

Zinc isotopic variations among ordinary chondrites

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Zinc is a moderately volatile element that may be capable of movement among minerals or even volatilization during thermal metamorphism, despite the absence of partial melts. We obtained high-precision isotopic measurements of zinc by MC-ICP-MS [1,2] from a suite of 70 ordinary chondrites (OCs), in order to study their variation across the metamorphic range. The samples included 23 LL-, 26 L-, and 21 H-chondrites; 26 of the 70 were non-Antarctic falls, 3 were non-Antarctic finds, and 41 were Antarctic finds. Serial leachates were obtained from the LL3.0 Semarkona, and magnetic (metal), silicate and sulfide fractions were separated in three samples in order to determine the contributions of each phase to the total zinc budget. Three whole rock samples were broken into several smaller pieces and each was measured in order to determine the small scale homogeneity of the zinc isotopes.

The $\delta^{66/64}\text{Zn}$ (reported against the JMC-Lyon standard) for the entire suite, combined with previous data [3,4] generally fell within a narrow range, with a mean of -0.04 ± 0.13 (2se). There was no significant difference measured between Antarctic and Non-Antarctic samples. Isotopic fractionation showed a slight trend across OC subtypes LL<L<H, and unequilibrated OCs were lighter than equilibrated OCs in each subgroup, but these effects were modest. There was also a general trend across petrologic grade, with the highest subtypes (5-7) heavier than the less metamorphosed subtypes (3-4), by 0.35‰ for LL to 0.68‰ for H. However, zinc concentration did not vary with metamorphic grade, but instead averaged 43-52ppm for all petrologic grades. Leachates and separates show that a large portion of the zinc in OCs is found in sulfide phases. On a small scale, these OCs exhibited a high degree of homogeneity.

The similar zinc content of all OCs rules out significant volatilization with increasing metamorphism. Variations in zinc isotopic ratios may reflect pre-accretion nebular processes, or may represent closed-system metamorphic changes in which the zinc moves between phases in a mass-dependent process.

[1] Moynier et al. (2006) *GCA* **70** 6103-6117, [2] Moynier et al. (2011) **5**, 297-307, [3] Luck et al. (2005) *GCA* **69** 5351-5363, [4] Moynier et al. (2007) **71** 4365-4379.

Carbonaceous material associated with apatite in the Chassigny meteorite from Mars

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Following the biologically important elements is key for the search for life beyond Earth. Carbon and Phosphorous are two fundamental biological elements for all life on Earth, and are found throughout Earth's geological record in minerals like graphite and apatite. Associations between disordered carbonaceous material and apatite are reported here for the first time in an extraterrestrial sample. These mineral-pairs were found in the Chassigny meteorite which is an olivine cumulate rock from the Martian mantle. Raman spectra and microspectroscopic images show the presence of disordered carbonaceous material associated with hydroxylapatite-maskelynite inclusions in olivine grains. Optical and electron microscopy suggest that there is a petrogenetic connection between carbonaceous material, hydroxylapatite, maskelynite, Ni-rich pyrrhotite, Cr-rich spinel, orthopyroxene, and olivine. Carbonaceous material is often associated with hydroxylapatite in fields of dozens of 2-30 micron-sized maskelynite inclusions in olivine, which is interpreted here, on the basis of the Raman D- and G-bands, to represent precipitation from low-temperature hydrothermal fluids.

Focused Ion Beam (FIB) was performed to micro-fabricate targets of these mineral associations. Analyses by TEM-EDS show that hydroxylated apatite grains a few microns in size are embedded as inclusions in maskelynite, which was also observed by Raman spectroscopic imaging. In addition, we also found numerous Ni-rich pyrrhotite grains (with up to 4%wt Ni). Cr-rich spinels also occur throughout the olivine cumulates. Such a petrographic context is important because Fischer-Tropsch synthesis produces short-chain alkanes from the reduction of carbon monoxide by dihydrogen and catalyzed by metals such as Ni and Cr.

It is here proposed that apatite acted as a template for aromatic and aliphatic carbonaceous material to condense because apatite and graphite both have a hexagonal structure and there is a near-integer factor of 3.85 difference between their unit cell sizes. The discovery reported here is thus also relevant to the possibility of life on Mars, to the production of organic molecules on Mars (including traces of atmospheric methane), and also to yield a natural example of an early stage of non-biological organic synthesis for the transition from a prebiotic to a biological world.