

NEW CONSTRAINTS ON THE FORMATION OF SHERGOTTITE EET 79001 LITHOLOGY A. L. A. Taylor¹, Y. Liu¹, J. B. Balta¹, C. A. Goodrich², and H.Y. McSween, Jr.¹ ¹Planetary Geosciences Institute, Department of Earth & Planetary Sciences, University of Tennessee, Knoxville, TN 37996, yangl@utk.edu, ²Planetary Science Institute, 1700 E. Ft. Lowell, Tucson, AZ 85719.

Introduction: The origin of Elephant Moraine (EET) 79001 has been an intriguing topic since its identification as a martian meteorite [1-11]. EET 79001 contains two lithologies, an olivine-phyric portion (EET-A) and a basaltic portion (EET-B), in an apparent igneous contact [2]. Several models have been proposed for the formation of EET 79001, including magma mixing, assimilation and fractional crystallization, fractional crystallization, and mixing after impact melting [1-11]. Here we report new constraints on the petrogenesis of EET-A based on the occurrence of disequilibrium orthopyroxene and olivine, and trace-element contents in olivine-hosted melt inclusions.

Samples and Methods: Three new sections of EET-A (524, 525, and 554) were provided by the Meteorite Working Group for this study. Mineral and glass compositions were analyzed and elemental X-ray maps of melt inclusions and olivines were obtained using a Cameca SX-100 electron microprobe.

Trace-element contents of melt inclusions were obtained using a New Wave Research UP213 (213 nm) Nd:YAG laser-ablation system, coupled to a ThermoFinnigan Element 2 inductively coupled plasma-mass spectrometer at the University of Notre Dame.

Results: Textures and mineral compositions of sections 524 and 554 are similar to those reported in previous studies. Large crystals in EET-A are herein referred to as megacrysts, a term without any petrogeologic implication.

Mineral inclusions. Round orthopyroxene inclusions (Mg# = 81 to 77) included in olivines of (Mg# = 73 to 68) are a common feature in sections studied here and other sections in Goodrich [7] (Fig. 1). The orthopyroxene inclusions are too Mg-rich to be in equilibrium with the olivine hosts, using $K_{D,Ol-lcpx}^{Fe-Mg} = 1.1-1.2$ [12, 13].

Pyroxene associations. Orthopyroxene appears as irregular patches mantled by pigeonite (Fig. 2), also noted by Goodrich [7]. The Al_2O_3 -Mg# and Cr_2O_3 -Mg# variations of orthopyroxene cores form a tight, vertical trend, which is different from pigeonite mantles and groundmass pyroxenes [7].

Trace-element contents of "melt" inclusions. "Melt" inclusions in sections 524 and 525 only appear in olivines of Mg# ≤ 75 , a similar feature (Mg# <77) noted for other sections [8]. Average REE abundances of four melt inclusions in olivine of Mg# 75-61 in EET-A are $\sim 1.4\times - 2.6\times$ higher than EET-A whole-rock, but are similar to those of EET-B whole-rock

(Fig. 3). The enriched REE in melt inclusions cannot be explained by addition the observed amount of Mg-rich olivine and orthopyroxene in EET-A, nor removal of late-stage melt. Owing to the limited number of inclusions analyzed, the average melt inclusion may overestimate the parent melt.

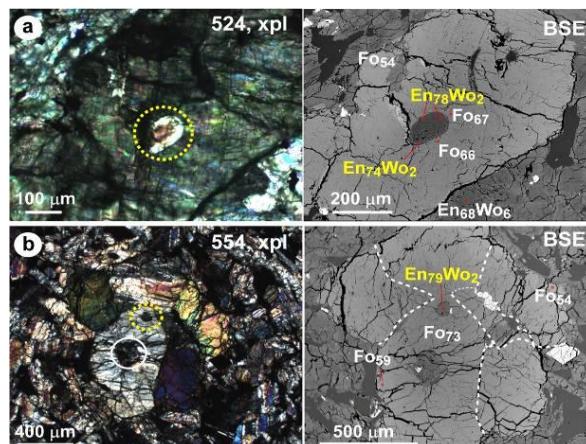


Fig. 1. Cross-polarized light (xpl) and back-scattered electron (BSE) images of orthopyroxene and olivine inclusions in olivines in EET-A sections 524 and 554. Yellow circles highlight the mineral inclusions, and the white circle identifies a melt inclusion. Compositions of olivine and inclusions are listed on the BSE images.

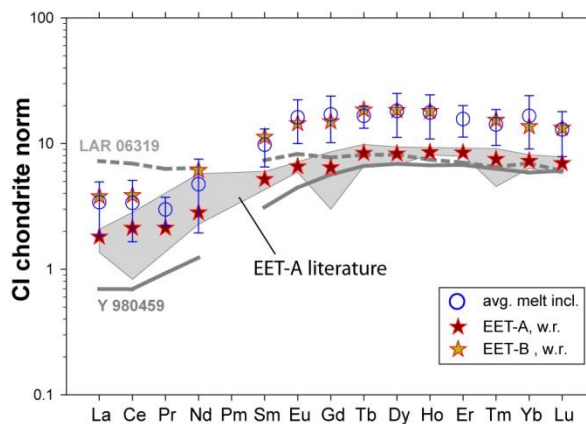


Fig. 2. CI-chondrite normalized REE of average melt inclusions (circles) compared to whole rock values of EET-A (stars) and olivine-phyric shergottite Y-980459 (gray line). The gray field plots whole-rock compositions of EET-A in the literature (from Mars Sample Compendium, 2003).

Discussion:

Definition of xenocrysts and implications. A major source of uncertainty in all petrogenetic models for EET-A is whether the large olivine and pyroxene megacrysts are phenocrysts or xenocrysts. Early studies regarded all megacrysts in EET-A as xenocrysts [1, 2]. Later studies showed that not all megacrysts are xenocrystic [7, 8]. Our observation of round orthopyroxene inclusions in non-equilibrium olivine hosts strengthens the argument that *the only xenocrystic pyroxene is orthopyroxene with Mg# >77* [7, 8]. The difference between [7] and [8] is whether all olivine are xenocrysts. Trace-element contents of melt inclusions in olivines of Mg# <76 concur with the definition of Goodrich [8] that olivines with Mg# ≥ 77 are xenocrystic.

However, the wide-occurrence of xenocrystic orthopyroxene as inclusions in olivine (Fig. 1) indicates that orthopyroxene kept dissolving when olivine crystallized from Mg# of 77 to 73. This differs significantly from previous studies implying simultaneous crystallization of phenocrystic olivine and pyroxene.

Source of xenocrysts. The source of xenocrystic olivine and orthopyroxene was previously suggested to be similar to lherzolitic shergottites such as ALHA 77005 and LEW 88516 [2, 3, 5, 6]. However, xenocrystic olivine and orthopyroxene in EET-A are more Mg-rich than any lherzolitic shergottites studied to date. This includes most other olivine-phyric shergottites, except for Y-980459 that contains Mg# ≤ 85 olivines. Consequently, EET-A xenocrysts could be derived from a magma similar to Y-980459, a primitive melt that is highly depleted in incompatible elements [14]. This conclusion also fits the prediction of Mittlefehldt et al. [6] in that the source for xenocrysts needs to be a melt highly depleted in incompatible elements.

High-P crystallization. The phase diagram of basalts at low P (<1 GPa) contains a reaction curve between olivine and pyroxene. Cooling and crystallization of a basaltic melt first produce olivine. Once the melt has reached the reaction curve, early-crystallized olivine is resorbed to form low-Ca pyroxenes (orthopyroxene or pigeonite), generating anhedral olivines and euhedral pyroxenes, commonly with olivines being encased by pyroxenes. The olivine stability field shrinks with increasing P. At ~1.2 GPa or higher for martian basalts (e.g., [15]), olivine and low-Ca pyroxene crystallize together from the basaltic melt.

Several lines of evidence suggest high-pressure conditions for EET-A. First, Mg-rich olivines have never been reported as inclusions in Mg-rich pyroxenes in EET-A. A feature typifies the low-P crystallization. Second, all EET-A sections studied to date only contain 7-12 vol% olivines, substantially lower

than the 26 vol% olivines calculated by thermodynamic modeling at 0.1 MPa using the EET-A whole-rock composition [12]. Third, if the incorporation of xenocrysts occurred at low pressure, we would expect EET-A to contain more xenocrystic olivine than pyroxene, as pyroxene is the first one to be consumed during heating and partial melting. However, two sections from the present study contain 0 and 1.9 vol% xenocrystic olivines, and 1.0 and 0.3 vol% xenocrystic orthopyroxenes, resp. These observations suggest that the abundance of xenocrystic orthopyroxene is likely comparable to xenocrystic olivine.

Several approaches were used to estimate the crystallization the pressure of EET-A. If we assume the olivine of Mg# ~77 was in equilibrium with the whole-rock, the $K_{D,ol-liq}^{Fe-Mg}$ (0.44) would imply pressures >1 GPa, according to the trend reported in Toplis [16]. The orthopyroxene-pigeonite pair in the pyroxene megacryst can be used to infer pressures of crystallization. However, the two-pyroxene thermobarometers were developed for high-Ca clinopyroxenes. With this in mind, the orthopyroxene-clinopyroxene thermometers and barometer (Eqn. 39) of Putirka [17] are applied to a neighboring orthopyroxene-pigeonite pair in the pyroxene megacryst. The Fe/Mg value between orthopyroxene and pigeonite in this pair (1.19) suggest that they are equilibrium with each other (1.09 ± 0.14 , [17]). Therefore, T and P can be estimated using the orthopyroxene and pigeonite pair, giving values of 1152-1229 °C and 0.83-1.2 GPa. The augite and pigeonite in groundmass pyroxenes are also used to constrain T and P but at a later stage of crystallization. Using the method of Lindsley (1983), we obtained ~1200 °C and ~1 GPa for the coexisting augite and pigeonite. These results suggest that the formation of phenocrystic olivine and pyroxene probably occurred at pressures near the co-saturation of olivine and orthopyroxene – i.e., high-P.

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