Asteroid Impact Gets More Support

The global distribution of shocked quartz at the Cretaceous-Tertiary boundary argues for an asteroid or comet impact and against a volcano as a cause of the mass extinction

THE debate over whether the impact of a huge asteroid or comet or a devastating volcanic eruption 65 million years ago ended the Cretaceous period, as well as the existence of many of its species of plants and animals, continues in this issue of *Science* (p. 705). Bruce Bohor, Peter Modreski, and Eugene Foord of the U.S. Geological Survey (USGS) in Denver report that they have found shock-disrupted quartz grains around the world at the Cretaceous-Tertiary boundary. Such grains had previously been found in nature only at sites of large impacts.

Try as they might, advocates of a volcanic end to the Cretaceous have failed to find the same kind of so-called shocked quartz grains in any volcanic rock. Because shocked quartz continues to maintain its exclusive link to impacts, the impact hypothesis would seem to be opening its lead over the sputtering volcano alternative.

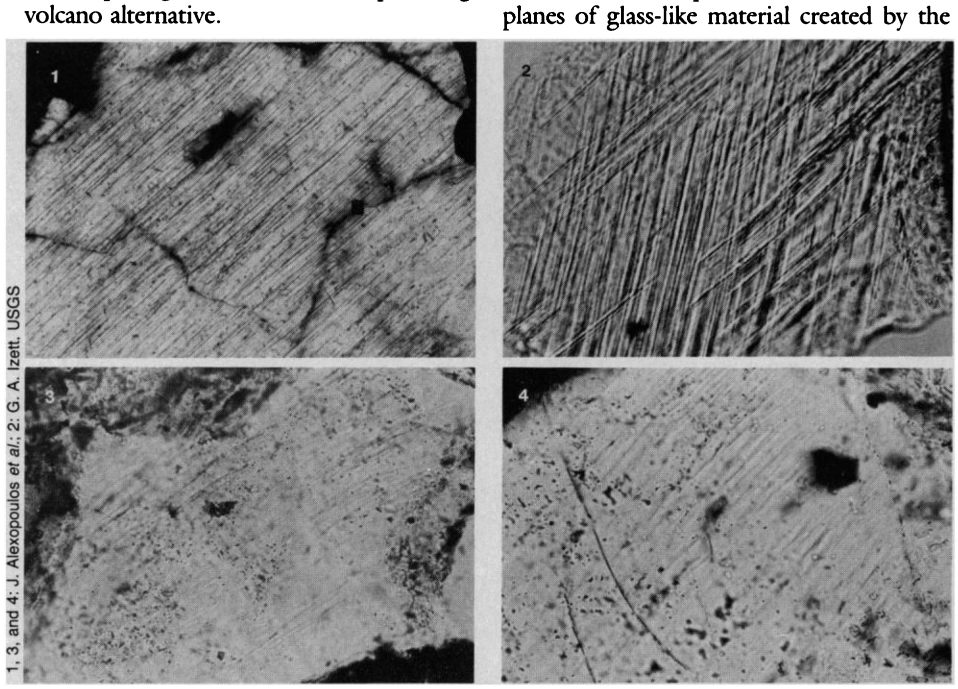
Bohor and his colleagues found shocked quartz grains at the Cretaceous-Tertiary boundary (abbreviated K-T to avoid confusion with other boundaries) at seven sites in addition to their initial discovery in Montana—the central North Pacific, New Zealand, southern Spain, two in Denmark, and two in northern Italy. At all sites the grains clearly have the characteristics of quartz that has suffered the 9 gigapascals (90,000 bars) or more of shock pressure generated by tons of meteorite hitting the ground at upwards of 15 kilometers per second. The shocked quartz coincided with the iridium originally taken to be from an asteroid that hit Earth.

Seen under an optical microscope, the grains are crisscrossed by at least two and as many as nine sets of closely spaced, parallel lamellae, each set intersecting the others and precisely oriented with respect to the crystal structure of the quartz. The lamellae are planes of glass-like material created by the shock-induced disruption of the crystal lattice. Tectonic deformation such as mountain building can produce only one set of lamellae, but the higher the shock pressure, the more sets of intersecting lamellae. "The one thing that everyone agrees on," says Glen Izett of the USGS in Denver "is that if you see multiple intersecting sets [of lamellae], then that's shock induced."

Aside from thoroughly confirming the coincidence at the K-T boundary of iridium and shocked quartz, the number and dispersion of these sites, combined with the relatively huge size of the quartz grains, adds further support to the impact hypothesis. Bohor and Izett found that the largest grains from western North America exceed half a millimeter in diameter and those from Europe, the North Pacific, and New Zealand are in the range of 0.1 to 0.2 millimeter.

Those are real boulders to researchers who study the long-range dispersal of debris from volcanoes. Sprinkling them around the globe in both hemispheres, as happened at the K-T boundary, presents a seemingly insoluble problem for advocates of a volcanic catastrophe. In contrast to the 1-micrometer droplets of sulfuric acid that drift around the globe for years after a Krakatau- or El Chichón–size eruption, a 0.1-millimeter quartz grain carried to near the top of the stratosphere by a rising eruption plume would fall to the ground in less than a day, according to calculations by Lionel Wilson of the University of Lancaster. Given a good tail wind, such a grain would travel 2000 to 3000 kilometers, which is hardly globe-girdling. The great Toba eruption of 75,000 years ago, 400 times more voluminous than Krakatau, lofted grains that large only 500 kilometers downwind.

To go farther, a grain would presumably have to rise higher, but the increasing temperatures above the stratosphere resist that and a more energetic volcanic plume tends to become unstable and collapse altogether. No known eruption has been strong enough to do it, says Wilson, but such grains might conceivably travel 6000 to 7000 kilometers. Then there is the problem of the months, not days, that volcanic particles require to cross from one hemisphere's circulation sys-



Shocked and nonshocked quartz. *Photomicrograph 1 is of a quartz grain from the Lake Mistastin, Labrador, impact structure. Number 2 is of a grain from the Cretaceous-Tertiary boundary impact layer at the Starkville South site south of Trinidad, Colorado. The appearance of the lamellae is similar in both, and both have two or more intersecting sets of lamellae (all not visible in this orientation of 1). Features in quartz from the roughly circular Salmon Fork structure (3), once suspected of being an impact crater, and a deformed scrap of ocean crust (4) appear quite different. In particular, grains from these sites have only one set of lamellae, which is typical of tectonic deformation. Fields of view are roughly 0.2 millimeter.*

tem to the other. Particles larger than a few micrometers fell out of the El Chichón cloud during the first couple of months while the cloud was still confined to the subtropical latitudes of the Northern Hemisphere.

Specialists may have no idea how large quartz grains from a volcano could spread around the world, but impact advocates have no detailed mechanisms either. They do have some confidence in eventually finding one, however, if only because of the awesome power of an impact. Unlike a volcano, which must depend on lifting particles with buoyant hot air, a 10-kilometer asteroid hitting Earth would release almost instantly and at one spot on Earth something like the energy of 100 trillion tons of TNT. With energy like that to work with, theorists have not found it hard to imagine either a hole being blown in the atmosphere through which large particles escape on ballistic trajectories, enough turbulence being created to carry them through the atmosphere, or some other mechanism coming into play that is beyond the ability of present computer models to simulate. Far more modest impacts have thrown small globules of glass up to 7000 kilometers.

Grain dispersion would seem to be a considerable sticking point for the volcano hypothesis, but its major problem now is that there is no physical evidence whatever, despite a considerable effort, that volcanoes produce the sort of shocked quartz so abundant at the K-T boundary. Neville Carter of Texas A&M University, Charles Officer of Dartmouth College, and their colleagues have searched the debris from the Toba eruption in northern Sumatra for signs of the high shock pressures so evident in the multiple sets of lamellae seen in quartz at the K-T. Carter believes he has found such evidence, primarily in the mottled appearance, called a mosaic texture, of quartz and feldspar grains.

Many experts on the effects of shock on minerals are not so sure. "Everyone agrees that the kind of quartz at the K-T has been shocked," says Bevan French of the National Aeronautics and Space Administration in Washington, D.C., "but the nature of the volcanic material is much more murky." Richard Grieve agrees. "I'm not convinced that it's the same stuff you get from an impact," he says.

In order to consider all the possibilities, James Alexopoulos of the University of Ottawa and Richard Grieve and Blyth Robertson of the Geological Survey of Canada compared quartz grains from a known impact site, a K-T site, Toba ash, and two sites deformed by crustal forces. They conclude that " . . . the appearance and orientation of planar features [lamellae] from a known impact structure and those observed in samples from the K-T boundary are essentially identical. Although other lamellar deformational features in quartz can result from other geologic processes, they only superficially resemble those from the K-T boundary and those believed to have resulted from impact."

Carter agrees. "There is no question that there is a difference," he says. Features ascribed to shock appear in much less than 1% of volcanic silicate grains in ash flows close by the Toba caldera, but they appear in 25% or more of K-T grains. Moreover, volcanic quartz never has more than one set of planar features. Carter saw no quartz lamellae whatever in distant Toba ash falls. That is consistent with Izett and Bohor's contention

Beyond the K-T Boundary

The discovery of exceptional concentrations of iridium at the Cretaceous-Tertiary (K-T) boundary 8 years ago touched off a search for other mass extinctions that might have been triggered by the impact of an iridium-carrying asteroid or comet. The search became particularly interesting when, in 1984, David Raup and John Sepkoski of the University of Chicago suggested that extraterrestrial impacts occur every 26 million years, leaving Earth's biological history punctuated by repeated mass extinctions.

So far, the pickings have been slim. It is clear that there is no other iridium anomaly like the one at the K-T boundary. Only one other global iridium anomaly has been found, but it lacks the massive, sudden extinctions of the K-T boundary. However, tantalizing single-site anomalies have been found recently that, if shown to be global, would support the hypothesis of periodic impacts and extinctions.

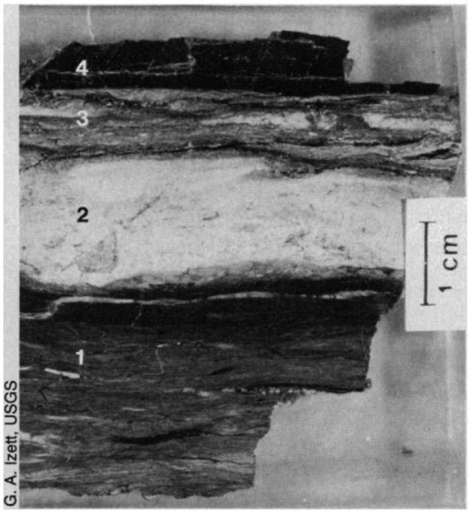
The one other global iridium anomaly occurs in sediments formed about 37 million years ago at the end of the Eocene epoch, as reported by Billy Glass of the University of Delaware, by Gerta Keller of Princeton University, and by others. It is only about one-hundredth the magnitude of the anomaly at the K-T boundary of 65 million years ago, is associated with only one of two or three layers of presumably impact-generated microspherules, and falls among four bursts of extinction that are spread over 5 million years.

Many other boundaries marked by major or minor episodes of extinction appear to be barren of extraterrestrial iridium, according to analysts involved in the search. Terrestrial iridium, on the other hand, has apparently been concentrated by geochemical processes at some boundaries, such as the Precambrian-Cambrian (590 million years), Ordovician-Silurian (438 million years), Frasnian-Famennian (367 million years), and the Mississippian-Pennsylvanian (320 million years). A major disappointment has been the failure of independent analysts to confirm early reports of an anomaly at the Permian-Triassic boundary (248 million years), which along with the K-T boundary marks one of the great mass extinctions. There are reports of iridium anomalies and, at other locations, impact-related shocked quartz in rocks of Jurassic age, but these have yet to be confirmed.

There are some intriguing new discoveries. Carl Orth and Moses Attrep of Los Alamos National Laboratory examined 45 meters of rock and found two small iridium anomalies just below the Cenomanian-Turonian stage boundary (91 million years) near Pueblo, Colorado. One anomaly appears to be a concentration of terrestrial iridium coincident with one of six bursts of extinction that span 1 million years across the boundary, as found by Erle Kauffman and R. Diner of the University of Colorado. The other anomaly coincides with the first burst of extinction in the series, but that layer contains no microspherules or shocked minerals. An impact is "a viable possibility" for the generation of this anomaly, the group says.

The other new development is a report by Frank Asaro of the Lawrence Berkeley Laboratory of a small iridium anomaly in a 230-meter deep-sea core from between New Zealand and Australia. The iridium concentration at the 11.7-million-year-old anomaly is about 15 times higher than background concentrations. It is the only anomaly in the first 50 meters of core analyzed.

Curiously enough, the two confirmed global iridium anomalies plus these two single-site anomalies form the regular sequence (11, 39, 65, and 91 million years) predicted by the hypothesis of impact-induced periodic extinctions. The surest test of the hypothesis lies in the detailed mineralogical, geochemical, and paleontological examination of boundaries. That work is well under way, but these suggestive results must still be shown to be reproducible around the world. ■ **R.A.K.**



The Cretaceous-Tertiary boundary. *This polished slab of the boundary interval from the Clear Creek North site 10 kilometers south of Trinidad, Colorado, includes the impact layer (3) where the peak of iridium abundance and shocked quartz grains are found. The iridium has also moved into the coal (4) above and the carbonaceous shale (1) below, but the shocked quartz has never been found beyond the impact layer. Layer 2 is a claybed.*

that Carter's features probably appear in contaminant grains picked up by ash flowing over the ground.

In light of this contrary evidence, Carter claims only that he has evidence of volcanic explosions generating shock pressures of 10 gigapascals or more, a claim that has yet to be accepted. That much shock is intense enough to produce shocked quartz of the sort found at the K-T, but he has found no example of it in volcanic ash. High volcanic temperatures probably make the quartz too plastic for it to record such shock levels, he says, except under rare circumstances theoretically predicted by Alan Rice of the University of Colorado. As yet no one has found a product of those circumstances.

If highly shocked quartz is found at the K-T boundary and at known impact sites but not in volcanic debris, the impact hypothesis would seem to be on solid ground. Officer, the leading spokesman for the volcano hypothesis, does not agree. He notes that Carter has found the same mineral features at and around the Gubbio, Italy, K-T boundary as he found at Toba. But Carter found no impact-shocked quartz at Gubbio. Therefore, Officer says, intense volcanism accompanied the K-T transition, and multiple sets of planar shock features are not always associated with the boundary.

Officer's implications aside, the burden of proof would seem to fall on the volcanic catastrophists. Carter's group is the only one of seven groups that has looked at the K-T boundary and not found quartz having multiple sets of lamellae. K-T shocked quartz has now been found in more than a dozen areas around the world at up to 12 sites in a single area. In fact, Bohor's group reports finding impact-type features at the K-T as close to Gubbio as in northern Italy. There have been no suggestions as to what would settle this contentious question, but one obvious possibility would be the cooperative collection and splitting of samples from volcanoes and a few of the best K-T sites.

Prime candidates for study might include the 20 K-T sites stretching from Alberta, Canada, to New Mexico that Izett and Bohor have compiled. These sites seem to have escaped much of the disturbance, alteration, and contamination that has helped fuel the impact-volcano controversy. In most cases the sediment layers include a carbonaceous shale at the bottom, a kaolinite bed, the K-T boundary impact bed, and a coal bed at the top. The 3- to 8-millimeter-thick impact bed always contains abundant shocked quartz, a peak in iridium, and the sudden increase in fern spores that marks the K-T boundary.

"There seems to be just one event there," says Izett. "I started off as a nonbeliever. What got me was the sudden appearance of these shocked minerals at the K-T. In the impact bed, you see grains everywhere that have these features in them. Just a millimeter or two below, you'll never see any of those features. That is staggering to me. The marine rocks [as at Gubbio] may not be the place to study the K-T. It may be in these quiet coal swamps." ■ RICHARD A. KERR

ADDITIONAL READING

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The Origin of the Modern Human Mind

The early stages of human evolution have for a long time dominated discussions in paleoanthropology. A new hot topic is now emerging, however, and this focuses on the origin of modern humans, Homo sapiens. *Major questions relate to where the first modern human stock arose (Africa or the Near East?), how they came to populate, in the first instance, the Old World (by global evolution or by replacement?), and how big an evolutionary change was involved in the transition (revolution or continuous, gradual trajectory?). A recent meeting* in Cambridge, England—the third on the topic in a year—addressed these issues. Presented here is a sample of some of the issues relating to the properties of the modern human mind.*

The Human Psyche Was Forged by Competition

There is nothing in the known universe like the human psyche, says Richard Alexander of the University of Michigan, and the job of the biologist is to explain how it evolved. Taking a strictly Darwinian approach he argues that "the human psyche evolved as a vehicle serving the genetic or reproductive interests of its possessors." Specifically, these interests include survival through to reproductive age, the successful acquisition of mates, and a rewarding set of social interactions with both kin and nonkin.

Most higher primates live in groups and are highly social. Humans are the same, but even more so. There is a range of socioecological explanations for group-living in primates, and this includes efficient exploitation of resources and defense against predation. The exaggerated degree of sociality in humans demands a further explanation, suggests Alexander, and this is "group-against-group, within-species competition." This central driving force for human sociality leads to "balance-of-power races with positive feedback upon cooperative abilities and social complexity."

Alexander's hypothesis derives from a theme of Darwin's, namely the "Hostile forces of nature." Darwin had in mind those natural forces that make life difficult, such as predators, parasites, food shortages, and cli-

*"The origin and dispersal of modern humans," 22 to 26 March, Corpus Christi College, Cambridge, England.