SM-ND, LU-HF, AND AR-AR INVESTIGATIONS OF ENSTATITE ACHONDRITES

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Introduction: Enstatite chondrites and achondrites (such as aubrites) are amongst the most reduced meteorite groups with mineral assemblages including nearly FeO-free enstatite, minor or no feldspar and unique sulfide mineral assemblages (e.g., troilite, oldhamite, niningerite) [1]. Notably, they have similar oxygen isotopic compositions to the Earth and Moon [2]. This relationship suggests that enstitatite chondrites and achondrites were formed within the same region of the protoplanetary disk and were potentially major contributors to the Earth and Moon. To evaluate potential isotopic heterogeneities between planetesimals and planets in Hf and Nd isotopic compositions and the chronology of planetary crust formation, we carried out analyses on three enstatite-rich achondrites including the ungrouped enstatite achondrite, Itqiy, and two aubrites, Khor Temiki and Larkman Nunatak (LAR) 04316. We investigated their trace element compositions, ^{147,146}Sm-^{143,142}Nd, ^{176}Lu-^{176}Hf stable and radiogenic whole-rock systematics, and pyroxene and plagioclase mineral separates for ^{40}Ar/^{39}Ar dating.

Results: The REE concentrations of Itqiy whole-rocks (unleached WR and residue WR-R after acid leaching) were measured by quadrupole ICP-MS at Western. Itqiy is highly depleted in LREE with $(Ce/Ce)_N$ (when normalized to CI chondrites) from 0.09 to 0.02 and $(Lu/Lu)_N$ from 1.2 to 0.9 for the WR and WR-R respectively. We find super-chondritic ^{147}Sm/^{144}Nd = 0.4438 and ^{176}Lu/^{177}Hf = 0.4523 for Itqiy WR (compared to CHUR ^{147}Sm/^{144}Nd = 0.1960 and ^{176}Lu/^{177}Hf = 0.0336 [3]), while the aubrites Khor Temiki and LAR 04316 have ^{147}Sm/^{144}Nd and ^{176}Lu/^{177}Hf ratios that range from 0.2022-0.2206 and from 0.0314 to 0.0478 respectively. The stable isotopic compositions of Hf, Sm and Nd were measured by Neptune Plus MC-ICPMS and Triton TIMS receptively at LMV. We find that Hf, Sm and Nd isotopic compositions for Itqiy are identical, within error, to the respective terrestrial standards. On the other hand, the aubrites Khor Temiki and LAR 04316 have detectable deviations from the isotopic standards, with excesses in ^{178}Hf of 12 ± 4 and 45 ± 5 ppm, and ^{180}Hf deficits of -12 ± 7 and -50 ± 7 ppm, respectively, and Sm isotopic deficits for ^{149}Sm of -195 ± 167 ppm and -1457± 15 and excesses in ^{150}Sm of 446 ± 95 and 2938 ± 25 ppm, respectively, but no detectable variations in Nd or other Sm isotopes. Itqiy shows the highest ^{142}Nd/^{144}Nd ratio measured on Solar System objects to date, with a μ^{142}Nd of 345 ± 17 ppm. Due to the almost monomineralic nature of the silicate portions of Itqiy and the two aubrites, we group these three enstatite-rich achondrites together. We find a whole-rock ^{176}Lu-^{176}Hf errorchron age of 4414 ± 160 Ma, a ^{147}Sm-^{143}Nd isochron age of 4630 ± 46 Ma, and an initial ^{146}Sm/^{144}Nd of 0.00817 ± 0.00034, which corresponds to a ^{146}Sm-^{142}Nd model age of 2 ± 6 Ma after CAIs (using ^{146}Sm/^{142}Nd$_i$ = 0.00828 and half-life ^{146}Sm = 103 Ma) [4]) thus an age of 4566 ± 6 Ma for these enstatite-rich meteorites. The Ar-Ar chronometry was carried out at Curtin. Khor Temiki yielded well-defined plagioclase and pyroxene Ar-Ar plateau ages with a weighted mean age of 4506 ± 14 Ma (P=0.67). Itqiy enstatite grains did not yield any plateau, but suggest a resetting event < 1.3 Ga. LAR 04316 gave imprecise mini-plateau ages with an average age of 4415 ± 46 Ma.

Discussion: We find that Itqiy WR is the most depleted planetary crust identified so far in incompatible elements, with normalized REE patterns, consistent with LREE-rich partial melt extraction from the source as previously found by [5]. These three meteorites do not have detectable isotopic heterogeneities for stable Nd stable isotopic compositions compared to terrestrial compositions, but we identified variable cosmogenic effects in the Hf and Sm isotopic compositions of Khor Temiki and LAR 04316, corresponding to irradiation at epithermal/thermal neutron ratios <1 [4] that affects ^{142}Nd abundances. When corrected, we find an early crystallization age within 2 ± 6 Ma of CAI formation from the ^{146}Sm-^{142}Nd systematics of these three meteorites together, slightly older than the Hf-W age for Khor Temiki [6]. Khor Temiki's ^{40}Ar/^{39}Ar age of ~4.51 Ga corresponds to the point at which plagioclase cooled below ~300°C, which could possibly be interpreted as the timing of cooling of the crust of the parent body or a brecciation event. LAR 04316 and Itqiy Ar systematics have recorded respectively early and late impact heating events at the surface of their parent bodies. Impact processes were suggested by [5] as a mechanism to explain the shock effects observed in enstatite of Itqiy. Reheating events recorded by the Ar-Ar ages did not affect the short-lived Sm-Nd systematics, but variably affected the long-lived Sm-Nd and Lu-Hf records.

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