PETROLOGY OF MESOSIDERITE(?) MIL03443,9: CONSTRAINTS ON EUCRITE PARENT BODY BULK COMPOSITION AND MAGMATIC PROCESSES. M. J. Krawczynski[1] L. T. Elkins-Tanton[1] and T. L. Grove[1], [1]Massachsusetts Institute of Technology, Dept. of Earth, Atm. And Planetary Sciences. Cambridge, MA 02139 (kraw@mit.edu).

Introduction: Diogenites are part of the howardite-eucrite-diogenite (HED) meteorite family, and are thought to all originate on the same parent asteroid (possibly 4 Vesta). This family of achondrites preserves a record of the igneous processes that occurred during the differentiation of small planetesimals that were probably abundant in the first few millions of years of solar system history and that were ultimately assembled to form giant planets. Diogenites are typically orthopyroxenite cumulates, however in recent years a subset of diogenites that are olivine rich have been identified.

The olivine-diogenites are critically important to understanding the differentiation processes on the eucrite parent body (EPB), because olivine is expected to be the sole crystallizing phase for a significant portion of magma ocean cooling. Thus, these meteorites may represent the most primitive mantle material yet found in the HED class. Here we present petrographic analysis of MIL03443 (originally classified as a mesosiderite but with more affinity for, and hereafter referred to as an olivine-diogenite), as well as some preliminary modeling of bulk EPB compositions that will aid in future experimental exploration of the relationship between diogenites and eucrites and early EPB evolution.

Olivine-diogenite MIL03443: This 1.0 x 1.5 cm thin-section displays a monomict-breccia consisting of > 90 % olivine, along with chromite (~5 %) and orthopyroxene (opx) (< 2 %). Troilite is also a minor phase and occurs as amoeboidal grains and inclusions in both olivine and opx. There are also trace amounts of augite (Mg# 82.5) present as small blebs (1- 25 μm) that typically occur along olivine-opx grain boundaries. The olivine is unzoned and has a constant Mg# of 74.7. Chromite is mostly Cr# 77.5, however there is one Cr-rich chromite included in an olivine grain with a Cr# = 87.3 (similar to [1]). The largest olivine and chromite fragments in the breccia are ~ 1.5 x 2 mm.

Opx grains are compositionally uniform, up to 0.2 x 0.3 mm, unevenly distributed and when in contact with olivine they show an undulating boundary (Fig. 1). There is no clear evidence of a reaction overgrowth relation with olivine. The composition of the opx ($Wo_{3.1}En_{73.5}Fs_{21.5}$,Mg# = 77.4) in this olivine-diogenite places it among the most calcic samples found to date, but with similar En contents to other olivine-diogenites [1,2]. Two-pyroxene temperature estimates from Ca-Mg-Fe exchange using QUILF [3] give 1034 +/- 40 ^{o}C. Fe-Mg exchange equilibria between olivine and opx indicate a closure temperature of 885 +/- 12 ^{o}C.

Application to EPB differentiation: There have been several attempts made to estimate the bulk silicate composition of the EPB [4,5,6]. There is also evidence that the EPB underwent global scale melting early in its history [6,7]. Taking these estimates for bulk composition as the starting point for global magma ocean crystallization, we can evaluate which one best fits the petrologic evidence from MIL03443.

The first silicate phase to crystallize from an EPB magma ocean after metallic core segregation will be olivine. For each of the three bulk compositions discussed here, we show olivine fractionation paths in the pseudo-ternary projection Oliv-Plag-Qtz (Fig. 2A). We have carried out fractional crystallization calculations for olivine crystallization down to the point where the liquid would be in equilibrium with the olivine in MIL03443 ($Fo_{74.5}$). The bulk composition of Righter and Drake (R&D) [6] is very close to the inferred position of low-Ca pyroxene saturation [7] at this point and 53 % olivine crystallization has occurred (Fig. 2A). When the fractionation path for the Dreibus and Wänke (D&W) [3] EPB is extended to $Fo_{74.5}$, the liquid plots well into the opx primary phase. When the D&W composition crosses the olivine – low-Ca pyx boundary, the olivine is very magnesian ($Fo_{84.7}$, at 44% crystallized) and thus would produce an olivine-diogenite assemblage that is more magnesian than any represented in our meteorite collection. The composition of Morgan et al. [2] is far from olivine – low-Ca pyroxene saturation when it crystallizes $Fo_{74.5}$. If the fractionation calculation were continued until it reached olivine - low-Ca pyroxene saturation the residual liquid would be very Fe-rich, and would not produce an olivine diogenite similar to MIL03443.

The diogenite-eucrite link: The nature of the link between the diogenite and eucrite members of the HED group remains an unresolved and important problem. Our fractionation calculation show that the R&D EPB composition can produce olivine – opx saturated liquids that would crystallize a cumulate assemblage similar to that found in MIL03443. At this point the EPB magma ocean would be about 50 % solidified and the top of the olivine cumulate would be about 52 km from the surface of the magma ocean. At this depth continued solidification of the EPB magma ocean would involve orthopyroxene alone, and the residual liquids would evolve to the 1 atm olivine + pigeonite + plagioclase peritectic and the compositional field of the eucrites (Fig. 2B) as first noted by [7].

Other explanations for the formation of diogenites are that they represent crystallization of pyroxenitic melts that are unrelated to eucrites [8,9]. At present there seems to be no single stage differentiation process capable of explaining all of the petrologic complexity observed in the HED's. However, the physics of differentiation processes in small bodies at low gravity may provide insights into potentially new magmatic processes like cumulate overturn near the end stages of differentiation as has been predicted to occur in other small bodies [10].

We are currently experimentally investigating the crystallization of the fractionated liquid that represents 53% crystallization of the magma ocean of R&D. We will use these experiments to provide constraints on the last stages of EPB magma ocean differentiation and incorporate these constraints into a rigorous treatment that includes the magma physics (Elkins-Tanton et al., this mtg).

References: [1] Irving et al. (2005) *LPS XXXVI*, #2188. [2] Righter (2001) *LPS XXXIII*, #1765. [3] Andersen and Lindsley (1993) *Comp. Geosci., 19,* 1333-1350. [4] Morgan et al. (1978) *GCA, 42,* 27-38. [5] Dreibus and Wänke (1980) *Z. Naturforsch., 35a,* 204-216. [6] Righter and Drake (1997) *MAPS, 32,* 929-944. [7] Bartels and Grove (1991) *Proc. Lunar Planet. Sci., 21*, 351-365. [8] Stolper (1977) *GCA, 41,* 587-611. [9] Jurewicz et al. (1995) *GCA, 59,* 391-408. [10] Shearer et al. (2006) *Rev. in Mineral., 60,* p. 397-412.

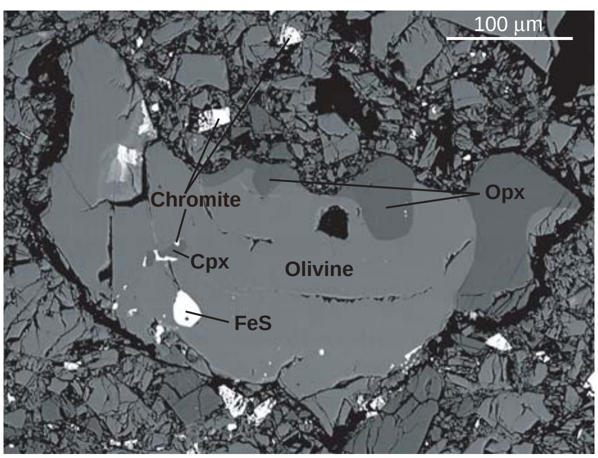

Figure 1: Backscattered electron image of olivine-diogenite MIL03443. Major phases are (in order of abundance in the thin section) olivine (light grey), chrome-spinel (white), and orthopyroxene (dark grey). The bright spots within the olivine and opx are sulfide inclusions. Notice the undulating boundary between the olivine and opx.

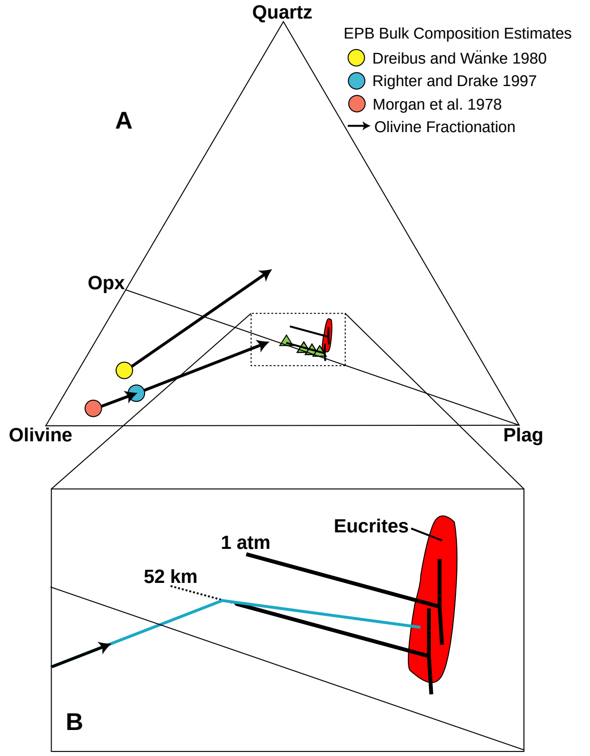

Figure 2: A) ternary projection through cpx that compares the early evolution of three different estimates for the bulk composition of the EPB. Fractionation calculations have been carried out on each composition until $Fo_{74.5}$ saturation. The composition of Righter and Drake (1997) closely approaches the 1 kilobar olivine – low-Ca pyx co-saturation of Bartels and Grove [7] (shown as green triangles). B) Expanded view showing the evolution of the post olivine-only stage in magma ocean crystallization. Boundary curves are the inferred reaction curve and peritectic at 52 km depth and at 1 atm [7].

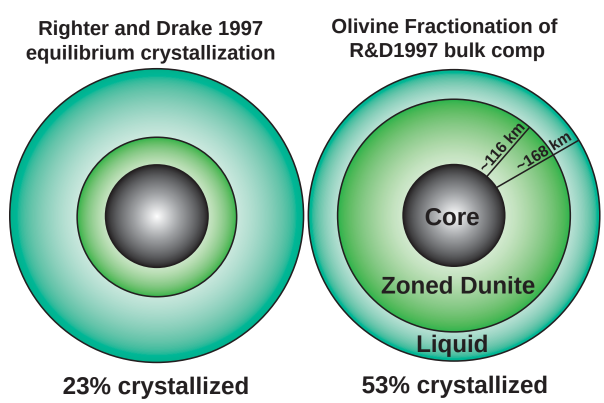

Figure 3: Cartoons of the extent of dunite cumulate piles formation expected in a whole 4 Vesta magma ocean. A) Righter and Drake [6] model B) our calculations of a R&D bulk composition.