

**CHONDRULES IN ENSTATITE CHONDRITES.** E. Jacquet<sup>1</sup>, L. Piani<sup>2</sup>, M. K. Weisberg<sup>3</sup> <sup>1</sup>Institut de Minéralogie, de Physique des Matériaux et de Cosmochimie, CRNS & MNHN, UMR 7590, 57 rue Cuvier, 75005 Paris, France ([emmanuel.jacquet@mnhn.fr](mailto:emmanuel.jacquet@mnhn.fr)), <sup>2</sup>Department of Natural History Sciences, Hokkaido University, Sapporo 060-0810 Japan. <sup>3</sup>Department of Physical Sciences, Kingsborough College, CUNY, Brooklyn, NY 11235, USA; Earth and Environmental Sciences, Graduate Center, CUNY, NY, NY 10024, USA; Department of Earth and Planetary Sciences, AMNH, NY, NY 10024, USA.

**Introduction:** Beside the classical porphyritic ferromagnesian chondrules in ordinary and carbonaceous chondrites, there is a whole world of unusual chondrules which, *to the extent* they can be traced to a common origin, may provide new powerful constraints on the chondrule-forming process(es). Among those, chondrules in enstatite chondrites (EC, divided in two chemical groups EH and EL; [1]) present especial interest. On the one hand, they may be compared in terms of size [2] and major silicate parageneses to type I chondrules in other chondrite clans, and their O isotope composition link them to inner solar system material [3]. On the other hand, their mineralogies, in particular opaque phases, testify to *extremely* reduced conditions—more so than any other known early solar system sample—which are as yet not understood astrophysically. With considerable progress accomplished in the last decade, it is timely to review the properties and origins of enstatite chondrite chondrules.

**Petrography, chemistry, O isotopes:** EC chondrules generally contain nearly FeO-free enstatite, subordinate silica, a volatile-rich mesostasis [2,4], Si-bearing kamacite and a wide array of sulfides such as troilite, niningerite (EH), alabandite (EL) etc. Olivine-rich chondrules and ferroan pyroxene fragments or spherules also occur in EC. All these phases show O isotopic compositions close to bulk EC [1], although some olivine grains scatter along the “primitive chondrule mineral” line of [5]. Bulk chondrules are depleted in siderophile and chalcophile elements [6] and show negative Eu and Yb anomalies not reflected in most of their ferromagnesian silicates [7-9].

Besides silicate chondrules, EC contain metal-sulfide nodules (MSN; [10-13]) which may be genetically related to them and in fact have sometimes been called “metal-sulfide chondrules” [13]; we thus included them in the scope of the review. They contain kamacite, sulfides, sometimes concentrically layered as in EH chondrites. Oldhamite in EH MSNs is enriched by 1-2 orders of magnitude in REE over chondritic values with frequent positive Eu and Yb anomalies [14-15]. MSN may contain silicates, such as the frequent enstatite  $\pm$  sinoite laths in EL’s [16-17].

**Condensation vs. melting:** Were the peculiarities of EC chondrules inherited from their putative precursors, presumably themselves the result of some con-

densation sequence, or were they acquired during their melting? Most of the past literature has envisioned the first option, with reducing conditions being achieved by supersolar C/O ratios (see [18] and introduction to [19] and references therein). For C/O  $\sim$  1, oldhamite, as an early condensate, would be predicted to concentrate REE but with Eu, Yb anomalies of the wrong sign; other condensate phases such as carbides would also be expected which are not observed.

The existence of relatively oxidized isotopically local phases in EC as well as the tetravalent state of a significant portion of the Ti in EC chondrules [20] suggest that the precursors of EC chondrules were actually quite “normal” and were melted in a O-poor and S-rich environment, leading to the sulfidation of silicate phases ([19], [4]). MSN in EH might have been expelled from chondrules [9] while those of EL may have an impact origin [16-17].

Whatever the stage where the reducing conditions applied, their astrophysical context remains to be determined. An origin inside the snow line would allow to decouple solids from water, but whether the S (and other volatile) enhancements can be reproduced in a nebular setting is still open to question.

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