

DIOPSIDE IN EQUILIBRATED ENSTATITE CHONDRITES: EET90102-THE FIRST DIOPSIDE-BEARING EL6 CHONDRITE Robert A. Fogel, Dept. of Mineral Sciences., American Museum of Natural History, New York, NY 10024

Introduction: Diopside has always been enigmatically absent from equilibrated enstatite chondrites (EEC's). Although diopside is sometimes present in unequilibrated enstatite chondrites, its abundance is always small and it is usually part of a disequilibrium assemblage. To this point in time, however, diopside has not been discovered in grade 5-6 E chondrites. The absence of diopside in EEC's is not well understood since the CaO content of EEC enstatites is either close to or right up against the diopside-enstatite phase boundary [1,2]. This fact suggests that diopside should have exsolved from EEC enstatite or have been otherwise stable at high T's. It is initially tempting to ascribe the absence of diopside to the stability of oldhamite (CaS) but this, as shown below, would be an oversimplification and under certain circumstances incorrect. This study reports the discovery of the first diopside-bearing equilibrated enstatite chondrite; the EL6 chondrite EET90102. Additionally, an analyses of the stability criteria for the presence of diopside in EEC at high metamorphic temperatures is made and the circumstances under which diopside is stable with or without oldhamite is determined.

Analytical: Section EET90102,9 was studied with optical microscopy, SEM and electron probe microanalyses. EPMA conditions were 15 KeV and 25 nAmps. Standard ZAF reduction procedures were used.

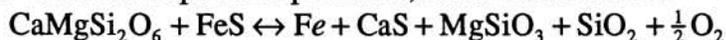
Results: EEC chondrites uniformly contain either no phases with birefringence higher than mid-first order or one highly birefringent phase which, if present, is always sinoite. Although the initial description of EET90102 reported the existence of one high birefringent phase, that report assumed that this phase was sinoite [3]. Close investigation of EET90102 for the current study found two high birefringent phases, which under SEM and EPMA, proved to be sinoite ($\text{Si}_2\text{N}_2\text{O}$) and diopside. This is the first report of the discovery of stable diopside in any EEC. Other than an important enstatite component in solid solution, EET90102 diopside, is reasonably pure, having very low abundances of minor elements. Diopside has notable quantities of Al_2O_3 (0.27 wt %), Na_2O (0.13 wt %) and FeO (0.23 wt %). Diopside is present texturally in anhedral-euhedral habits and is also present interstitially to enstatite in some relict radial pyroxene chondrules. Diopside is homogeneously distributed throughout the section, and modally makes up a bit over 1 volume % of the section .

Enstatite is the dominant phase in the rock making up ≈ 72 volume %. Enstatites have CaO contents (0.72 wt %) similar to that of other EL6 chondrites (0.74 wt %). Al_2O_3 contents (0.09 wt %) are lower than nominal EL6 chondrites (0.29 wt %). FeO contents (0.48 wt %) are somewhat higher than typical EL6 chondrites (0.18 wt %), although secondary fluorescence from Fe and FeS are hard to quantify and make FeO contents in E chondrite silicates, in general, maxima. TiO_2 , CrO, MnO, NiO and Na_2O are at or below detection consistent with nominal EL6 compositions.

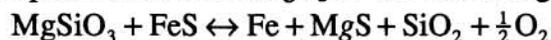
Kamacite is the dominant Fe-bearing phase comprising over 8 volume %. Kamacite Si-content is 0.75 wt % which is somewhat lower than that found in typical EL6 meteorites (1.1-1.4 wt %) but clearly not in the compositional range of EH metal (2.6-3.6 wt %). Ni contents (7.03 wt %) are also within the EL field (≈ 6.4 wt %). A noticeable difference between EET90102 metal and that of nominal EL6 metal is the high P contents (1.18 wt %) which is much higher than normal EL kamacite (0.13 wt %). Since schreibersite has yet to be found in EET90102, the high P contents of the metal can be explained by the lack of schreibersite precipitation in this rock.

Albite is also present, with an average composition of roughly $\text{Ab}_{83}\text{An}_{11}\text{Or}_6$. This is close to the nominal EL6 composition of $\text{Ab}_{81}\text{An}_{15}\text{Or}_4$. Albite is modally the second most abundant mineral present at about 11 volume %. Cr- and Ti-rich troilite is present in abundance (≈ 7 volume %) having variable Cr and Ti contents ranging up to 5 and 1.5 wt % respectively. Sinoite is also homogeneously distributed throughout EET90102 often forming in clusters of euhedral crystals. Sinoites are very pure except for an FeO concentration of ≈ 0.3 wt % .

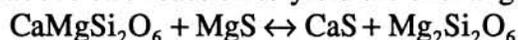
Diopside Stability: At metamorphic temperatures, the master reaction:



can be used to describe the stability of diopside within an E chondrite assemblage. Assuming close to unit activities of FeS, Fe, MgSiO₃ and the presence of a silica polymorph, the dominant control on the stability of diopside resides on the f_{O_2} of the assemblage. Similarly, the reaction:



establishes f_{O_2} as the dominant control on MgS stability. The calculated f_{O_2} of both reactions are very close to each other even considering dilution of MgS activity by FeS and MnS to make this reaction applicable to EL ferro-alabandites. If cubic sulfides are stable within an E chondrite assemblage, diopside can still be stable if the meteorites bulk composition falls within strictly defined phase fields. This bulk compositional control on diopside stability can be seen by taking a linear combination of the above two reaction to yield the exchange reaction:



thus, f_{O_2} is not the sole arbiter of diopside stability. The proper bulk compositions required to stabilize diopside in the presence of oldhamite can be seen in the quadrilateral CaMgSi₂O₆-Mg₂Si₂O₆-CaS-MgS (below) which has been constructed from two-pyroxene and two cubic sulfide phase stability data[5,6] and thermodynamic calculations on the stability of the above reaction. The exchange reaction is calculate to go to the right; however, if diopside is in excess of MgS a ternary field of diopside stability still exists and is nearly as big as that of the ternary niningerite stability field. The two stable ternary fields are diopside-enstatite-oldhamite and enstatite-oldhamite-niningerite; thus, *both* diopside and oldhamite can be present in the same E chondrite composition even under extreme reducing conditions. Addition of FeS and MgS to the above calculations deforms the phase fields somewhat but does not change the stability of the ternary fields. In fact, lowering MgS activity only serves to further stabilize diopside.

The appearance of diopside in EET90102 can be explained best by the bulk composition of this rock which lies slightly away from the nominal EL6 bulk compositions into the diopside-oldhamite-enstatite stability field. Nominal EL6 compositions are shown on the diagram by the stippled pattern. It is of importance to note the closeness of these nominal compositions to the ternary phase boundaries. Slight changes in bulk composition can easily result in the formation of stable diopside; thus, it seems in hindsight inevitable that a diopside-bearing EL6 chondrite would be found. Although CaS is not present in EET90102, the meteorite is weathered and contains an oxidized phase having tens of wt % CaO which I interpret as being comprised partially of weathered oldhamite. In light of these fact, the lack of diopside in previously discovered EL6 chondrites can be thought of as an artifact of poor sampling.

Classification of EET90102: In light of a) the mineralogical similarities of EET90102 to nominal EL6 compositions and b) the above phase equilibrium arguments for the stability of diopside in metamorphic E chondrites, it seems most logical to classify EET90102 as a diopside-bearing EL6 chondrite and not as a new E chondrite subgroup.

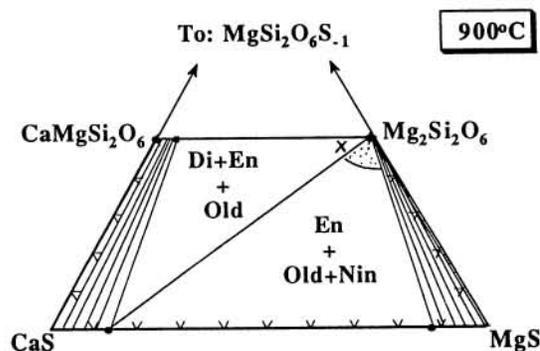


Fig. X=EET90102; Stippled=nominal EL6 bulk composition

REFERENCES & ACKNOWLEDGMENTS: [1] Dodd (1981) *Meteorites*; [2] Fogel et al (1989) *GCA* 53, 2735-2746; [3] *Ant. Met. New.* 15-2, 1-39; [4] Keil (1968) *JGR* 73, 6945-6976; [5] Davidson et al. (1988) *Am. Min.* 73, 1264-1266. [6] Skinner B.J. and Luce F.D. (1971) *Am. Min.* 56, 1269-1296.