AN ACHONDRITE-DOMINATED METEORITE FLUX BEFORE THE L-CHONDRITE PARENT ASTEROID BREAKUP EVENT 466 MYR AGO?

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Introduction: Today, ordinary chondrites dominate the meteorite flux to Earth, with L chondrites being the most abundant group. The type abundances of meteorites that fall today are different than the types of asteroids that are best positioned to deliver them [1,2]. This implies that today's meteorites originated predominantly in a few asteroid breakup events [3,4] and that today's meteorite flux is not representative over 100-Myr-time scales. In order to investigate the past meteorite flux at such timescales an approach has been developed in which extraterrestrial minerals are extracted from ancient slowly formed sea-floor sediments [5]. Here we studied relict extraterrestrial chrome-spinel grains recovered from Middle Ordovocian sediments that were deposited 467 Myr ago, before the L-chondrite parent body breakup (LCPB) event.

Samples and Methods: We extracted chrome-spinel grains from marine limestone from the Lynna River section near St. Petersburg, Russia [6] by acid dissolution. The sampling interval GAP7 was chosen to avoid contributions from the LCPB [7]. The first sample consisted of 46 coarse chrome-spinel grains (63–200 μm) extracted from 270 kg of rock, the second sample comprised 184 chrome-spinel grains 32–63 μm from ~114 kg of rock. Opaque grains were handpicked under a reflected light microscope and chrome-spinel was identified with SEM/EDS [8]. Major and minor elements were analyzed with quantitative SEM/EDS or EPMA on polished epoxy grain mounts. We used previously established methods for a Cameca IMS-1280 to analyze three oxygen isotopes in the 230 grains in two sessions [7,9,10]. Unkowns were bracketed with UWCr-3 chromite standard [8]. Hydride peak tailing interferences of $^{16}O^{1}H$ on ^{17}O were corrected for. Data with hydride corrections >1‰ was rejected as justified previously [10].

Lower noise levels due to an improved detector system allowed us to use a smaller primary Cs^{+} beam (~11 μm spot size compared to ~15 μm previously) for the smaller grains of the second sample with shorter analyses times and similar external reproducibility [11].

We use three oxygen isotopes in conjunction with diagnostic TiO_2 concentrations to classify relict chrome-spinel grains as demonstrated in previous studies [9,10]. In some cases an unambiguous classification was not possible due to overlap between different types of meteorites in oxygen isotope space and in elemental compositions [9,10]. Sediment-dispersed extraterrestrial chrome-spinel grains (SECs) originate mostly from coarse micrometeorites [12,13]. We argued that coarse micrometeorites are useful to reconstruct the composition of the flux of coarse-chromite bearing meteorites [7,9,10].

In addition to SECs we also extracted chrome-spinels from recent surface-recovered meteorites to determine the chrome-spinel abundances in different types of meteorites.

Results and Discussion: The chrome-spinel abundance is variable in different types and sometimes even in the same types of meteorites [7]. However, our study on the recent falls and finds also shows that the abundances of coarse chrome-spinels are not very different on average in HED meteorites and in primitive achondrites, and slightly higher in equilibrated ordinary chondrites (EOCs) [7]. From our SEC data we find a large diversity of meteorite types that include ordinary chondrites, HED achondrites, primitive achondrites and ungrouped achondrites, including some that are not found today (Fig. 1). Surprisingly, the fraction of achondrites before the LCPB was very high and comprised at least 44% of the coarse chrome-spinel bearing meteorite flux (based on the coarsest SECs, the 63–200 μm size fraction), whereas it is only ~7% today. Today, ungrouped and primitive achondrites are rare in the meteorite and micrometeorite populations. The recovered achondritic SECs in our study include a sample that matches the composition of ungrouped fossil achondrite Österplana 065 which was found in slightly younger sediments of the same epoch [14]. This suggests that this type of meteorite, which is absent from today's collections, might have been common in the Middle Ordovician. Ordinary chondrites made up at most 56% of the flux. Because of their higher average chrome-spinel abundance their actual flux may have been lower than the achondrite flux. The LL chondrites, the rarest ordinary chondrite group today, were more common than H chondrites and as frequent as L chondrites. It is less surprising that L chondrites were less abundant at that time and that they became a much more important component after the LCPB, where they made up ≥99% in sediments immediately deposited after the event [10]. The distribution of meteorite types in pre-LCPB sediments is confirmed by our results from the smaller size fraction of SECs (32–63 µm).

The high abundance of LL chondrites and HED achondrites 467 Myr ago can be explained by the fact that this time window was closer to the respective peak meteorite flux after major collisional events that can be regarded as the most probable sources. The main source of the LL chondrites was likely the Flora asteroid family-forming event 950 +200/–170 Myr ago [15] and of the HED meteorites the formation of the ~500 km wide Rheasilvia impact basin on asteroid 4 Vesta ~1 Gyr ago [16]. The high abundances of primitive and related ungrouped achondrites indicate that some of the partially differentiated asteroids had disrupted and generated the higher flux that we observed. These disruption events were probably small compared to the LCPB so that the collisional cascade did not result in a large flux today.

Conclusions: Our study shows that the meteorite flux before the LCPB was strikingly different than it is today. We provide clear evidence from the sedimentary record that the composition of the flux of extraterrestrial material to Earth is biased today and varies on timescales of 10-100 Myr and larger. Studies of extraterrestrial material from different time windows [5] are in progress and, together with this study, will contribute to our understanding of the evolution of the asteroid belt.

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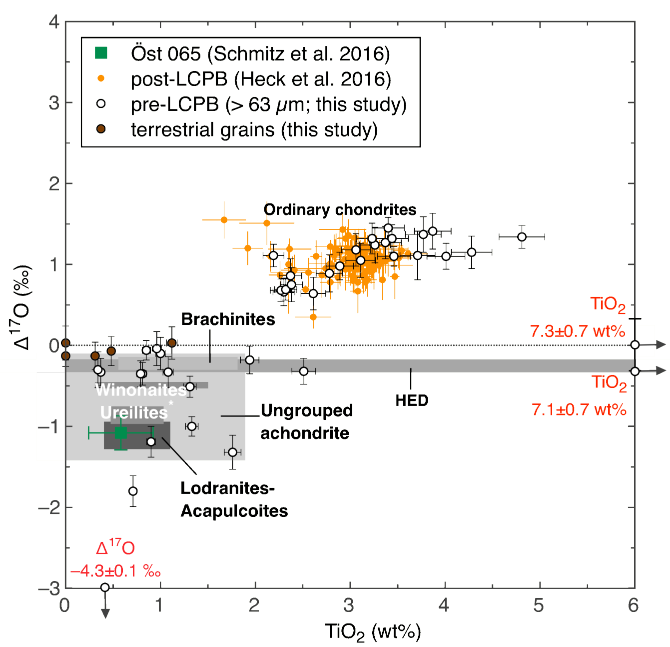

Figure 1. Relict chrome-spinel grains can be classified by comparing their $\Delta^{17}O$ values, the deviation from the terrestrial mass fractionation line (dotted line), and their TiO_2 concentrations to data from different meteorite types (reference data compilation from [7]). Error bars are 2σ and shown if larger than the symbol.