Petrology and Geochemistry of Xenolithic Fragments in Elephant Moraine 79001. Kuehl E.C.[1,2], Castle N.[2], Jones J.H.[2], and Treiman A.H.[2] [1]Department of Earth and Planetary Sciences, Washington University in St. Louis, St. Louis, MO 63130 (ethan.kuehl@wustl.edu), [2]Lunar and Planetary Institute, USRA, 3600 Bay Area Blvd, Houston, TX 77058.

Introduction: The Elephant Moraine, EET 79001, meteorite is a shergottite (i.e., Martian) meteorite that includes lithic and mineral clasts that are distinct from the host basalt. Our goal is to investigate these clastic fragments, which are in Lithology A (Lith-A) of the meteorite — an olivine-phyric basalt with a fine-grained (~0.15 mm) pyroxene-plagioclase groundmass [1,2]. The olivine megacrysts and olivine ± orthopyroxene lithic clasts (both 0.5-3.3 mm) are believed to be xenolithic in origin [1-3,5] and have been earlier labeled as Lithology X [3].

Earlier work on these xenolithic materials have focused only on a few fragments [1-5], and there has been no attempt at a complete description of the xenolithic suite. In this study we present major and minor element compositions and zoning of olivine megacrysts and lithic clasts. The goal of this study is to constrain the origin of lithology X and to evaluate whether the collection of olivine megacrysts and xenolith clasts originate from a single source lithology.

Methods: Five thin sections of EET 79001A (68, 453, 494, 555, and 556) were obtained from Curation at the Johnson Space Center (JSC). Optical microscopy was used to identify xenocrysts and clasts within the thin sections. Backscatter electron (BSE) images were acquired using a JEOL Scanning Electron Microscope (SEM).

Mineral and glass compositions were determined using electron microprobe analysis (EMPA) on both a Cameca SX-100 and a JEOL 8530F at JSC by wavelength-dispersive spectroscopy (WDS). EMPA was calibrated using well-characterized mineral standards. Olivine, pyroxene, and spinel were analyzed using a 20 keV accelerating voltage with a 20-30 nA current and a ~1 µm beam diameter. Feldspar composition glasses (maskelynite) were analyzed using a 15 keV accelerating voltage with a 10 nA current and a 5 µm beam diameter.

Results: Analysis of 19 olivine megacrysts and 4 olivines in lithic clasts shows that the two populations are distinct. Among the four lithic clasts analyzed, two are distinctive: (i) the first (L2 of Table 1) contains a major-element-equilibrated, euhedral ~200µm olivine grain; and (ii) the second (L3 of Table 1) contains high-magnesium, low-Ca, pyroxene cores. Two populations of anhedral, ferroan olivine megacrysts were also identified: (i) one that is more ferroan (N3 of Table 1) than any other olivine found in EET 79001; and (ii) a slightly less ferroan (N2 of Table 1), unequilibrated olivine, but with a restricted Mg# and distinctive morphology.

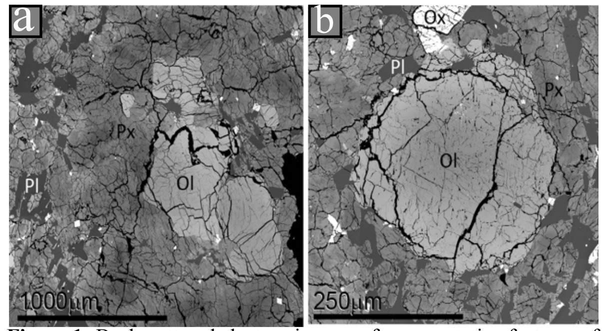

Figure 1: Backscattered electron images of representative features of EET 79001. a) Xenocryst of olivine & low-Ca pyroxene in lithology A (Lithology L1). b) Olivine megacryst in Lithology A (Lithology M1). Symbols: Pl - plagioclase; Px – low-Ca pyroxene; Ol - olivine; Ox - oxide, likely chromite.

The pyroxenes in the lithic clasts are distinct from those in the Lith-A groundmass in being more magnesian (Mg# 56.2-86.6 versus 43.7-73.1) and in having different zoning patterns in both BSE images and optical microscopy. Based on optical microscopy, the lithic clast pyroxenes may be sector-zoned, whereas the groundmass pyroxenes are normally zoned with a quench texture that suggests rapid growth of the pyroxene [6]. Among the xenolithic pyroxenes, one grain is distinctive – an equilibrated pyroxene grain partially enclosed in a zoned olivine megacryst (N1). This association of a zoned olivine and an unzoned pyroxene suggests a complex petrogenesis, since cation diffusion in pyroxene is significantly slower than in olivine [7].

Discussion:

Relations to Lithology A. The xenoliths and megacrysts are not cognate (i.e., early phenocrysts and glomerocrysts) with their host Lith-A. The olivine megacrysts have sharp contacts and chemical contrasts with the Lith-A groundmass, suggesting that the megacrysts were not in equilibrium with the Lith-A magma. A hypothetical liquidus olivine grown from the Lithology A groundmass would have had Mg# ~70, but most of the olivine xenocrysts have Mg# much lower than that (Fig. 3). Either the parent liquids of these olivines were more ferroan than the Lith-A liquid, or there has been extensive subsolidus modification.

Similarly, pyroxenes in the xenolith clasts are not in chemical equilibrium with those of the Lithology A groundmass. The lithic clasts' pyroxene cores are more magnesian than the groundmass pyroxene cores, implying that the clast pyroxenes did not originate from the same melts as the groundmass.

Table 1: Varieties of lithic clasts and megacrysts in EETA79001 Lithology A.

Name	Type	Olivine	Pyroxene	Petrographic notes
		Mg#	Mg#	
M1	Mega	47.5-78.6	N/A	Dominant megacryst population
L1	Clast	60.3-69.5	42.7-84.2	Dominant lithic clast population (88 L1; 556 L1)
L2	Clast	61.3-63.9	56.2-82.0	Euhedral equilibrated olivine (453 L1)
L3	Clast	61.9-68.3	59.5-86.6	Magnesian pyroxene cores (68 L1)
N1	Other	51.8-68.5*	57.1-59.2	Equilibrated pyroxene inclusion (453 Px1)
N2	Other	51.2-57.1	N/A	Ferroan olivine rim population (494 Fa1)
N3	Other	40.7-44.9	N/A	Ferroan olivine population (555 Fa1)

N/A = “not applicable

* This olivine hosts the equilibrated pyroxene.

Multiple Lithologies. The chemical compositions of minerals in the megacryst and clasts suggest they represent seven lithologies (Table 1). The six groups of olivine each represent a separate lithology with distinctive crystal shapes and ranges in Mg# (Fig. 3). The olivine megacryst populations (M1, N2, N3) all are out of Fe-Mg equilibrium with lith-A groundmass pyroxenes. The lithic clasts show a range of textural relationships between their olivines and pyroxenes. Two of the lithic clast populations (L1, L2) contain similar pyroxene compositions, while the third (L3) has more magnesian cores.

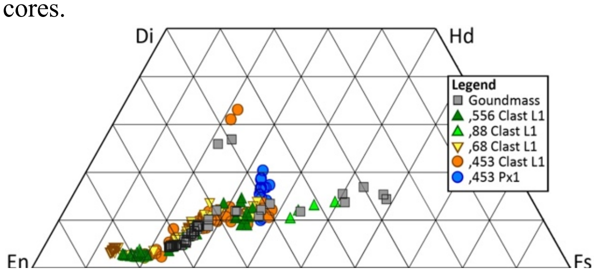

Figure 2: Pyroxene major element compositions. Symbols are: gray squares - Lithology A groundmass; green triangles - Lithology L1, the most common clast type; orange circles - Lithology L2, as in lithic clast 453 L1; yellow triangles - Lithology L3, as in lithic clast 68 L1; blue circles - Lithology N1 as in pyroxene 453 Px1.

Again, a unique fragment N1 is a single equilibrated pyroxene grain included in an olivine grain; rather than enclosing olivine as in L clasts. Also, unlike the other lithic clast pyroxene population, the N1 olivine is in direct contact with the Lith-A groundmass and has a composition more like olivine of the megacrysts than of olivines in the lithic clasts. Because of these differences, N1 is categorized by itself.

Implications: Compositions of pyroxenes and olivines in the EETA 79001A xenolithic matter demonstrate a more complex history for the meteorite than previously understood. Its megacrysts and xenoliths were not derived from a single protolith, but from several protoliths with distinct ranges of mineral compositions. From the ranges in mineral composition, one can infer that either the protoliths came from many different

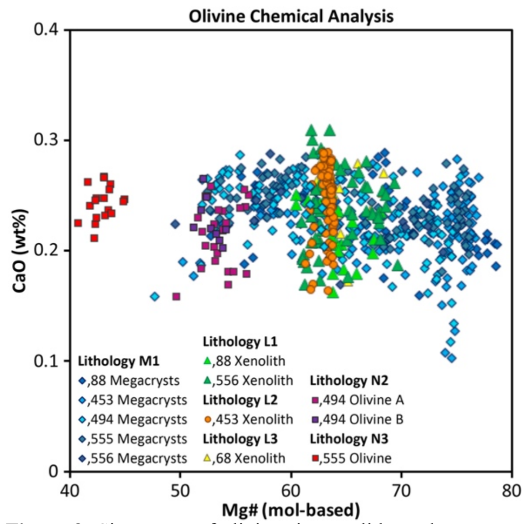

Figure 3: Six groups of olivines in xenoliths and megacrysts, based on olivine composition and morphology.

magmatic sources, or from fewer sources but with differences in time-temperature histories.

From their mineral compositions, the olivine megacrysts are clearly not merely grains broken from lithic clasts, i.e., differing degrees of disaggregation of a single source rock. Rather, it appears that the difference in mineral modes of these two populations represents different source lithologies. The olivine megacrysts likely represent an olivine-dominated lithologies, like dunites. The lithic clasts, with sub-equal proportions of low-Ca pyroxene and olivine, are consistent with source lithologies of harzburgite or olivine-pyroxenite. The fact that pyroxenes in the xenoliths are chemically zoned (except for the unique N1 pyroxene grain) suggests limited time-at-temperature, i.e. not originating in Mars’ mantle. If the Lithology X suite is indeed from within the Martian crust, it is reasonable that it could represent cumulates from earlier magmatism in the same system as the Lithology A host liquid. The presence of maskelynite in these xenoliths implies that they (and possibly also the olivine megacrysts) formed within the stability field of plagioclase peridotite (i.e., <10 kbar), which corroborates a crustal origin, rather than derivation from the Martian mantle.

The absence of basaltic clasts within Lithology X suggests that there are ultramafic components within the Martian crust.

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