SHOCKED QUARTZ AND MORE: IMPACT SIGNATURES IN K-T BOUNDARY CLAYS AND CLAYSTONES; Bruce F. Bohor, U.S. Geological Survey, Box 25046, MS 901, DFC, Denver, CO 80225

Quartz grains displaying multiple sets of planar features (shock lamellae) have been described from numerous Cretaceous-Tertiary (K-T) boundary clays and claystones at both marine and nonmarine depositional sites around the world (1-6). All these sites also show anomalously high amounts of iridium and enrichments of other siderophile elements in cosmic ratios within these boundary units. This combination of mineralogical and geochemical features has been used in support of an impact hypothesis for the end-Cretaceous event (7).

Recently, it has been suggested that some combination of explosive and nonexplosive volcanism associated with the formation of the Deccan traps in India could have been responsible for the mineralogy and geochemistry seen in the K-T boundary units (8,9). Besides the obvious contradiction of simultaneous explosive and nonexplosive volcanism from one locality during an instant of geologic time, there remains the difficulty of spreading both iridium (and trace elements in cosmic proportions) and quartz grains around the world by volcanic (atmospheric) transport (10). In addition, the ability of volcanism to produce the type of shock metamorphism seen in minerals at the K-T boundary has not been demonstrated. Multiple sets of shock lamellae in quartz (as many as 9 sets per grain) are considered characteristic of shock metamorphism in rocks at the sites of known impact craters (11) and are the type of deformation seen in quartz from K-T boundary clays and claystones. Single sets of poorly defined lamellae described from rare quartz grains in certain volcanic deposits (9) are characteristic of tectonic deformation and do not correspond to the shock lamellae in quartz from K-T sediments and impact structures (12). So-called "shock mosaicism" in quartz and feldspar grains described from volcanic deposits (9) can result from many processes other than shock metamorphism, and therefore is not considered to be an effect characteristic solely of shock.

The mineralogy of shock-metamorphosed grains at the K-T boundary also argues against a volcanic origin. Izett (13) found, in addition to individual shocked grains of quartz and feldspar (oligoclase and potassium-feldspar, including microcline), composite shocked grains and lithic fragments of quartz-quartz and quartz-feldspar with curved to sutured grain boundaries. This mineralogy suggests derivation from impact into continental quartzites, metaquartzites, and granites--not from volcanic eruptions. Badjukov et al. (5) also found compound quartz and quartz-feldspar grains in K-T boundary sediments in the U.S.S.R.

In addition to shocked quartz, several other features of K-T boundary layers attest to an impact origin. Magnesioferrite (spinel group) crystals containing extraterrestrial amounts of Ni and Ir have been found in both marine (14) and nonmarine (15) K-T boundary layers. Their small size and euhedral shapes, skeletal morphologies, and trace- and minor-element contents indicate derivation by condensation from a cloud of vaporized bolide. The association of the magnesioferrite crystals with shocked quartz and Ir in the uppermost layer of the K-T boundary claystone in nonmarine sections suggests that this layer represents vaporized and shocked material that was ejected vertically during impact through the hole in the atmosphere caused by the incoming bolide and transported globally above the stratosphere.

Hollow spherules as much as 1 mm in diameter are nearly ubiquitous in K-T boundary layers. These spherules resemble microtektites in outward appearance; the term spherule is not always applicable, because teardrops, dumbbells, and other splash forms are similar to the forms of microtektites. Although microtektites are solid and composed of glass [except for the closely associated clinopyroxene (cpx) spherules], the walls of the K-T spherules can be composed of several different minerals, depending on the geochemistry of the depositional environment and later diagenesis. The central voids of these spherules may be filled with clay or with secondary minerals, such as calcite, gypsum, and barite. I propose that these K-T spherules are melt droplets formed during impact, ejected as microtektites, and transported within a hot cloud where devitrification formed an outer crystalline rind. Replacement of the crystalline walls and solution of the glassy cores took place later after deposition. These spherules cannot be infillings of marine prasinophytic green algae, as has been proposed (16), because of their occasional nonspherical shapes and because similar spherules are found in both marine and nonmarine K-T boundary clays and claystones.

In the Western Interior of North America, the K-T boundary occurs in nonmarine rocks at sites from New Mexico to Alberta, Canada. The boundary event is represented by a claystone 2-3.5 cm thick that has two distinct layers (3,4). A thin, dark, upper layer contains concentrations of shocked quartz grains, the maximum size of which exceeds 0.5 mm. It also contains rare magnesioferrite crystals and the highest iridium anomaly in the boundary claystone. The lower, thicker, light-colored layer is composed mainly of kaolinite, and contains hollow spherules, a lesser amount of Ir, and no magnesioferrite. Recently, I discovered rounded, lappili-sized clay clasts containing shocked quartz grains and vesicles in this kaolinitic layer. I believe these clasts to be altered impact glass lapilli, probably emplaced ballistically. The fine-grained matrix surrounding these clasts also contains angular shocked quartz grains. Rounded sandstone clasts in this layer may be lithic clasts of target rock. These findings, along with the presence of microtektite-like spherules in the kaolinitic layer, strongly suggest that the entire K-T boundary claystone represents a distal ejecta deposit. The relatively greater thickness of this deposit in the Western Interior, compared to sites elsewhere in the world, adds to the evidence for an impact on or near the North American continent. Previously, this hypothetical location for the crater was based only on the maximum sizes of shocked quartz grains (17).

REFERENCES: (1) Bohor, B.F. et al. (1984) Science 224, p. 867-869; (2) Bohor, B.F. et al. (1987) Science 236, p. 705-709; (3) Bohor, B.F. et al. (1987) Geology 15, p. 896-899; (4) Izett, G.A. and Bohor, B.F. (1985) in GSA Absts. with Prog. 18, p. 644; (5) Badjukov, D.D. et al. (1986) in Lunar Planet. Sci. Conf. XVII, LPI, Houston, p. 18-19; (6) Preisinger, A. et al. (1986) Nature 322, p. 794-799; (7) Alvarez, L.W. (1987) Physics Today 40, p. 24-33; (8) Officer, C.B. and Drake, C.L. (1985) Science 227, p . 1161-1167; (9) Carter, N.L. et al. (1986) Geology 14, p. 380-383; (10) Seitz, R.M. and Bohor, B.F. (1988) Naturwiss. (in press); (11) Bunch, T.E. (1968) in Shock Metamorphism of Natural Materials, Mono Book, Baltimore, p. 413-441; (12) Alexopoulos, J.S. et al. (1988) Geology (in press); (13) Izett, G.A. (1987) U.S.G.S. Open File Rept. 87-606, 125 pp.; (14) Bohor, B.F. et al. (1986/87) Earth Planet. Sci. Lett. 81, p. 57-66; (15) Bohor, B.F. and Foord, E.E. (1987) in Lunar Planet. Sci. Conf. XVIII, LPI, Houston, p. 101-102; (16) Hansen, H.J. et al. (1986) Geol. Soc. Denmark Bull. 35, p. 75-82; (17) Bohor, B.F. and Izett, G.A. (1986) in Lunar Planet. Sci. Conf. XVI, LPI, Houston, p. 68-69.