CRETACEOUS/TERTIARY BOUNDARY

Zircon can take the heat

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THE remarkable properties of zircon ($ZrSiO_4$) have allowed geochronologists to unravel further details of the Cretaceous/Tertiary (K/T) boundary impact event, which coincided 65 million years ago with the extinction of over half the species on the Earth. Zircon is a mineral unrivalled in its resistance to thermal, chemical and mechanical breakdown and has long been exploited as a resilient carrier of radioactive uranium, allowing researchers to look through complex geological histories and date the primary ages of crystalline rocks. Now zircon has been put to the ultimate test. On page 731 of this issue, Krogh *et al.*[1] demonstrate that tiny crystals of zircon (1–4 millionths of a gram), blasted from the Chicxulub crater in Mexico by an extraterrestrial impact equivalent in energy to about 10,000 times the world's nuclear arsenal[2], preserve an isotopic record of both the age of the target rocks and the age of the impact event itself.

Krogh *et al.*, in this and a previous study[3], provide geologists with an important new tool for directly linking impact craters to specific layers in sedimentary rocks that contain a record of the geochemical and biological trauma induced by the impact events. For impacts that are geologically young, tiny glass spherules derived from rock melted by impact and blasted into the atmosphere (microtektites) are sometimes found in marine sediments and provide a time marker as well as a geochemical link back to the source crater. For the giant impact that occurred 65 million years ago, these glassy spherules have been found in K/T sediments at only two sites — both of which were within about 1,000 km of the crater. The glasses have a distinct neodymium and strontium isotopic signature that has allowed them to be linked directly to melts found within the Chicxulub impact structure[4–6]. At other locations on Earth, however, K/T boundary glass has been chemically transformed to clay, obscuring the chemical fingerprint of the materials.

Crystals

Krogh *et al.*[1,3] have established that zircon crystals present in target rocks can survive the impact as well as subsequent chemical alteration and provide a unique isotopic fingerprint of the target material even in the absence of impact glass. Zircon contains an important isotopic record because, on crystallization, the mineral incorporates uranium into its crystal structure but excludes lead. Following crystallization, two independent radioactive clocks begin ticking at different rates: ^{238}U decays to ^{206}Pb with a half-life of 4.5 billion years, and ^{235}U decays to ^{207}Pb with a half-life of 0.7 billion years. Some of the zircons analysed from the K/T boundary have essentially remained closed chemical systems and thus the two U–Pb clocks yield the same (or concordant) ages. Others, which display shock-induced planar deformation features (like the zircon on the cover) and granular textures, lost some of their radiogenic Pb and thus yielded two different (or discordant) ages. Krogh *et al.*[1] used a routine method in U–Pb geochronology which combines the two parent–daughter systems on a 'concordia diagram' (see their Fig. 1) and allows estimation of both the primary age (upper intercept) and the age of disturbance (lower intercept) for a population of zircons. There was nothing routine, however, about obtaining precise lead isotope ratio measurements on single zircons weighing 1–4 micrograms. Samples contained only 5–200 picograms of radiogenic lead, and therefore extreme care had to be exercised in an ultraclean laboratory to reduce background lead contamination to just 2±1 pg.

The most notable finding of Krogh and co-workers was that most single zircon crystals from Chicxulub crater breccias, as well as K/T boundary sediments from both Haiti and Colorado, fell on a single U–Pb isotopic variation trend, indicating a target basement age of 545±5 million years followed by episodic Pb loss about 55–65 million years ago. This story is complicated slightly by a subset of samples that fell on a second trend, indicating that the target also had some material with a basement age of about 420 million years.

Krogh *et al.*'s results strengthen three conclusions that were proposed by previous workers on the basis of strong (but somewhat circumstantial) evidence: first, that the Chicxulub structure is indeed the source of K/T boundary ejecta, and the buried crater at Manson, Iowa, was not involved; second, that ejected material found in the marine Haitian K/T sediments was derived from the same source as ejecta from the continental Colorado K/T sediments; and third, that Palaeozoic silicate basement rocks beneath ~2 km of sedimentary rocks were ejected from the Chicxulub crater during the impact.

Thirteen years have passed since Alvarez *et al.*[7] proposed, on the basis of rather sparse geochemical evidence, that an asteroid struck the Earth at the end of the Cretaceous period, wreaking havoc on the environment. In the ensuing years, investigators working to test this theory have documented a wealth of evidence in its support, leaving no viable alternative theory. Debate is now focusing more specifically on whether the impact directly caused the K/T boundary extinctions[8]. Before the identification of the site of the impact, several extinction mechanisms were proposed that could apply to any impact, regardless of the target location. These included global cooling and darkness from the dust lofted by the impact[7], and acidic rainfall resulting from nitric acid produced by shock heating of the atmosphere[9]. Now that Krogh and co-workers' study and previous work[4,10–12] have firmly established that the Chicxulub structure was formed by the K/T impact, researchers are moving on to investigate environmental consequences specific to the target geology.

Climate

In an unlikely coincidence, the K/T bolide landed in an area (the Yucatán Peninsula) that is underlain by a thick sequence of volatile-rich rocks including limestone ($CaCO_3$), dolomite ($MgCO_3$) and anhydrite ($CaSO_4$). An inevitable outcome of the impact, therefore, was the degassing of at least some of these rocks by melting and shock-devolatization, dramatically changing the chemistry of the Earth's atmosphere. The huge (but difficult to quantify) amounts of CO_2 and SO_2 added to the atmosphere would have had an effect much like that which humans are currently inflicting on it by burning fossil fuels. Predicted consequences of the impact would be global cooling and acid rainfall for several years as a result of increased SO_2 levels[13,14], followed by global warming for tens of thousands of years as a result of increased CO_2 concentrations[15,16]. Recognizing this, scientists now have the unique opportunity to study how the Earth's biogeochemical cycles respond to sudden changes in atmospheric composition, and whether (or how) this contributed to the nearly simultaneous extinction of over half the species on the Earth. □

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