THE K/T IMPACT EXCAVATED OCEANIC MANTLE: EVIDENCE FROM REE
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A substantial array of chemical, physical, and isotopic evidence indicates that an impact into oceanic crust terminated the Cretaceous Period. Approximately 1,350 $\text{km}^3$ of debris fell out globally in a wide variety of marine and nonmarine sedimentary environments producing a layer approximately 3 mm thick. In western North American nonmarine sequences this 3 mm fallout layer is underlain by an approximately 15 mm thick layer of an unusual composition. This 15 mm layer is commonly speculated to represent an accumulation of lower energy ejecta from a nearby impact site.

We have analysed boundary clay layers from Scollard Canyon, Alberta, and Starkville, Colorado [1] using neutron activation and have discovered that the 15 mm ejecta layer and the 3 mm fallout layer have anomalous REE abundances and distributions (see Figure 1). The distributions are characterized by HREE abundances approximately 3 times CI chondrites with an overall pattern similar to average continental sediments such as PAAS; the LREE are 50% more depleted than the HREE, producing a slightly flattened pattern. These anomalous REE distributions are similar to those observed in the K/T fallout layer in Pacific abyssal clays [2], and shelf carbonate sequences [3,4]. Smit and ten Kate (1981) attempted to model this REE distribution by diluting typical continental sediment with chondritic material but noted that this model was not consistent with the siderophile trace element abundances of the fallout layer. Subsequent isotopic evidence [5,6] also invalidates this model.

How did this extraordinary REE pattern form? Thin sections of the 15 mm ejecta layer show pervasive clay mineral alteration as widely reported. However, because REE are characteristically geochemically immobile, and because the surrounding rocks have REE concentrations approximately ten times larger, this pattern cannot be a result of weathering or metasomatism. In addition, the REE patterns of the clay layer are similar even though preserved in disparate sedimentary and geochemical environments, indicating a lack of mobilization of the REE or contamination by indigenous material. This pattern is not exhibited by any common terrestrial rock.

We propose that this pattern is the result of mixing of oceanic crust, overlain by continental sediments, with depleted oceanic mantle. Data from the 15 mm ejecta layer will be modelled since it lacks the siderophile trace element anomaly of the 3 mm fallout layer, so a chondritic component does not have to be considered, and representative samples of the 15 mm ejecta layer are more easily acquired. We tentatively assume that this layer represents distal ejecta of an impact in the eastern Pacific Ocean because of its restricted geographic distribution and relict textures. In thin section the Starkville ejecta layer, although pervasively altered to clay minerals, shows distinct angular to subangular relict grains up to 5 mm diameter set in a poorly sorted matrix.

Our preliminary mixing model results indicate material was excavated to a minimum depth of approximately 40 km yielding a minimum diameter for the transient crater of about 200 km, although this result is very sensitive to the thickness assumed for oceanic crust. The REE pattern modelling yields a minimum crater size using "enriched" MORB instead of "typical" MORB. Our model results indicate that the bulk of the layer must have formed from depleted mantle material. DePaolo et al. (1983) modelled the provenance of the K/T boundary fallout layer using Sm-Nd and Rb-Sr isotope systematics and
Nd and Sr concentrations. They concluded that a substantial fraction of the boundary clay layer was derived from oceanic crust and mantle. They assumed contamination of the fallout layer by local material, which we feel is unlikely because of the similarity of the REE pattern at all localities. Instead we propose that the oceanic crust had a thick veneer of continentally-derived sediment; specifically greywacke turbidites in an abyssal plain fan adjacent to a continental margin. These sediments would account for the shocked quartz and alkali feldspar grains found in the boundary layer. Since the REE pattern does not show the negative cerium anomaly associated with marine carbonates and abyssal clays, a significant contribution from these sediments is apparently excluded.

IMPLICATIONS. A 200 km diameter (or larger) crater is bigger than scaling laws allow with a suite of canonical K/T impactors. However, recent results from the Halley comet flybys indicate that comets have less silicate dust than previously believed. This new understanding of cometary compositions allows a 20 km diameter comet massing $10^{19}$ gms, dissipating $10^{32}$ ergs on impact. A larger crater also resolves the longstanding paradox of why an approximately 100 km crater at the K/T boundary would create a mass extinction, while other similar sized craters, such as Popigai, have no associated mass extinction. Such a large crater would also explain the apparent lack of other events similar to the K/T impact in the Phanerozoic. If more detailed modelling of the REE pattern requires that the crater be much larger than 200 km diameter, this would be in contrast to the lack of very large young craters throughout the solar system.


Figure 1. The REE abundances are normalized to the CI abundances of Evensen et al., 1978, G.C.A. 42: 1199-1212. (1) Data from the 15 mm K/T ejecta layer sampled at Scollard Canyon, Alberta. (2) Average continental sediments represented by PAAS. (3) Typical MORB. (4) "Averaged" depleted mantle harzburgite composition from literature values. This flat pattern is somewhat arbitrary, but the mixing model is insensitive to details of the pattern.