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The nature of the KT impactor. A ^{54}Cr reappraisal

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Abstract

According to the variations observed in the various meteorite classes, ^{54}Cr represents an isotopic tool for planetary body discrimination. In the search for the nature of the Cretaceous-Tertiary (KT) impactor, Cr isotopic measurements were already performed at KT boundary. The current work is aimed to modernize Cr isotopic data with high-precision measurements to confirm a carbonaceous chondrite type infall, the contribution of which is also estimated. Isotopic signatures of two marine clays (Caravaca, Stevens Klint) exhibit an isotopic ratio which would represent a mixing of a carbonaceous chondrite of CM2 type with terrestrial material in a ratio 6% to 19%. A single impactor may account for both marine and continental Cr isotopic signatures.

Keywords: KT-boundary; carbonaceous; impactor; ^{54}Cr; CM2

1. Introduction

The exact nature of the sudden biological transition at the KT boundary is still under debate especially because the two candidates events volcanism versus impact occurred closely around 65 Ma ago. The Deccan eruption was certainly brief and intense at 65.6 ± 0.3 Ma (e.g. [1–4]) but the contemporary impact of an asteroid (or comet) is also proved since the discovery of the Chicxulub crater (e.g. [5–9]). Without going into the extinction origin debate this paper focuses on one peculiar aspect: the nature of the impactor at Chicxulub. What kind of extraterrestrial material hit the Earth at Chicxulub? Meteorites (what types)? Comets? To investigate the issue we use as tracer the isotopic composition of chromium. Chromium isotopic variations have been studied in various classes of meteorites. In the past well-resolved ^{53}Cr isotopic variations have been evidenced in meteorites and attributed to the extinct radioactivity of ^{53}Mn [10]. This effect has been detected in KT sites [11]. ^{53}Cr is a good indicator of extraterrestrial origin [10–12] but is not the best tracer to identify the different types of extraterrestrial objects. In this paper we use ^{54}Cr signature, which is in our view a far more robust indicator for mainly two reasons. First, ^{54}Cr variations are usually larger than ^{53}Cr variations in meteorites. Second, the ^{54}Cr signature of one meteoritic class is specific whereas ^{53}Cr, which relates to ^{53}Mn decay, often varies within the same class or frequently exhibits identical signatures in different classes. Widespread ^{54}Cr variations are present in carbonaceous chondrites at the mineral scale or at the bulk-rock scale [12–15]. More recently another set of anomalies have been found for basaltic achondrites [16,17] and ordinary chondrites [18]. We thus have a quite large catalog of ^{54}Cr variations, which may be used as a tracer for the source of impactor. For such purpose we have used the recent developments in high precision multicollection mass spectrometry, which

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have improved the precision of isotopic analyses, enabling us to resolve small differences in ^{54}Cr.

2. Analytical procedure

2.1. Mass spectrometry

Cr possesses four isotopes: 50 (4.3%), 52 (83.8%), 53 (9,5%), 54 (2.4%). Two isotopes are used for instrumental mass fractionation correction. The choice of the normalizing isotopes, which has been discussed earlier [19] is usually ^{50}Cr and ^{52}Cr. Cr isotopic ratios are measured on a 9-cup Triton multicollector thermal-ionization mass spectrometer. The major difficulty in Cr high precision measurements, which means a few parts per million in accuracy, is the large relative mass difference between Cr isotopes (8%). Two implications follow. First in simultaneous collection of all Cr isotopes, depending on the cup configuration ^{50}Cr and ^{54}Cr ion beams can be far from the instrument axis, possibly increasing beam aberrations in last generation high precision spectrometers. Second the instrumental fractionation between extreme isotopes is well above 1% and a significant correction has to be applied. This possibly results in the second-order dispersions observed at the 20–50 ppm level, which have to be taken into account when higher precisions are required. The procedure described below has been designed to control these two factors, which may alter the precision of the data.

High intensity ion beams of 1.10^{-10}A are routinely used. Each single run is a combination of five successive static multicollection measurements (Table 1). The Cr isotopic beams are adjusted to a set of cups and measured in the static mode, next the isotopes are shifted by one mass unit in the cup array and centered in the cups using the zoom optics of the instrument to peakcenter and adjust the peakshapes. Then the ratios are measured again in the static mode. This procedure is repeated four times to provide the full set of successive static measurements. This enables us to crosscheck in real time the performance of the measuring system and optics.

2.2. Data reduction

Isotopic ratios are measured independently in each measurement configuration and compared to one another to evaluate the relative cup efficiency.

An exponential fractionation law is used to normalize the highly fractionated ^{53}Cr and ^{54}Cr data relative to $^{52}Cr/^{50}Cr$ [20]. Nevertheless after correction some variability is present at the 20 ppm level for $^{53}Cr/^{52}Cr$ and 50 ppm level for $^{54}Cr/^{52}Cr$ whatever the measured instrumental fractionation is. These residual $^{53}Cr/^{52}Cr$ and $^{54}Cr/^{52}Cr$ dispersions are correlated (Fig. 1) so it is tempting to benefit from this well-resolved correlation to improve $^{53}Cr/^{52}Cr$ precision by using $^{54}Cr/^{52}Cr$ as an additional internal correction ratio. As our dispersion is controlled during sessions of measurements no such second-order correction similar to that used by Lugmair and Shukolyukov [21] is applied. The 2σ individual data reproducibility or external precision is typically 12 ppm on $^{54}Cr/^{52}Cr$. Samples were repeated several times and averaged. This allows one to resolve unambiguously differences between carbonaceous chondrites, various types of meteorites and terrestrial ^{54}Cr. As there is no isotopic standard of sufficient precision for $^{53}Cr/^{52}Cr$ and $^{54}Cr/^{52}Cr$ we assume that the average value of $^{54}Cr/^{52}Cr$ in analytical standards, i.e., 0.02821075 is equal to the average terrestrial composition, in agreement with our measurements of the terrestrial rocks outside the KT samples. Some instrumental bias may exist (e.g. $^{54}Cr/^{52}Cr=0.0282085$ in [21]). This results from instrumental differences, but as far as reproducibility is warranted, this bias has no consequence on the interpretation, as data are converted in epsilon differences relative to the terrestrial composition, thus validating interlaboratory comparison.

2.3. Chemistry

Cr chemical separation from the matrix elements is performed using cation exchange of trivalent Cr as developed by [19] with a special care in the present study to obtain a higher than 80% yield. Blanks are negligible (Chemistry blanks of the order 4 ng and acid

Table 1
Cup configurations for Cr isotopic analysis

Line	L4	L3	L2	L1	C	H1	H2	H3	H4
1	49	50 (Cr)	51	52 (Cr)	53 (Cr)	54 (Cr)	55	56	57
2	48	49	50 (Cr)	51	52 (Cr)	53 (Cr)	54 (Cr)	55	56
3	47	48	49	50 (Cr)	51	52 (Cr)	53 (Cr)	54 (Cr)	55
4	46	47	48	49	50 (Cr)	51	52 (Cr)	53 (Cr)	54 (Cr)
5	50 (Cr)	51	52 (Cr)	53 (Cr)	54 (Cr)	55	56	57	58