Japan Geoscience Union Meeting 2010
(May 23-28 2010 at Makuhari, Chiba, Japan)

PPS009-08 会場: 301A 時間: 5月27日13:45-13:58

ケイ酸塩と硫化物から考察するエンスタタイトコンドライトの変成史

Metamorphic and nebular reaction histories of enstatite chondrites from silicates and sulfides.

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Enstatite chondrites (ECs) are highly reduced meteorites that mainly consist of Mg-pyroxene (enstatite), metal (kamacite), and Fe-sulfide (troilite). The enstatite contains only very low concentrations of FeO, and the metal phase exhibits relatively high Si abundances. Both characteristics are a consequence of very low O2 fugacities during condensation and accretion of the EC parent bodies (e.g., Brearley and Jones 1998).
Minor element variations in silicates in ordinary chondrites have revealed subtle variations in metamorphic grade and some details of element transfers during metamorphism (Grossman and Brealy, 2005). In contrast, although a general sense for metamorphic grade in enstatite chondrites has been determined (e.g., Zhang et al., 1995), a detailed understanding of metamorphic petrogenesis remains elusive. Yet, under the low f(O2) conditions characteristic of ECs, metamorphic reactions are bound to differ from those in other chondrite groups.
In this study, we collect multiple analyses of olivine, pyroxene and troilite from a set of ECs to assess variations in composition and approach to equilibrium (uniform compositions) during metamorphism. We investigated 6 polished thin sections of 3 EH3 (ALHA81189, ALH 84170, Sahara 97096), two EH5 (St. Marks, LEW 88180), and one E6 (NWA 974) chondrites.
All meteorites studied consist mainly of enstatite with silica, plagioclase, kamacite, troilite, and (Mg,Mn,Fe)S. Olivine is present in ALHA81189, ALH84170, and Sahara 97096 EH3s, but not in the higher petrologic types. Daubreelite, niningerite, oldhamite are present in complex nodules with troilite and/or kamacite in the EH3s; sulfides are more dispersed in St.Marks, LEW88180, and NWA974. Textures show a distinct contrast, with the type 3 chondrites having well-defined chondrules, and the type 5 and 6 chondrites having diffuse chondrule boundaries.
Enstatite is the dominant phase in ECs. The average Fs content in pyroxene decreases with increasing petrologic type. The range of composition becomes smaller in type 5 and 6 than E3s, indicating equilibration during metamorphism.
Troilite in the ECs generally has minor but detectable concentrations of Mn, Cr and Ti compared to the troilite from ordinary chondrites, reflecting low f(O2) conditions (detection limits: Mn, 0.04; Cr, 0.03; Ti, 0.02 wt%). Chromium ranges up to 4 wt% in individual troilite grains, but Mn and Ti concentrations are below 1 wt%. Nonetheless, concentrations of these elements are systematically higher than in ordinary chondrites and reflect the low f(O2) formation conditions of ECs. Wide ranges in composition make it difficult to ascertain whether troilite compositions vary systematically with petrologic type. Furthermore, troilites from the type 5 and 6 chondrites typically do not have more uniform compositions than in the type 3 chondrites.
Based on preliminary detailed X-ray mapping, the ranges in composition of troilite in EH3s may be

due to variations between grains of homogeneous composition. In contrast, troilite from St. Marks shows wide variations in composition within grains. EBSD data from St. Marks show that enrichments in Cr and Ti tend to coincide with grain or sub-grain boundaries. Thus, Cr and Ti of troilite in EHs may be roughly analogous with Cr in ferrous olivine of ordinary chondrites (Grossman and Brearly, 2005). In any case, even though EC pyroxene and troilite experienced similar metamorphic thermal histories, approaches to equilibrium compositions in these mineral groups do not match. Uniformity of Fs-content in pyroxene probably represents a near-peak metamorphic temperature condition, whereas variations in minor elements (Mn, Cr, Ti) in troilite in type 5 and 6 E chondrites reflect post-peak partial re-equilibration. In contrast, wide ranges in minor element composition of troilite of type 3 ECs reflect variations in f(O2) [and f(S2)?] in different regions of the solar nebula where chondrites components formed.

キーワード:隕石,コンドライト,エンスタタイトコンドライト,変成

Keywords: meteorites, chondrites, enstatite chondrites, metamorphism