CHROMIUM ISOTOPE EVIDENCE IN IMPACT EJECTA FOR THE NATURE OF THE IMPACTORS OF THE SUDBURY AND VREDEFORT STRUCTURES.

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Introduction: Collisions between planetary bodies, as well as asteroid and comet impacts are fundamental processes in the formation of our solar system. However, compared to its satellite, traces of ancient impacts on Earth are rare because they have been totally or either partially erased by long-term geological history. The identification of the nature of an impactor is also a difficult task, because projectile fragments rarely survive a hypervelocity collision. The remains of the impactor are diluted in a far larger volume of target rock, which makes impossible to detect such remnants without detailed trace element and isotopic investigations. The Sudbury and Vredefort impact structures represent the most ancient preserved geological features that bear witness to the early bombardment of our planet. The nature of both impactors has not yet been clearly identified [1] [2] [3]. In this study, using chromium (Cr) isotope analyses on ejecta samples related to these two events, we evaluate the type of projectile at their origin.

Samples and method: We measured the Cr isotope compositions of 8 bulk samples. The petrological descriptions and locations of Sudbury ejecta were previously published by [1], as well as the PGE, major and trace element concentrations. Samples PR10 and PR9 come from Pine River drill core (Canada), and C9 and C18 from Coleraine drill core (USA). Samples that are possibly related to Vredefort impact structure - FD22, FD26 and GL1, GL5 are respectively from the spherule layer in Karelia (Russia) [4] and from the spherule layer in Ketilidian orogen (South Greenland) [5]. The chemical procedure following the method of [6] includes dissolution of ~30 mg of sample and two separation steps of Cr on cationic exchange resin AG50W-X8. ε^{53}Cr and ε^{54}Cr isotope compositions and Cr concentrations were measured at the Institut de Physique du Globe de Paris (IPGP) by TIMS Fisher scientific Triton and ICP-MS-HR Element 2, respectively. The ε notation corresponds to the relative deviation in per 10,000 of the ^{54}Cr/^{52}Cr and ^{53}Cr/^{52}Cr ratios from the terrestrial standard value.

Results: Sudbury ejecta (PR9, PR10, C9 and C18) exhibit large variations from -0.20±0.09 to 0.26±0.07 for ε^{54}Cr and from -0.04±0.05 to 0.19±0.04 for ε^{53}Cr. PR9 and PR10 have higher chromium concentrations and lower Cr isotope values than C9 and C18. This is also true for the PGE abundances given in [1], which show larger enrichments for Pine River (PR) rocks than for Coleraine (C) rocks. C18 exhibits a terrestrial Cr isotope signature (~0) and is characterized by a low Cr concentration. C9 is more enriched in Cr and shows significant positive Cr isotope values. PR10 is the most enriched in siderophile elements but exhibits no Cr isotope anomaly, whereas PR9 has a small but significant ε^{54}Cr deficit for almost similar siderophile elements content.

Isotope compositions of the samples that are possible Vredefort ejecta (FD22, FD26, Russia, and GL1, GL5, South Greenland) range from 0.35±0.07 to 1.26±0.09 for ε^{54}Cr and from 0.07±0.04 to 0.18±0.04 for ε^{53}Cr.

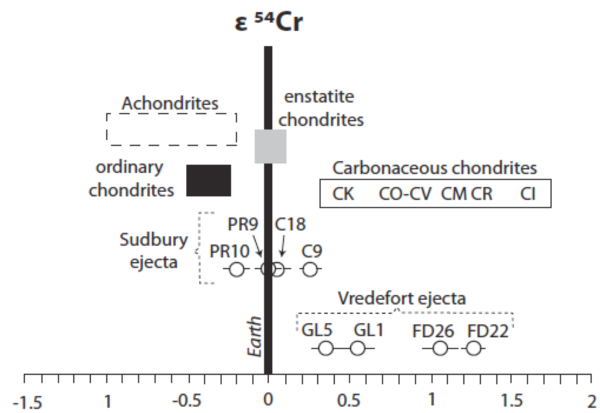

Figure 1. ε^{54}Cr isotope compositions of Vredefort and Sudbury ejecta, and comparison to meteorites

Discussion: The results we obtained for Sudbury ejecta samples provide very different information. On the one hand, the low Cr and other siderophile element concentrations of C18 argue in favor of a terrestrial signature. On the other hand, the absence of ^{54}Cr anomalies for PR10 despite its HSE enrichments could suggest that 1) there is no detectable trace of the impactor in this rock, indicating that all the Cr is of terrestrial origin. This may be also valid for the PGE, which might be concentrated in this layer because of preferential remobilization during magmatic processes related to the impact, or 2) the impactor may be an enstatite chondrite. However the chondritic component identified by [1] [2] of the other sample from the same site (PR9) exhibits a negative ^{54}Cr anomaly, that cannot be explained by the involvement of an enstatite chondrite but only by an ordinary chondrite (see Fig.1). The ^{54}Cr deficit (ε^{54}Cr =-0.20±0.09) may be explained by an admixture of 2-3 % of an ordinary chondrite component (ε^{54}Cr =-0.40; Cr=3600 ppm), diluted in continental crust material [7]. Therefore, we suggest that Sudbury impactor is more likely of ordinary chondritic composition.

However, the Cr isotope composition of C9, being different from the rest of the samples needs to be explained. The coupled excess of ^{53}Cr and ^{54}Cr could be interpreted in two ways. 1) The large impactor at the origin of Sudbury might have locally recorded some cosmogenic effects that would have strongly affected and increased ε^{54}Cr and ε^{53}Cr values, so that it can still be detected in this impactite despite large dilution in the terrestrial matrix. 2) There is the presence of a carbonaceous chondrite influence. Thus, the trace of the impactor recorded at Coleraine area is not identical to the one sampled at Pine River. It might therefore be indicative of a previously unknown impact event close in time and space to Sudbury.

The ε^{54}Cr and ε^{53}Cr measured for the possible ejecta samples from the Vredefort impact structure unambiguously confirm that these rocks are not related to the Sudbury event, but to Vredefort impact. To our knowledge, this study is the first geochemical investigation that infers the type of impactor responsible for Vredefort structure. Earlier studies (on impact melt rock samples directly from Vredefort, not ejecta) have shown the presence of a meteoritic component [3] [8], but have not been able to distinguish the impactor type. All samples show positive ^{54}Cr anomalies that point towards the field of carbonaceous chondrites and translate various mixing proportions between the impactor and a heterogeneous target rock. Among carbonaceous chondrites, CI-type and CR-type are the only one that can match the FD22 composition, which has a ε^{54}Cr composition of ~1.26. All other types of carbonaceous chondrites show lower values. The composition of FD22 can be explained by mixing 4% of CI component with 96% of a terrestrial target material with the composition: ε^{54}Cr=0, Cr=40 ppm. CI-type also matches the isotope composition of the most Cr-enriched sample (GL5) if 1.5% is diluted in a more enriched crustal target assemblage (~160 ppm). The involvement of a CR impactor (ε^{54}Cr=1.3, Cr=3415 ppm) cannot be totally excluded but would require a terrestrial component characterized by a very low Cr concentration (5 ppm) in order to reproduce the concentration and isotope composition of FD22. Assuming that the spherule layers sampled here are really related to the Vredefort impact event (which is likely for the Karelia samples and, with the new results, more likely than before even for the Greenland samples), we propose that the bolide that hit the Earth at about 2.2 Ga at Vredefort was a body of CI composition.

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