CARBONACEOUS OR ORDINARY CHONDRITE AS THE IMPACTOR AT THE K/T BOUNDARY? CLUES FROM Os, W AND Cr ISOTOPES.

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Introduction: Two major events – a bolid impact and an extensive volcanic activity – occurred 65 Myrs ago. Focusing on the extraterrestrial projectile, we try to determine its nature thanks to its isotopic composition in Os, W and Cr. Os and W are both siderophiles. Since high Ir and other siderophile abundances have been reported for the K/T layer all over the world, Os and W should be enriched as well, and thus seem to be a good choice for this study. The Cr isotopic composition has been measured as well. Indeed, each type of meteorite is characterized by a typical pattern of different isotopic signatures.

Several authors claim the bolid had a chondritic nature [1-3] even if some other ones put forward the hypothesis of an iron meteorite [4]. We will discuss both hypotheses from isotopic data. We analyzed not only K/T boundary sediments but Ni-rich cosmic spinels as well, because this phase is thought to derive from the K/T impactor [5]. Spinels are of particular interest because they should have kept the extraterrestrial signature, contrary to the sediments that may have been affected by mixing and dilution with terrestrial material.

Description of the samples: Samples from three marine sites – Stevns Klint, Caravaca and Bidart – have been analyzed. In Stevns Klint, the K/T boundary is composed of gray clay with thin ochre veins of iron hydroxides and pyrite residues. In Caravaca, the boundary corresponds to a very thin layer of ochre clays. The boundary in Bidart is marked by ochre clay as well. Scarce sulfides are dispersed in the sediments; they have not been encountered on the other sites. In fact, the site of Bidart is in a reducing environment where sulfides have not been reoxidized into goethite contrary to Stevns Klint and Caravaca. For each of the three sites, we have analyzed sediments from the late Cretaceous and the early Danian as reference samples, as well as sediments from the K/T boundary itself. Ni-rich spinels from Bidart have also been studied.

The nickel-rich spinels: Highly oxidized Ni-rich spinels with an unusual composition have been found on the different sites of the K/T boundary. Several formation processes are proposed for these spinels: either they come from the vaporization of the extraterrestrial bolid at the time of the impact, or from the direct condensation of the vapor phase [6] or from the oxidation of meteoritic particles melted and recondensed in the impact cloud [7]. Robin et al. (e.g. [8]) rather suggest that spinels are formed by high velocity interaction of meteoritic debris with the terrestrial atmosphere, when the debris are slowed down at a low altitude, under a high oxygen fugacity. Whatever formation scenario is considered, spinels carry the trace of the impactor. Besides, the low REE content precludes the hypothesis of a mixing with more than 10% of terrestrial material [9]. Therefore, these minerals are expected to show the real isotopic signature of the projectile.

Os isotopes: The K/T boundary is enriched in Os relative to the surrounding sediments. The enrichment is too high to be explained by a sedimentation gap, without any "exotic" input of Os. A mixing of local sediments with 0.11 to 8.4% of a chondrite or with a lower percentage of an iron meteorite could match the Os concentration measured at the boundary. The high variability of the Os enrichment from one site to another is likely due to the different conditions of sedimentation and probably linked to the redox degree. Caravaca and Stevns Klint are characterized by anoxic conditions: pyrite precipitates and scavenges platinoids contrary to what happens at Bidart, thus explaining the higher concentration in Os in Caravaca and Stevns Klint relative to Bidart.

Concerning the isotopic composition, the $^{187}Os/^{186}Os$ ratio dramatically decreases at the boundary (in agreement with previous results from [10]) and then increases again, without reaching the value of the late Cretaceous. The fact that the isotopic ratio remains slightly radiogenic above the boundary is likely due to the residence time of Os in the ocean. The $^{187}Os/^{186}Os$ ratio of the K/T sediments (1.37 to 1.97) is higher than the ratio of any kind of meteorites. Note that considering the low Re/Os ratio of the sediments at the boundary, the radioactive decay of ^{187}Re only affects the $^{187}Os/^{186}Os$ ratio by 0.05 units at maximum until present time. To explain our isotopic data, one has to consider a mixing of 0.02 to 0.1% of chondritic material with terrestrial sediments, depending on the site, or even a smaller proportion of meteorite if it is an iron meteorite, richer in Os. These values do not agree with the mixing calculations explaining the concentration data. As the Re/Os ratio is more than 10 times higher in the spinels than in the K/T sediments, we suggest that the latter contained more Re in the past (lost since that time by alteration and oxidation) and that the Os isotope ratio is in fact disturbed. Thus, it is not possible to conclude about the nature of the impactor from Os data.

W isotopes: The K/T boundary is highly enriched in W too. The concentration is in fact so high that no simple mixing equation between sediments and a meteorite can explain the data. As for Os, W concentrations could be explained by a scavenging of chacophile elements at the time of sulfide precipitation. Tungsten may be trapped in sulfides, or redox conditions at the time of the deposit may favor its precipitation into sediments.

Given that the W isotopic composition of iron meteorites is typical among all other meteorites, we have used tungsten isotopes to check if the hypothesis of an iron meteorite as the impactor can be definitively rejected. Contrary to the Re-Os system, the Hf-W system is based on a short-lived radionuclide. The ^{182}Hf isotope was already extinct 65 Myrs ago, so that no correction due to an in situ radioactive decay is necessary before discussing the results. As expected, the isotopic composition of sediments from both sides of the boundary cannot be distinguished from other terrestrial samples. On each of the three sites, the boundary itself does not present any tungsten isotopic anomaly. Two interpretations are possible: either the extraterrestrial material is diluted enough into the sediments so that the isotopic signature has been erased, or the extraterrestrial projectile has an isotopic composition almost identical to that of the Earth. Ordinary chondrites present a signature between –0.64 and –2ε. Irons and carbonaceous chondrites are depleted in ^{182}W by at least 2 ε relative to the silicate Earth. Thus, the extraterrestrial signature has been completely diluted by mixing with terrestrial sediments – and a physico-chemical process explains the enrichment in W – or the impactor is possibly an ordinary chondrite with little mixing, if future data on ordinary chondrites show an average composition at the upper end of the presently available range. Schönberg et al. [11] have shown that some early Archean samples present an unradiogenic signature of about –1 ε, witness of the Late Heavy Bombardment of the Earth. They argue that the metamorphosed sediments contain a component derived from meteorites. The relationship between this observation and the K/T boundary sediments is not clear yet.

The spinels are expected to keep the signature of the extraterrestrial body, particularly because tungsten is a refractory element. Losses by volatility at the time of impact, for example, are therefore highly unlikely. Spinels show a small deficit of (0.34±0.9)ε in ^{182}W. The large error bar precludes any clear conclusion whether or not a meteoritic signature is really present. In case of a positive answer, the W composition of the spinels is in favor of an ordinary chondrite.

Cr isotopes: Sediments from the site of Caravaca have been analyzed, as Shukolyukov and Lugmair already did [3], but also sediments from Bidart, with a special emphasis on the spinels of this latter site. All K/T samples (sediments and spinels) are apparently depleted in ^{53}Cr by about 0.5ε (after renornalisation of ^{54}Cr to the terrestrial value) whereas ordinary chondrites display an excess of about 0.5ε. Among meteorites, only carbonaceous chondrites present a negative value for the ^{53}Cr/^{52}Cr ratio relative to the terrestrial value. As more than 90% of the Cr present in spinels is of extraterrestrial origin (estimation based on concentrations and mixing equations) the Cr isotopes unambiguously show that the K/T impactor was a carbonaceous chondrite. Shukolyukov and Lugmair reached the same conclusion too.

Conclusions: W and Cr data clearly indicate that the impactor was chondritic; this result is not contradicted by Os data. The more likely conclusion at present, based on the analysis of Cr isotopes in the spinels, is that the projectile was a carbonaceous chondrite. These isotopic results also confirm the extraterrestrial origin of these minerals. The W isotope composition of the spinels does not fully agree with the hypothesis of a carbonaceous chondrite, but a refined measurement is required to discuss this discrepancy in more details.

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