; vertical bars indicate $\pm 1\ \sigma$ at each point. To reach subjective equations with the same levels of illumination, the high group required systematically greater intensities of sound than the low group. When a single composite score (mean of the subject's three deviations from the respective over-all means at the three levels of illumination) is assigned to each subject, the mean of such scores is +3.74 db ($\sigma = 2.82$) for the high group and (necessarily) −3.74 db ($\sigma = 2.57$) for the low group; $t = 8.31$, and $p < .0_51$.

Subsidiary results may be of some interest. Figure 2 summarizes the first-order estimations of relative magnitude for light (N=36), for sound at the lower level ($N = 18$), and for sound at the higher level ($N = 18$). The graphical points indicate mean scores (*4*), and the straight lines have been fitted by the method of orthogonal polynomials (*5*). The slope of the light line is .50; and the slopes of the low-level and high-level sound lines are, respectively, .40 and .43, considered in terms of acoustic energy. Results for individual subjects are not shown. Among all 36, however, mean slope of individual light function was .49; the range of individual slopes was from .24 to .78 ($\sigma = .11$). Among the 18 subjects in the low group, mean slope of sound function was .39 (range, .18 to .56; $\sigma = .11$), and among the 18 subjects in the high group, mean slope of sound function was .42 (range, .23 to .60; $\sigma = .10$). Again, all slopes were computed by the method of orthogonal polynomials.

It would appear that the cross-modality equation of "sensory magnitude" is a process strongly subject to contextual effects and thus presumably not an absolute judgment of sensory quality. We suspect that the slopes of our light and sound lines are somewhat larger than usually reported (*1*, *6*; although see *7*), too, because of the context (a narrow range of stimulus values) in which they were obtained. Finally, the great variability among slopes of individual light and sound functions is worthy of note; such variability is not suggestive of a simple sensory process (*8*).

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Coesite Discoveries Establish Cryptovolcanics as Fossil Meteorite Craters

Abstract. Discovery of coesite in St. Peter sandstone from the central uplift of the Kentland structure, Newton County, Indiana, and in shatter cones of Lilley dolomite of Middle Silurian age from the central uplift of the Serpent Mound structure near Sinking Springs, Ohio, proves that shatter cones are evidence of meteorite impact.

The association of the high-pressure silica polymorph, coesite, with meteorite craters is now widely accepted, a little more than a year after this important discovery by E. C. T. Chao and associates (*1*). Coesite has been found by these workers at Canyon Diablo (Barringer) Crater, Arizona, the Rieskessel of Miocene age in Germany, Wabar Crater in Saudi Arabia, Bosumtwi (Ashanti) Crater in Ghana, and at the artificial Teapot Ess Crater at the Nevada Proving Ground. This work has recently been summarized by Dietz (*2*).

Shatter cones, first discovered at the Steinheim Basin early in this century, have been associated with many cryptovolcanic structures by Dietz (*3*). Shatter cones are associated with six of these structures in the United States. Chao discovered a small fragment of shattered sandstone in the fallout at Canyon Diablo Crater (*2*).

Coesite was concentrated from a Serpent Mound shatter cone that weighed over 2 lb by dissolving the carbonate in hydrochloric acid. The residue was treated by methods described by Chao and co-workers (*4*). Sufficient material was recovered for petrographic identification and photomicrography. Small individual grains in the acid residue have a mean refractive index of 1.591 and show the strain characteristic of natural coesite. In the specimens collected the coesite content appears to be only 10 parts per million. An x-ray rotation photograph was taken of a hand-picked grain which gave the reflections for the 3.1-A d spacing, the strongest reflection of coesite. The x-ray diffraction spots were of low intensity; therefore it was assumed that coesite is present as small inclusions in the large grain. The refractive index of the grain is 1.560, and the grain is amorphous, as the only pattern on the x-ray film other than that of coesite is a diffuse halo. Core drilling of this uplift might yield material of higher coesite content.

The low coesite content in the Serpent Mound material prompted a field trip to the McCray quarry in the Kentland structure, 3 miles east of Kentland, Indiana. Coesite was detected optically in St. Peter sandstone and in breccia. The finest fraction (−320 mesh) from St. Peter sandstone (about 98 percent silica) was found to contain most of the coesite. The residue after hydrofluoric acid treatment consisted predominantly of zircon with smaller amounts of tourmaline and coesite. Table 1 shows the seven d spacings of coesite with which zircon and tourmaline did not interfere. In addition there are four coesite lines coincident with zircon and two with tourmaline. Comparison with Boyd and Eng-

Table 1. Comparison of x-ray diffraction powder data (d spacing and intensity) between Kentland coesite (as found in this study) and synthetic coesite (as found by Boyd and England, *5*).

Synthetic coesite		Kentland coesite	
d(A)	Intensity	d(A)	Intensity*
6.19	3		
4.37	2		
3.436	52	3.438	M
3.099	100	3.089	VS
2.765	8	2.77	W
2.698	11		
2.337	3		
2.295	6	2.29	W
2.186	4	2.18	W
2.033	6		
1.849	5	1.84	VW
1.839	3		
1.794	4	1.79	W
1.787	4		
1.715	9		
1.698	10		
1.655	6		
1.584	5		
1.548	6		
1.409	2		
1.345	6		

* Intensity: M, moderate; VS, very strong; W, weak; VW, very weak.

land's data (*5*) shows excellent agreement (see Table 1). Figure 1 is a photomicrograph of a coesite grain from the St. Peter sandstone. The highest concentration of coesite found in Kentland material is 100 parts per million, in the St. Peter sandstone of Middle Ordovician age.

The two coesite discoveries reported here are from material in which the concentration is from 2 to 3 orders of magnitude more dilute than reported earlier in meteorite crater glasses (*1, 4*). They may also represent the oldest sources of natural coesite now known. The Serpent Mound structure is post-Lower Mississippian and pre-Illinoian and the Kentland structure is post-Middle Ordovician and pre-Pleistocene in age.

The largest shatter cone at Kentland described by Dietz is 6 feet long (*2*). However, Shrock (*6*), even in 1937, suggested that the "great curved fault surfaces in the McCray quarry have essentially the same characteristics as the small shatter cones and are believed to have been formed in the same way by the same forces." Dietz discovered small shatter cones as float on the central uplift of Serpent Mound in 1959 (*3*).

We believe that the central uplift remaining at Kentland is an imbrication of megashatter cones. The photograph on the cover of this issue of *Science* shows the mold of the top of one of the smaller megashatter cones. This is one unit of several conical structures that comprise a large megashatter cone which is a large portion of the extreme southeast face of McCray quarry. The exposed over-all dimensions of this large megashatter cone are 250 feet wide at the quarry floor and 160 feet high. The root extends downward below the quarry floor for an unknown distance.

From a reconnaisance field observation, several characteristics pertaining to vertical uplift (1500 feet, according to Shrock, *6*) and intense rock failure are apparent. Numerous drag folds occur along high angle normal faults which appear to radiate outward from the center of impact. The Platteville carbonates, which in normal stratigraphic sequence overlie the Glenwood and St. Peter sandstones, have developed fracture cleavage and envelop the observable megashatter cones, the apexes of which all point upward. The bedding of these carbonates parallels the surfaces of the megashatter cones. This indicates that those beds that now constitute the megashatter cones have been displaced upward, causing deformation of the originally overlying strata. Complex fractures were also observed in the sandstone of the megashatter cones. Thus the entire uplift may have been one large megamegacone containing a small central crater produced by the explosive jet of the meteorite when it reached its maximum penetration. This uplifted structure in the center of a large crater thus would have many megacones which were thrust upward and outward together from this center, the voids between cones being filled with folded and compressed overlying strata. The interstices then remaining in the entire mass were instantly injected with compressed breccia. No shatter cones were observed in any of the breccia at the quarry, which indicates that the breccia was injected after the explosive impact. Without the present large quarrying operation this magnificent and geologically awe-inspiring structure would be hidden.

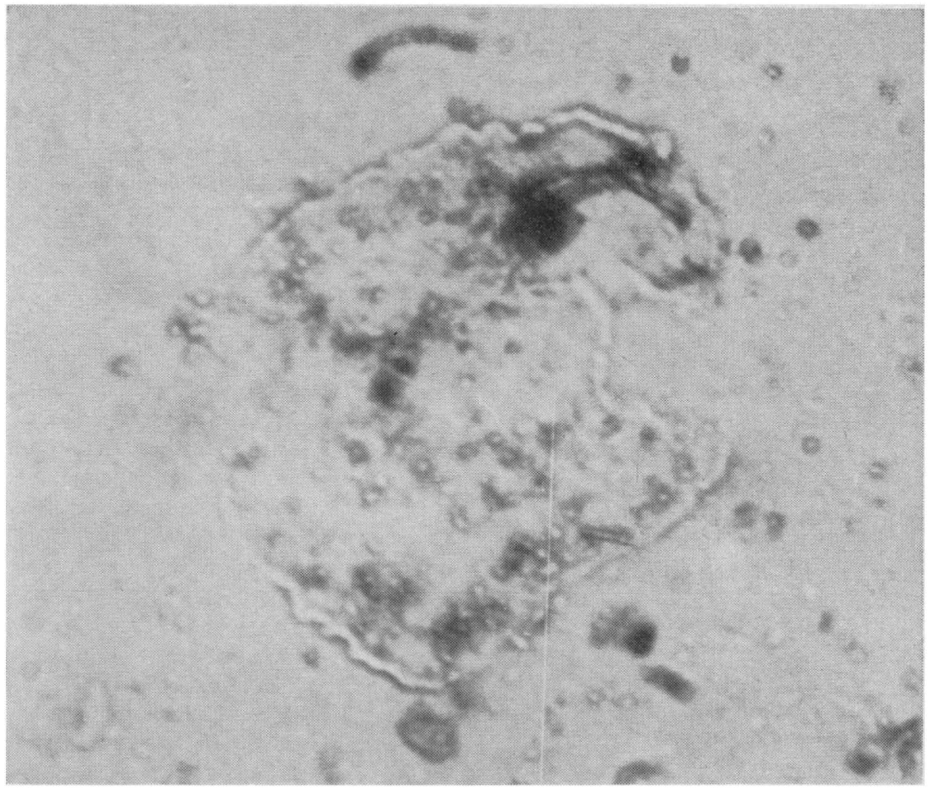

Fig. 1. A photomicrograph (taken slightly out of focus) of coesite from St. Peter sandstone, Kentland, Indiana, in 1.591 immersion oil. The grain diameter is 79 μ.

The McKee quarry, situated about 1100 feet to the east of McCray quarry, has many small shatter cones ranging in size from a few inches to several feet long, mostly pointing horizontally away from the center of the disturbance. The shatter cones are in Platteville carbonates which elsewhere overlie the St. Peter sandstone. This outcrop may have been displaced as a unit from near the center of the explosion.

Further study and core drilling of these features offers the most economical way of attaining some understanding of the root structures and central uplifts of terrestrial and lunar craters. These six known structures in the United States are indeed invaluable but as-yet unexploited national scientific assets to those interested in the cosmosciences (*7*).

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7. Mr. Karl Hoover of the Ohio Geological Survey is thanked for taking one of us (A.J.C.) to the central uplift of the Serpent Mound structure and helping collect shatter cones on a muddy December day in 1960. The quarry officials at McCray quarry and Mr. McKee, owner of the small quarry, are thanked for their cooperation during our visit. This work was supported by grant NsG-47-60 from the National Aeronautics and Space Administration.

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