Petrogenetic relationships between diogenites and olivine diogenites: Implications for magmatism on the HED parent body.

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Introduction: The howardites, eucrites, and diogenites constitute a suite of meteorite lithologies (HED) known to be related through O isotope systematics [1,2,3]. Many of them are believed to be remnants of an ancient and complex basaltic magma system on asteroid 4 Vesta [4,5,6,7]. The eucrites are pigeonite- and plagioclase-bearing basalts that represent surface or near-surface basaltic liquids or crystal accumulations from basaltic liquids. Diogenites are predominantly orthopyroxenites that represent very efficient subsurface accumulations of orthopyroxene (± olivine) from basaltic magmas. To a first approximation, howardites are two component brecciated mixtures of eucrites and diogenites. There are several distinctly different chemical-thermal models that have been proposed for the anatomy of the HED parent body and the petrogenetic relationship between its dominant magmatic components [i.e. 4,8,9,10,11,12,13,14,15].

Diogenites range in olivine from 0% to almost 50%. The orthopyroxenites with significant olivine have been referred to as olivine diogenites (greater than 5% olivine). Olivine-bearing diogenites have been loosely used to refer to diogenites with between 1 to 5% olivine. The proposed relationship among the diogenites range from being coupled in which all the diogenites represent accumulations of pyroxene ± olivine during crystallization of layered intrusive complexes or a magma ocean [13,14,15] to being uncoupled in which the diogenites represent pyroxene cumulates and the olivine diogenites represent HED parent body mantle from which eucritic melts were extracted. Pyroxene and olivine have experienced varying degrees of post-magmatic thermal metamorphism [i.e. 16,17].

Here, we use electron and ion microprobe data derived from orthopyroxene and olivine from diogenites with varying amounts of olivine to elucidate the metamorphic reequilibration between the two minerals and the petrogenetic relationship among the diogenites.

Analytical approach: Olivine-bearing diogenites (LAP03569, MET00424, MET01084), olivine diogenites (GRA98108, LAP03979), and diogenite clasts in a howardite (GRA98030) were analyzed in this pilot study. Olivine and orthopyroxene in these basaltic lithologies were first imaged and mapped by SEM followed by major element analysis using a JEOL JXA-8200 electron microprobe. A suite of trace elements were analyzed (Sc, V, Cr, Ti, Mn, Co, Ni, and Y) by previously documented analytical approaches [18] using a Cameca 4f ims ion microprobe. All instruments are housed in the Institute of Meteoritics at the University of New Mexico.

Results:

Abundance and distribution of olivine. In the samples studied, the modal abundance of olivine ranges from <1% to 20%. However, as shown for EETA79002, the distribution of olivine within each diogenite is very heterogeneous [19] and we anticipate that examination of additional thin sections will show a much more varied abundance of olivine in individual samples.

Major-Minor Elements. The chemical composition of olivine in the diogenites and howardite analyzed in this study exhibited limited variation within individual grains and between samples. The olivine compositions in the olivine diogenites range between Mg#=73-70, olivine-bearing diogenites between Mg# =73-63, and the diogenite clasts between Mg# 71-68. CaO ranged from .004 to .118 wt. % in our samples and appear not to be related to model abundance of olivine.

Fowler et al. [14,15] analyzed orthopyroxene from a suite of 21 diogenites using both electron and ion microprobes. Orthopyroxene from our data set and the data set produced by Fowler et al. [14] exhibits a range of Mg# from 81 to 66. The orthopyroxene in the olivine diogenites and olivine-bearing diogenites from our study ranged in composition from Mg# 77 to 68. The Ti and Al abundances in the orthopyroxene from these two data sets are shown in Fig. 1. The Al (wt.%) ranges from approximately 0.1 to 0.75% and is generally correlated with Ti (<0.01 to 0.2 wt%).

Trace Elements. While the Mg# of olivine in the diogenites exhibit very limited variation, Ni and Co in olivine exhibit significant differences among the diogenites and Ni-Co zoning is exhibited in several samples (Fig. 2). Nickel and Co ranges from 3-104 ppm and 10-126 ppm, respectively. Nickel and Co are strongly correlated within individual samples and among the diogenites. Olivine exhibiting textural characteristics indicative of substantial metamorphism and recrystallization exhibit no Ni or Co zoning. MnO ranges from 0.3 to 0.6 (wt.%) and generally exhibits a negative correlation with both Ni (Fig. 3) and Co. In the diogenites, thus far analyzed in this study, Ni, Co, and Mn in olivine appear not to be related to the model abundance of olivine in the diogenite lithologies.

Previous studies [11,14,15] illustrated that incompatible trace elements (Zr, Yb, Y) in orthopyroxene from diogenites exhibited a strong positive correlation with incompatible elements such as Ti (wt.%). In the orthopyroxenes, Y ranges from less than 0.1 ppm to 4 ppm, Yb ranges from less than 0.03 ppm to 0.7 ppm, and Zr ranges from less than 0.5 ppm to 10 ppm. The incompatible elements in the orthopyroxene exhibit little relationship to the model abundance of olivine.

Discussion: The overlap of olivine and orthopyroxene minor and trace element characteristics among the diogenites suggests that they represent a continuum rather than two distinct processes. The lack of correlation between Ni-Co and modal abundance of olivine is consistent with the observations of Bowman et al. [17,19] that the modal abundance of olivine in many samples is a product of small scale modal variations. The new data on the olivine from the diogenites does not allow us to distinguish between a magma ocean and crustal layered intrusion models for the origin of diogenites. However, <u>if</u> the calculated melt compositions extracted from the olivine data preserve a magmatic signature, they trace Ni-Co melt evolution from olivine diogenites to diogenites to eucrites (Fig. 4).

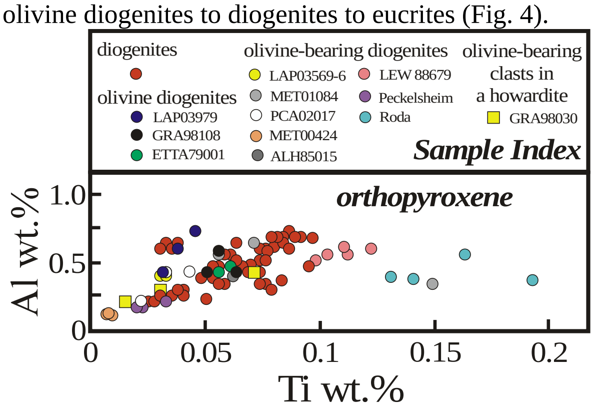

Fig. 1. Ti (wt.%) versus Al (wt.%) in orthopyroxene from diogenites (less than 1% olivine), olivine-bearing diogenites (between 1-5% olivine), olivine diogenites (greater than 5% olivine), and olivine-bearing howardites [11,14].

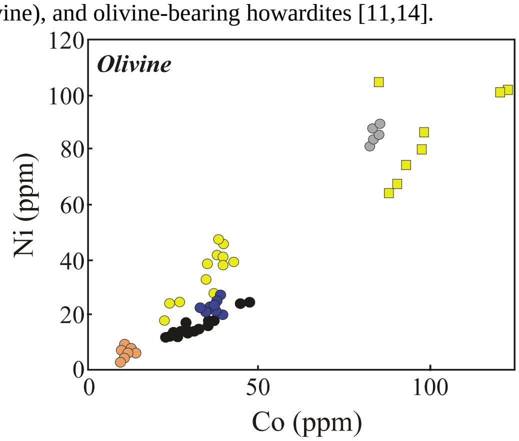

Fig. 2. Ni (ppm) versus Co (ppm) in olivine from olivine-bearing diogenites, olivine diogenites and olivine-bearing clasts in a howardite. Symbols are defined in Fig. 1**.**

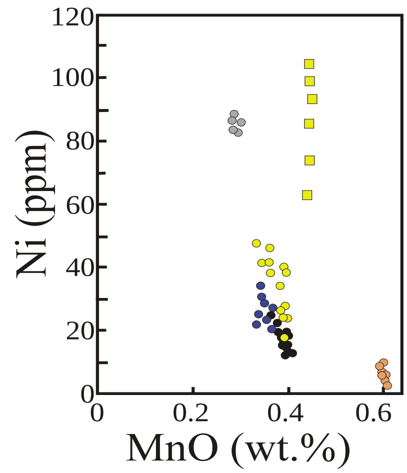

Fig. 3. Ni (ppm) versus MnO (wt.%) in olivine from olivine-bearing diogenites, olivine diogenites and olivine-bearing clasts in a howardite. Symbols are defined in Fig. 1.

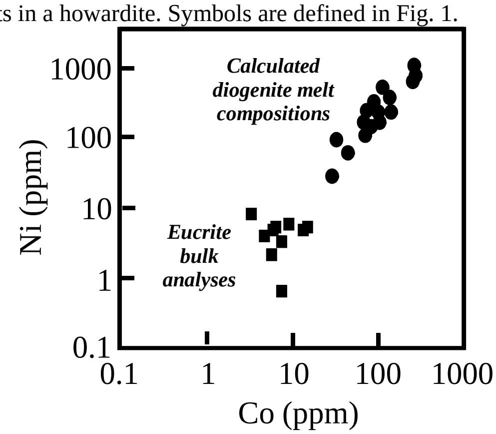

Fig. 4. Comparison between bulk eucrite compositions and calculated diogenite melt compositions.

References: [1] Clayton, R.N. and Mayeda, T.K. (1982) *LPS XIII, 117-118*. [2] Clayton, R.N. and Mayeda, T.K.. (1996) *GCA 60, 1999-2017*. [3] Clayton, R.N. (1993) *Ann. Rev. Earth Planet. Sci. 21, 115-149.* [4] Consolmagno, G.J. and Drake, M.J. (1977) *GCA 41, 1271-1282*. [5] Drake, M.J. (1979) In *Asteroids (eds. Gehrels and Matthews) 765-782*. [6] Binzel, R.P. and Xu, S. (1993) Science 260, 186-191. [7] Binzel, R.P. (1996) In *Workshop on the Evolution of Igneous Asteroids: Focus on Vesta and the HED Meteorites. (eds. Mittlefehldt and Papike) p. 2* [8] Mason, B. (1967) *GCA 31, 107-115.* [9] Stolper, E. (1977) *GCA 41, 587-611*. [10] Warren, P. (1985) *GCA 49, 577-586*. [11] Shearer et al. (1997) *MAPS 32, 877-889.* [12] Righter, K. and Drake, M.J. (1997) *MAPS 32, p. 929-939*. [13] Grove and Bartels (1992) Proc. *LPSC XXII, 437-445.* [14] Fowler et al., (1994) *GCA 58, 3921-3929.* [15] Fowler et al.. (1995*) GCA 59, 3071-3084*. [16] Mittlefehldt (1994) *GCA 58, 1537-1552*. [17] Bowman et al. (1999) *Am. Min. 84, 1020-1026*. [18] Shearer et al. (2006) *Am. Min. 91, 1657-1663*. [19] Bowman et al. (1997) *MAPS 32, 869-876.*