Mineralogy, petrology, O and Mg-isotope compositions of AOAs from CH carbonaceous chondrites

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Amoeboid olivine aggregates (AOAs) in CH chondrites are texturally and mineralogically similar to those in other carbonaceous chondrite groups. They show no evidence for thermal metamorphism or alteration in an asteroidal setting and consist of nearly pure forsterite ($Fa_{<3}$), anorthite, Al-diopside, Fe,Ni-metal, spinel, ±low-Ca pyroxene (Fs_1Wo_{2-3}) and CAIs. The CAIs inside AOAs are composed of Al,Ti-diopside, spinel, perovskite, melilite ($Åk_{13-44}$), anorthite, hibonite, and grossite. The CH AOAs, including CAIs within AOAs, have isotopically uniform ^{16}O-rich compositions (Δ^{17}O = −23.5±2.2‰) and on a three-isotope oxygen diagram plot along ~slope-1 line. The only exception is a low-Ca pyroxene-bearing AOA that shows a range of Δ^{17}O values, from −24.3‰ to −15.2‰. Melilite, grossite, and hibonite in four CAIs within AOAs show no evidence for radiogenic ^{26}Mg excess (δ^{26}Mg*). In contrast, anorthite in 5 out of 6 AOAs measured has δ^{26}Mg* corresponding to $(^{26}Al/^{27}Al)_0$ of $(4.4\pm0.6)\times10^{-5}$, $(4.2\pm0.6)\times10^{-5}$, $(4.0\pm0.6)\times10^{-5}$, $(1.7\pm0.2)\times10^{-5}$, and $(1.7\pm0.2)\times10^{-6}$. Anorthite in another AOA shows no resolvable δ^{26}Mg*: $(^{26}Al/^{27}Al)_0 < 2\times10^{-6}$. We infer that CH AOAs formed by gas-solid condensation, aggregation of the condensates mixed with the previously formed CAIs, thermal annealing, and possibly melting to a small degree in a ^{16}O-rich gaseous reservoir during a brief epoch of CAI formation. The lack of resolvable δ^{26}Mg* in melilite, grossite, and hibonite in CAIs within AOAs reflects heterogeneous distribution of ^{26}Al in the solar nebula during this epoch. The observed variations of the inferred initial $^{26}Al/^{27}Al$ ratios in anorthite of the mineralogically pristine and uniformly ^{16}O-rich CH AOAs could have recorded (*i*) admixing of ^{26}Al in the protoplanetary disk during the earliest stages of its evolution and/or (*ii*) closed-system Mg-isotope exchange between anorthite and spinel+forsterite+Al-diopside during subsequent prolonged (days-to-weeks) thermal annealing at T>1000°C and slow cooling rates (~0.01 K hr^{-1}) that has not affected their O-isotope systematics. The proposed thermal annealing may have occurred in an impact-generated plume invoked for the origin of non-porphyritic magnesian chondrules and Fe,Ni-metal grains in CH and CB carbonaceous chondrites about 5 Ma after formation of CV CAIs.

Rare-earth element speciation in ferromanganese oxides from the Indian Ocean

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Oceanic ferromanganese oxides are major sinks for rare-earth elements (REE); hydrogenous oxides being especially suitable for cerium enrichment. Deep-sea muds and ferromanganese nodules and encrustations are considered as potential future sources of REEs. There are differing views on the relative importance of two oxides of Fe and Mn as the REE carriers. Here we present results from sequential leaching experiments performed on different types of ferromanganese oxides from the Indian Ocean in order to quantify the amount of REE associated with the hydrous Mn oxides and Fe oxides. A four-step sequential leaching method is employed here, which is intended to selectively leach metals that are surface adsorbed/loosely bound, Mn-oxide bound, Fe-oxide hosted or held in aluminosilicate residue respectively. Results of this sequential extraction experiment work have revealed that nearly all REEs are closely associated (above 95%) with Fe-bearing phase. The shale-normalized patterns of iron-oxide bound fraction show a distinct similarity in shape and magnitude with the bulk REE patterns except for Ce. Similar magnitude suggests that much of the REEs are hosted by iron-oxyhydroxide phase. Likewise, ~90% of cerium is bound to iron oxide phase and this phase displays a positive Ce anomaly which is typical of low temperature ferromanganese oxides. In contrast, Mn-oxides exhibit a weak positive Ce fractionation. A pronounced positive cerium anomaly in the iron oxide phase suggests an important role of Fe-oxide in acquiring positive Ce anomaly. Enrichment of other tetravalent elements such as Zr, Th and Hf in this phase suggests that the Ce-oxidation must have taken place before the adsorption.

A distinct europium positive anomaly and depleted HREE is seen in the manganese oxide phase in many of the samples. Fractionation of Eu from other REEs and reduction of Eu^{+3} to Eu^{+2} can only occur at temperatures above 200–250°C and characteristic of hydrothermal plume particulates and seawater. This is interesting and may pose a question as to whether the hydrothermal sources are contributing Mn to the CIB nodules.

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