Mineralogical features and REE distribution in ortho- and clinopyroxenes of the HaH 317 enstatite chondrite.

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Introduction: HaH 317 is an EL4 enstatite chondrite found in 2001 during a scientific expedition by G.Pratesi and other Italian collectors. Two dark brown stones, a larger one of 103 g and a smaller one of 2 g were found in the Hammadah al Hamra region. Classification and mineralogy have been reported by [1]. This meteorite shows well defined chondrules and enstatite crystals of 50 µm size that suggest a petrologic type 4. Major phases are enstatite, kamacite and troilite; other minor phases are diopside and plagioclase in very small grains (<5 µm). Niningerite and oldhamite have been found in very small grains, too. Figure 1-3 present the main mineral assemblages shown by the meteorite.

Instruments and methods: SEM images and EMPA analyses have been performed both at the Earth Sciences Department of the University of Florence, by means of Jeol microprobe and at the Natural History Museum of London by means of Jeol SEM and Cameca microprobe, respectively. LA-ICP-MS analyses have been performed at the EMMA laboratories of the NHM.

Experimental results: EMPA analyses on enstatite show that it's a nearly pure En pyroxene (Fs = 0.61, En = 98.54, Wo = 0.85 mol %). Kamacite shows a rather low Si content (Fe = 90.46, Ni = 7.51, Si = 0.57, P = 0.53, Co = 0.47 Wt. %). Plagioclase composition (An = 26.60 mol %) as well as the presence of diopside (Wo = 46.85, En = 52.91, Fs = 0.24 mol %) are unusual if compared to other known EL chondrites. Inside the chondrules, whose average size ranges from 600 to 1200 µm, very small rounded grains containing a calcium chloride phase (1-3 µm size) have been observed. Based on texture, mineralogy and chemistry (mainly An content of plagioclase > 13 mol%, presence of niningerite and Si content of kamacite <1.9 Wt. % [2, 3]) the meteorite is classified as an EL4 chondrite.

Laser ablation. Analyses have been performed both on diopside and on enstatite grains. Due to the small dimensions of diopside grains (ranging from a few microns to about 300 µm), only 8 of them were large enough to be detected with a 60 µm laser spot (Fig. 3). A correspondent number of enstatite grains have been detected, too. Several elements (39), mainly minor and trace elements, have been detected and all of them were found to be above detection limits.

Discussion: While being occasionally found in Unequilibrated Enstatite Chondrites (UECs), diopside has been reported in very few cases in Equilibrated Enstatite Chondrites (EECs).

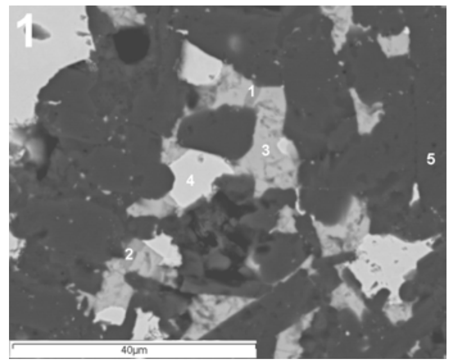

Figure 1: SEM-BSE image of a typical mineral assemblage in HaH 317 enstatite chondrite; 1, 2 are niningerite grains; 3 is a kamacitic Fe-Ni alloy; 4 is a troilite grain; 5 is an enstatite grain.

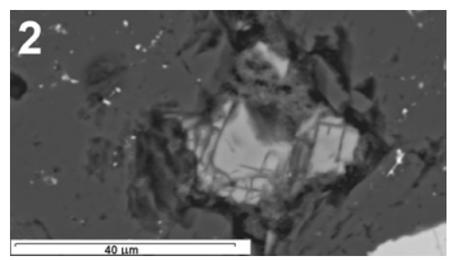

Figure 2: SEM-BSE image of an oldhamite grain.

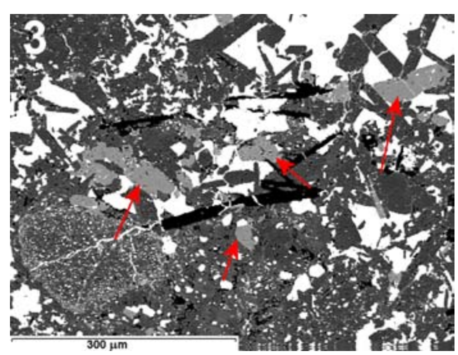

Figure 3: SEM-BSE image of some diopside grains selected for laser ablation analyses (red arrows);

The scarceness of these occurrences is in contrast with a theoretical prevision based on enstatite CaO contents of EECs, since these are consistent with the formation of stable diopside during metamorphic equilibration [4]. No REE data are reported on EL4 meteorites, while several analyses have been performed on EH4-6 (St.Mark's, Indarch, Abee) [5] and on EL6 (Jajh deh Kot Lalu, EET90102) EECs [5,6]. Furthermore only a few data are available on diopside REE contents of enstatite chondrites, mainly due to the small dimensions of the grains available for analysis [6,7]. These authors reported REE data obtained from 8 diopside grains of EET90102 EL6 chondrite and from 7 diopside grains of Qingzhen and Sahara 97159 EH3 chondrites.

In Figures 4 and 5 the REE patterns of 6 diopside and 6 enstatite grains of HaH317 meteorite are presented. Analytical data have been normalized to CI chondrites according to [8].

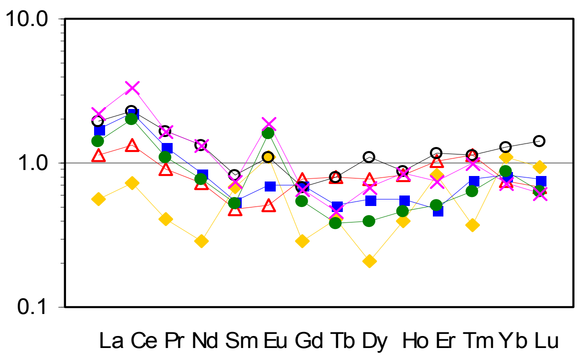

Figure 4: REE patterns for 6 diopside grains.

Diopside patterns seem to be significantly different from those obtained by [6] and [7]. A marked LREE enrichment is rather evident in at least 5 grains out of 6. In details, Ce and Eu positive anomalies are displayed by 6 and by 4 out of 6 grains, respectively, and the LREEs enrichment decreases ranging from La to Sm. HREEs show a relatively flat pattern, with slight positive and negative anomalies displayed by Dy in different grains.

Ce anomalies have been reported in pyroxenes from Antarctic eucrites and shergottites [9, 10, 11] and enstatite chondrites [5], and are suggested to be due to partial oxidation of Ce (III) to Ce (IV), less soluble than trivalent REEs, in the terrestrial environment.

Eu negative anomalies have been reported for diopside by [7], especially for EH3 chondrites, but no positive Eu anomalies have ever been reported before for diopside. Eu anomalies commonly found in UECs chondrites (both from diopside and enstatite grains) are usually negative and are explained as consistent with partitioning between low-Ca pyroxene and melt during igneous fractionation under reduced conditions. In extremely reduced conditions Eu can be divalent, resulting more incompatible in pyroxene than trivalent REEs. Enstatite grains from Jajh deh Kot Lalu EL6 chondrite and from aubrites not always show negative Eu anomalies.

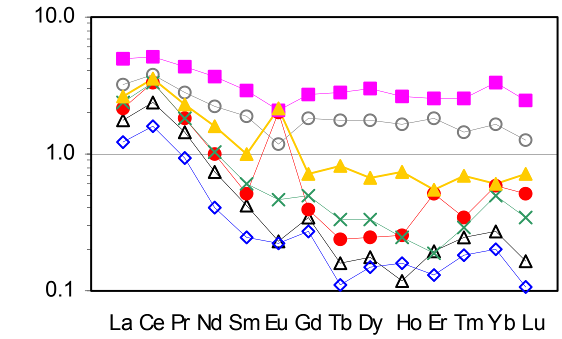

Figure 5: REE patterns for 6 enstatite grains.

Enstatite grains present the same LREEs enrichment displayed by diopside, but their REE/CI ratios are extremely variable from grain to grain, especially for HREEs. However LREEs patterns appear to be rather constant, with a marked decreasing from La to Sm. Eu anomalies show some uncertainties (2 of them are positive and 4 slightly negative) that can't be easily understood. A slight Yb positive anomaly is displayed by 5 out of 6 enstatite grains, in disagreement with analytical data on enstatite presented by [6] for UECs and in good agreeement with REEs data for diopside in EECs [6].

Conclusions: The characteristics presented both by diopside and by enstatite grains (Ce and LREE enrichments) have never been reported before. These data seem to be distinctive of EL4 chondrites and point to a different partitioning behaviour of REEs in transitional, partially equilibrated, enstatite chondrites, in comparison with UECs and EECs. Another interesting feature seems to be the great spreading of HREEs/CI ratios in enstatite grains (ranging from 0.1 to 20). However a petrogenetic interpretation of these data seems to be speculative at present and needs further data to be completed.

References: [1] Pratesi G. and Moggi Cecchi V. (2003) *MAPS* **38,** 7, A200. [2] Keil K. (1968) *JGR, 73,* 6945-6976. [3] Zhang Y. *et al.* (1995) *JGR 100,* 9417-9438. [4] Fogel R.A. (1997) *MAPS* **32**, 577-591. [5] Hsu W. and Crozaz G. (1998) *GCA* **62**, 1993-2004. [6] Floss C. and Fogel A. (2001) *LPS* **32**, Abstract #1402. [7] Anders E. and Grevesse N. (1989) *GCA* **53**, 197-214. [8] Floss C. et al. (2003) *GCA* **67**, 543-555 [9] Floss C. and Crozaz G. (1989) *EPSL* **107**, 13-24. [10] Harvey R.P. *et al.* (1993) *GCA* **57**, 4769-4783. [11] Hsu W. and Crozaz G. (1996) *GCA* **60**, 4571-4591