TRACKING DOWN TRACES OF THE CHICXULUB PROJECTILE IN K-Pg BOUNDARY DEPOSITS.
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Introduction. In 1980 the idea of a large impact event at the "K-T" boundary was developed, initiating immediately intense research in order to substantiate a causal link between this catastrophic event and the mass extinction at the end of the Mesozoic. In strong contrast to these efforts, numerous, in part very strange objections were forwarded, discarded, just to be replaced by even more unsubstantiated ideas to discard the "impact-induced extinction hypothesis". Now, 32 years later, the Chicxulub impact event is world-wide recognized as the exclusive and only reason for the K-Pg boundary event, despite the fact that not all processes are understood in detail. World-wide more than 350, very diverse K-Pg boundary sites [1,2] are known – they contain the clues for solving the open questions.

Appropriate sites for understanding the Chicxulub event. Recent publications made it very clear that (i) undisturbed distal K-Pg deposits are the most appropriate places for assessing the time-scale of the K-Pg boundary event (e.g., [3,4]), and the mode of deposition of materials that clearly derived from the Chicxulub impact site at Yucatan, Mexico [5-7]; (ii) sites closer to the impact site, however, allow for a better understanding of early processes occurring during the impact, e.g., earthquakes, tsunamis, or mega-slumping [8,9]; (iii) drill cores inside the Chicxulub crater or along its outer slopes, in contrast, document often processes that are related to post-impact re-adjustment, localized slumping, and reworking [see details in [10]).

The distal K-Pg boundary layers proper have been deposited in less than a year [4], with the time-limit given by the settling time of <10-µm-sized particles of the expanding "ejecta" plume in the sea-water column. Sites closer to the crater with high-energy deposits may record a much shorter time-span [8], whereas for example, the K-Pg section in core YAX-1 inside the crater is incomplete, therefore unsuitable for constraining the duration of the K-Pg event [10].

Open questions. What are real pristine deposits? Can we decipher different killing mechanisms? What happened in the plume? But here we focus on the most interesting problem in the view of the "impact people", namely, where is the main mass of the projectile?

The Chicxulub projectile and its whereabouts. The best estimate for the nature of the Chicxulub bolide comes from the chromium isotope anomaly detected in the Stevens Klint K-Pg deposit, Denmark, which constrains the projectile to a carbonaceous chondrite of type CM2 [11]. So far, roughly 1.5 % of the projectile mass has been detected world-wide in the K-Pg boundary layer; this extraterrestrial matter is present mainly by platinum group elements (PGE) as well as other siderophile elements (Ni, Co ...).

Rarely, a contamination of or even a major contribution of extraterrestrial matter to the K-Pg event bed was proposed, based on rare earth elements (REE) distribution patterns [12] that are slightly inconsistent with REE patterns typical for the upper continental crust (UCC). Such material, i.e., target rocks, is expected to form the overwhelming mass of the ejecta. In most K-Pg deposits, this ejected matter is diluted or even totally masked by a "local, often high-energy component", contributing to the sedimentation in the K-Pg layer (e.g., [4,8,11]).

Numerical models [6] indicate a deposition of >500km³ projectile material, corresponding to >2 x 10^9 tons of mainly silica, iron, and magnesium in the K-Pg event bed. Detecting the "meteoritic" origin of these major elements, however, in a matrix of siliceous detritus, is practically impossible.

Fig. 1. Spherules from the K-Pg boundary, La Lajilla, Nuevo Leon, Mexico. (Upper) Optical micrograph of a ~600 µm-sized, partly altered particle (courtesy Hans Kerp, WWU); (lower) back-scatter electron image with element maps showing dissolution-precipitation features due to alteration (Ti festoons) and a co-genetic calcite bleb (T. Salge, Bruker-Nano Berlin).

REE distribution patterns of Chicxulub impact spherules. Trace element, especially REE patterns may partly overcome the above outlined problem. Recent LA-ICP-MS analyses [4,11] show that siliceous spherules – hydrated glass or altered to chlorite, both with excellently preserved textures – in sections from ODP 207, the Chicxulub event bed at Shell Creek, Alabama, and La Lajilla (Fig 1.) and La Popa, NE Mexico, have very low trace element contents.

The REE patterns of the spherules are flat and unfractionated, corresponding quite well to a typical CI-pattern (Fig. 2). The REE abundances are chondritic or – surprisingly – sub-chondritic (i.e., = 0.1 x CI), rarely exceeding the CI abundances. Mixing calculations indicate that the REE contribution of UCC material is on the order of 2 %, but usually much less. While the reason for the sub-chondritic REE abundances is currently not understood, the flat REE patterns cannot originate from any known alteration process; they truly reflect a "meteoritic" component in the (glass) spherules. Accepting this fact, the siliceous host material (i.e., the spherules) must consist also of projectile material. Yet spherules with high aluminum and iron contents (i.e., not typical "meteoritic" elements) obviously contain a substantial component derived from upper crustal rocks in the target area. Calcite inclusions (cf., Fig. 1) derive from vaporized/molten platform sediments covering the target area at end-Cretaceous times.

The PGE in the spherules are mostly below detection limit, and the abundance of Ni, Co, and Cr is less than 0.01 x CI, indicating strong fractionation of the metal-sulfide component from the lithophile elements of the CM2 projectile during the impact process.

Depending on the sampling site, the spherules with the flat REE distribution patterns amount to between 10 and ~70 vol% of the Chicxulub event bed. The widespread occurrence of this (?) condensed projectile matter in the K-Pg event bed reconciles observations with impact models (Fig. 3; [6]). We expect that refined models will help to solve pending questions on chemical fractionation in the plume!

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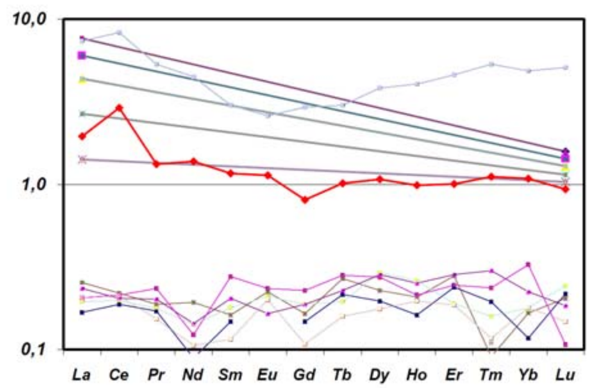

Fig. 2. Flat CI-normalized REE patterns for Fe-rich "glass" spherules from the K-Pg boundary at La Popa, Nuevo Leon, Mexico. Note absence of a Cerium anomaly, indicating an only very minor alteration, and the sub-chondritic REE abundances. The sample in red is slightly disturbed (positive Ce anomaly), its pattern can be modeled by adding between 0.5 and 2 % of UCC-REE to a CI pattern. The blue line corresponds to a calcite spherule from this locality. Grey are mixing lines between UCC and CI (10%, 8%, 6%, 4%, and 0.5% UCC). Microprobe and Element 2 LA-ICP-MS data (spot size 60 – 235 µm) WWU Münster [11]; see [4] for details on the analytical technique.

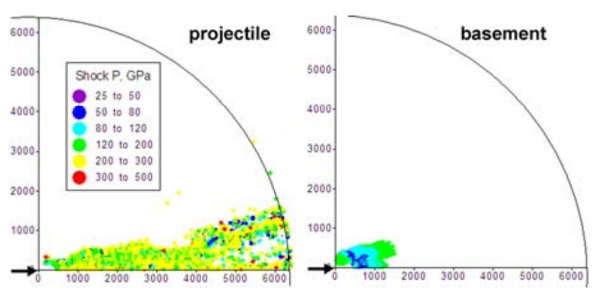

Fig. 3. Modeling results of a 45° "Chixculub" impact showing the distribution of ejecta that was deposited in the ballistic mode only; scale in km. Note the much higher abundance of projectile matter compared to ejecta from the crystalline basement in the target area. Not shown is the widespread occurrence of ejected platform sediments.