Implications of occurrences of silica for the origin and metamorphism of enstatite chondrites

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Enstatite chondrites formed by some of the same processes that resulted in formation of ordinary and carbonaceous chondrites (e.g., heating and cooling of dust to form chondrules, parent body metamorphism, impact events). Thus, the anatomy of an enstatite chondrite is broadly similar to the anatomies of chondrites from other groups. However, reduced mineral assemblages and the prevalence of enstatite over olivine indicate that E chondrites formed in a part of the solar nebula characterized by low oxygen fugacities and enriched SiO_2.

One distinguishing feature of E chondrites is the presence of free silica. In this study, we use textural occurrence, mineral species, and Si and O isotopic compositions of silica in three EH chondrites to evaluate nebular and metamorphic processes. Samples consist of polished thin sections of ALHA81189 (EH3), ALH 84170 (EH3) and St. Marks (EH5). Textural occurrence and elemental compositions were determined using a JEOL JXA-8900 electron microprobe and silica polymorphs were determined using a Jobin Yvon LabRam 300 Raman spectrometer at Waseda University. Isotopic data were collected using the Cameca ims-1270 secondary ion mass spectrometer at Hokkaido University.

Silica occurs as thin rims on chondrules, fine-grained spherules and relatively coarse crystals in ALHA81189. Very fine-grained SiO_2-rich materials with tiny grains of metal were also identified in one grain and one rim on a silica spherule. Cristobalite is the only crystalline polymorph identified in this sample (some poorly defined spectra may be of glass). ALHA81189 is characterized by high abundances of olivine in chondrule interiors, and unfragmented chondrules compared to other type 3 EH chondrites. Some silica rims and coarse silica crystals are present in ALH 84170; however, no spherules have been identified. Both cristobalite and quartz are present in ALH 84170, and tridymite has been identified previously (Kimura et al., 2005, MaPS v. 40, p. 855-868). Silica in St. Marks consists of coarse grains of quartz.

Oxygen and silicon isotopic compositions of most of the silica objects are similar to whole-rock values for EH chondrites, suggesting that the silica rims and spherules formed from the same oxygen and silicon reservoir as the EH chondrules. Fine-grained silica-rich material in the rim of one spherule in ALHA81189 is somewhat enriched in ^{17}O and ^{18}O; this may have resulted from fractionation during reduction of FeO-bearing silicates.

Ranges of oxygen isotopic compositions are wider in ALH 84170 and St. Marks than in ALHA81189. We attribute this to equilibration during metamorphism in the case of St. Marks, which resulted in grain coarsening, homogenization of oxygen isotopes and recrystallization of silica phases to quartz. In contrast, multiple silica polymorphs are present in ALH 84170. Some (or all) of the cristobalite in ALH 84170 crystallized during high-temperature, fast-cooling events in the nebula, probably associated with chondrule formation, and did not recrystallize during parent body metamorphism. In contrast, quartz in this rock is likely metamorphic. If so, the presence of both polymorphs in ALH 84170 indicates that impact gardening post-dated or coincided with parent body metamorphism. This is consistent with the high degree of fragmentation of chondrules in ALH 84170.

ALHA81189 is characterized by intact, olivine-bearing chondrules with silica rims, silica spherules and the cristobalite polymorph. These observations indicate minimal metamorphic overprint and a lack of equilibration during chondrule formation. Isolation of olivine in chondrule interiors probably led to local gas enrichments in SiO and the consequent formation of silica rims and spherules. The cristobalite polymorph, spherical shape and absence of heavy isotopic enrichments suggest that the spherules formed by supercooling of SiO_2 liquid condensates.