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* QUARTZ GRAIN SHAPE; NEW IMPACT theory

PLANETARY IMPACTS: OBSERVATIONS, THEORY AND EXPERIMENTS

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"More answers, more questions"

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Was the Cretaceaus/Tertiary (K/T) extinction caused by a massive impact? If so, where is the crater? Are other boundaries in geologic time punctuated by major impact events? If so, are they periodic? At the 18th Lunar and Planetary Science Conference, impact studies continue to shed light on questions of general interest to earth and planetary scientists. But with each answer comes new questions, keeping research in impact science very active.

The question of whether a giant impact or some other major cataclysm ended the Cretaceous Period, killing the dinosaurs and many other forms of life, is still under debate. The impact hypothesis has been supported by the presence at the boundary clay layer of quartz grains which show shock features. One of the arguments against the impact picture is the existence of shock-like features in quartz grains from known explosive volcanic sources. J. Alexopoulos (University of Ottawa) and co-workers at the Geological Survey of Canada compared planar deformational features in quartz grains from various geologic environments worldwide. They found that the appearance and orientation of planar features in quartz grains from known impact sites are indistinguishable from those in grains from the boundary layer. Although similar deformations can be generated by other geologic processes, they differ in appearance. The same group of researchers also studied anomalous features in quartz grains from the Vredefort cryptoexplosion structure in South Africa, reported by P. B. Robertson (Geological Survey of Canada) and co-workers. Earlier work had suggested that these quartz grains had suffered two distinct shock events separated in time. It was argued that two different impacts at the same location was such a remote possibility that Vredefort must be volcanic instead. This interpretation meant that the use of shock features in quartz to indicate impact was questionable.

The new study found an alternative explanation for the anomalous deformations. If the post-shock temperature at the impact site was sufficiently high, some of the defects in the quartz would be annealed, giving rise to the unusual distributions of orientations not normally observed for shock-induced planar features. They concluded that Vredefort is, therefore, an impact structure, and that shocked quartz grains are still good evidence that the K/T boundary event was an impact. However, the case of the Vredefort structure is not settled. W. V. Reimold (University of Witwatersrand, South Africa) and colleagues from the Max Planck Institute in West Germany determined the age of pseudotachylite, a structure at the Vredefort site which exhibits violent deformation features. Using the ^{40}Ar-^{39}Ar dating tool, they discovered that there were two distinct episodes of pseudotachylite formation separated by 250 million years. They concluded that the South African structure was formed tectonically over a long time period, rather than catastrophically by an impact.

While the outcome of the Vredefort debate may have bearing on the K/T extinction story, other evidence supporting the giant impact hypothesis continues to mount, and the search goes on for the impact site. D. D. Badjukov of the Vernadsky Institute of Geochemistry and Analytical Chemistry and others in the USSR determined the abundance of shocked quartz grains from the K/T section at Sumbar, USSR, and used this data along with global iridium content of the boundary to estimate the quantity of material ejected by the impact. They looked for craters big enough to supply a sufficient amount of ejecta, which would contain shocked quartz and feldspar (implying a continental target) and magnetite spheroids (implying an oceanic target or a large basaltic component). They came up with two pairs of craters in the Kara region of the USSR which have potassium-argon ages very close to the 65 million year requirement, and are in a region which contains both continental material and basalt. However, the Kara craters do not appear to be large enough to have supplied a sufficient amount of ejecta. The Soviet researchers proposed that the Kara impactors were only part of a larger object that broke up before the collision. Based on the morphology of the Russian craters, they suggest the object had a northeastward trajectory, and the main body impacted the polar region. They also use this trajectory to explain the large quantities of shocked quartz found in the United States, a fact previous workers have used to suggest a North American impact site.

An impact into the east Pacific is favored by A. R. Hildebrand and W. V. Boynton of the University of Arizona. They found anomalous rare earth element abundances and distributions in boundary clays from Alberta and Colorado. They suggested that a mixture of material derived from oceanic crust and mantle, together with a small amount of continental sediment (to account for the shocked quartz and feldspar) can give rise to the rare earth element concentrations they observe. The Arizona team chose an east Pacific site because the North American boundary layer is so much thicker than elsewhere, and thus apparently represents an accumulation of low energy ejecta from a nearby location.

While the K/T boundary is getting so much attention from impact researchers, another question can be asked: is this impact-extinction connection unique, or have impacts demarked periods and eras throughout geologic time? D. D. Badjukov and others have examined quartz grains from the Triassic-Jurassic (T/J) boundary at a location in the Austrian Alps. They found tectonically derived lamellae but they also found grains with reduced refractivities and with multiple sets of planar features, having orientations and morphologies associated with shocked quartz. Based on the concentration of quartz grains, the Soviets speculated that a T/J collision could be larger than that at the K/T boundary, even changing convection patterns in the mantle.

Frank T. Kyte and co-workers at UCLA examined 2.3 million-year-old (late Pliocene) sediments from the antarctic basin. They recovered large quantities of vesicular impact melt, as well as unmelted meteoritic particles. They also determined iridium concentrations up to four times greater than those at the K/T boundary. They estimated that the debris and iridium anamoly in their sediments is due to the impact of a 560 meter diameter body in the late Pliocene. Lei Zhou and Frank T. Kyte of UCLA, on the onter hand, are skeptical of any claim that an impact is associated with the Precambrian/Cambrian boundary. They examined a geochemical anamoly from this boundary in the Guizhou Province in China. Previous workers had connected the high iridium concentration to another possible impact event. The UCLA group found that the relative abundance of siderophiles in this boundary is very different from that of chondritic material. In particular, the osmium/iridium ratio is over twenty times that found in chondrites. Because there are no known processes by which this elemental ratio could be so greatly increased above chondritic values, these workers do not believe an impact explanation merits any special consideration.

While some researchers look for evidence of major impacts in the geologic record, others are asking the question: is there evidence for a periodic component in the earth's crater ages? Previous statistical studies of the cratering record have led to the hypothesis that the earth has been bombarded by cometary showers every thirty million years. R. J. Durrheim and W. V. Reimold of the University of Witwatersrand, South Africa have incorporated an improved data set into their statistical study, and find evidence for 36 and 90 million year periodicities. R. A. F. Grieve and A.K. Goodacre of the Geological Survey of Canada subjected several data sets to a detailed time-series analysis in which they added a component of random noise to the measured crater ages to account for age uncertainties. They conclude that the statistical evidence for periodic cratering is only marginally significant, and while it may be true, it may just as well be fortuitous. Because other geophysical phenomena, such as mass extinctions, magnetic reversals, and tectonic and volcanic activity are periodic, the question of periodic cratering may be related and will continue to be of interest. Improved crater age determinations are necessary to answer the question, so knowing the effect of high pressure shocks on isotopic dating methods is important. A. Deutsch of the University of Munster, West Germany, performed laboratory shock experiments on samples of gneiss from Argentina. This researcher found that the isotopic ratio of rubidium to strontium was unchanged for shock pressures up to 60 GPa, leading to the conclusion that the Rb/Sr geological clock is not reset in impact craters below this pressure.

On the question of a link between meteorite impacts and mass extinctions, John D. O'Keefe and Thomas J. Ahrens of Caltech extended a previous model of fragment size-velocity distribution to determine the amount of very fine particles which could be entrained in the atmosphere due to a large impact. They show that the hypothesized impact is large enough to eject a sufficient quantity of fine material to blanket the earth's atmosphere and shut off solar radiation, severely changing the earth's climate by a process similar to "nuclear winter" scenarios. This type of model can be constrained by data presented by C. A. Polanskey and T. J. Ahrens of Caltech. They obtained coral samples from drill cores and the ejecta blanket of a nuclear explosion crater at Eniwetok Atoll in the South Pacific. They were able to show, by using electron paramagnetic response techniques, that the more heavily shocked ejecta travels greater distances and is thus ejected at higher velocities.

Laboratory impact experiments are also continuing to answer questions on a planetary scale. D. Crawford and P. H. Schulz of Brown University have detected electromagnetic emissions from low angle hypervelocity impacts into sand and dry ice. These observations were made using r.f. coil detectors in various locations and orientations. Several mechanisms for signal production were proposed, which may lead to an understanding of how remanent magnetization can be produced in materials surrounding an impact site. The Brown researchers also made use of high speed photography, spectroscopy and ultrasonic pressure detectors to characterize clouds of vapor generated by the low-angle impacts. For high velocity impacts of aluminum projectiles into dry ice, a brilliantly glowing vapor cloud containing as much as 70 projectile masses was observed. The spectra showed strong emission lines of aluminum oxide from the cloud, so shock-induced chemical reactions between the projectile and target materials are taking place.

Other experimental research relating shock waves to chemistry in planetary materials was performed by James A. Tyburczy of Arizona State University and Thomas J. Ahrens of Caltech. They calorimetrically determined activation energies for dehydration of shocked serpentine, and found that the kinetics of dehydration are significantly more rapid than for unshocked serpentine. They conclude that shock-activated hydrous minerals on planetary surfaces may have higher outgassing rates under appropriate temperature conditions than would otherwise be expected. They also speculate that there may be a significant shock-enhancement of chemical weathering rates of planetary surface materials. Experimental support for this speculation was obtained by Mark B. Boslough and Randall T. Cygan of Sandia National Laboratories, who subjected several silicate minerals to various shock environments, and measured the difference in subsequent dissolution rates. They found that in some cases, in addition to shock-comminution which increased specific surface areas by a factor of three, the surface-normalized dissolution rates doubled.