Elephant Moraine 87521: two pyroxenes, two chromites, and two ilmenites, but only one fractionation series. J. S. Boesenberg[1, 2] and J. S. Delaney[1], [1]Geological Sciences, Rutgers University, 610 Taylor Road, Piscataway, NJ 08854, [2]Earth and Planetary Sciences, American Museum of Natural History, Central Park West, New York, NY 10024, bosenbrg@amnh.org.

Introduction: Elephant Moraine (EET) 87521 is a polymict mare basalt breccia containing very-low-titanium (VLT) basalt components and rarer KREEP components. [1] showed that within pyroxene from VLT lithic clasts of EET87521, there were two distinct trends in a plot of Ti/(Ti+Cr) versus Fe/(Fe+Mg) (Figure 1). They suggested that the two fractionation trends (A and B) were the result of different VLT lavas that had different original Ti/(Ti+Cr) and/or Fe/(Fe+Mg) ratios. They further suggested the two lavas may derive from the same source magma and simply experienced different degrees of olivine fractionation. [2] arrived at a similar conclusion that EET87521 pyroxenes represent two separate magmas based on their REE and major element compositions.

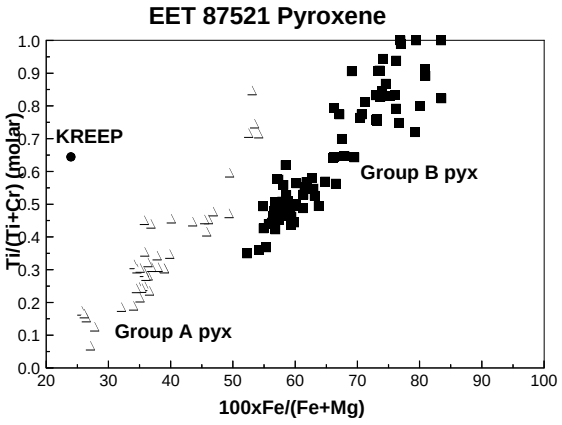

Figure 1: VLT lithic clast pyroxene from EET87521 showing two subparallel trends in a plot of Ti/(Ti+Cr) vs. Fe/(Fe+Mg). Note: KREEPy pyroxene appear to plot separately from the A and B trends [1].

We analyze here spinel (chromite and ulvospinel) and ilmenite and re-examine the petrologic setting, compositional variation, and crystallization pathways of the pyroxene to determine whether these co-existing phases support a two magma hypothesis.

Analysis: Nine NASA/JSC polished thin sections of EET87521 (-8,-57,-58,-59,-60,-62,-63,-64,-67) were analyzed by the Cameca SX-100 electron microprobe at AMNH.

Results: EET87521 contains two trends/populations of pyroxene that were discussed previously [1]. During this re-examination, spinels and ilmenites were analyzed. Based on plots of Ti/(Ti+Cr) versus Fe/(Fe+Mg) (from hereon referred to as TTC and FFM), the spinels consist of TWO populations of *chromites* and one population of ulvospinels. Although spinels were reported on by [3] for EET987521, they did not see the trend because only a single thin section (-55) was analyzed. The chromites mimic the pyroxenes in having different crystallization trends; however they display curves rather than linear trends. Chromites in trend A (7 of 37 grains) have FFM values of 61 to 84 and TTC values of 0.02 to 0.35 (filled green circles), while chromites (8 of 37 grains) and ulvospinels (22 of 37 grains) in trend B have FFM values of 83 to 100 and TTC values of 0.04 to 1 (empty green circles). The ulvospinels are associated only with the second population of chromites, not the first. There are also TWO populations of *ilmenites* (Fig. 2) present in EET87521. The ilmenite populations can be separated by their FFM contents, with an unusual Mg-rich group (4.5 wt% MgO) and a "normal" Fe-rich group. Of the 78 ilmenites analyzed, 5 were Mg-rich.

Discussion: The crystallization of EET87521 is best explained as a single, continuous fractionation series, rather than two separate fractionation series. First, there are no group A pyroxenes or spinels with values approaching 1. Two, there is no separation in FFM between the end of group A (pyroxene or chromite) and beginning of group B (pyroxene or chromite, respectively). The FFM ratios are continuous with only the TTC ratios varying. Three, despite claims by [1] that VLT magmas are "particularly unlikely candidates to precipitate Ti-rich oxides" or ilmenites are "extremely unlikely to enter the fractionation sequence", there are, in fact, ilmenites present in EET87521 that DID enter the fractionation sequence and DO influence the TTC ratio of the pyroxene (and chromite). Four, there are no ilmenites

(Mg-rich or normal) or ulvospinels found in intimate association with group A clasts. All of the ilmenites and ulvospinels are associated with the group B clasts or Fe-rich glass. Finally, based on an estimate of Fe-Mg partitioning, the Mg-rich ilmenites are in near equilibrium with pyroxene having FFM values of 53.

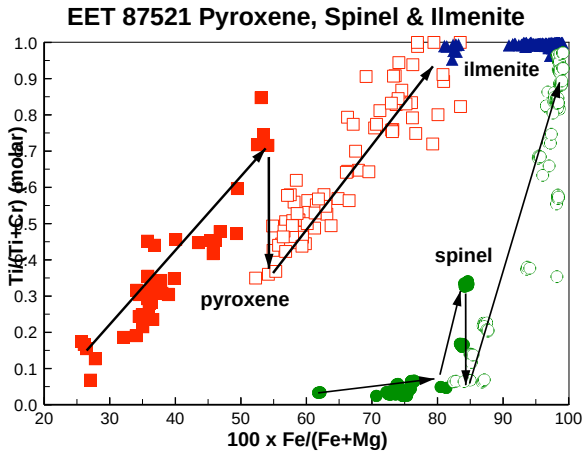

Figure 2. Ti/(Ti+Cr) versus Fe/(Fe+Mg) plot showing fractionation trends of pyroxene (red), spinel (green) and ilmenite (blue). Pyroxene and spinel co-crystallize throughout the sequence but are briefly interrupted by a Mg-ilmenite which drastically reduces their Ti abundances. The final ulvospinels and ilmenites are typical late stage lunar differentiates.

In the envisioned fractionation of EET87521, pyroxene (filled red squares) co-crystallized with chromite (filled green circles) until the pyroxene approached its maximum TTC value of ~0.85. [Fe/Mn systematics actually indicate multiple phase saturation of the liquidus by feldspar, olivine, pyroxene, and spinel]. At this point, formation of the early Mg-rich ilmenite (FFM~82, Fig 2) briefly replaced chromite as the liquidus oxide phase and drastically depleted the parent melt of Ti. Thus, newly crystallizing pyroxene, FFM~52, only had TTC values of ~0.35. Additionally, once chromite (FFM~ 82) re-emerged as the co-crystallizing phase, its TTC value had also decreased, from 0.32 to 0.06. The final crystallization sequence occurred as pyroxene (open red squares) plus chromite (open green circles) crystallized and was soon replaced by pyroxene plus ilmenite, and finally pyroxene plus ilmenite plus ulvospinel. The break in composition between chromite and ulvospinel is caused by a miscibility gap between ~900 and >1000°C in the $FeCr_2O_4$-Fe_2TiO_4-$FeAl_2O_4$ ternary. Although the Luna 24 VLT soils have spinel trends encompassing the full range of compositions as those seen here, EET87521 appears to have the longest continuous pyroxene and spinel fractionation trends seen in any individual VLT basalt.

The only VLT basalts discovered so far are either meteorites or soil samples from the Apollo 17 and Luna 24 sites. Thus, their origin and geologic setting largely remain a mystery. The significance of VLT basalts occurring in an otherwise hi-Ti locality (A17) leaves open the possibility for the genesis of VLT from a Hi-Ti basalt source. One possibility of producing VLTs is by a density driven separation, where the relatively MgO-rich, olivine-rich, VLT basalt differentiates and floats upon the Fe-rich, high ilmenite, Hi-Ti basaltic magma, before being erupted. Although initially counter-intuitive, olivine bearing VLT basalts such as EET87521 have mid-range olivine compositions which are capable of floatation [4], particularly upon a dense ilmenite dominated magma. An explanation for the large diversity of basaltic compositions thus might be possible from a common source.

Finally, since EET87521 contains unique compositional trends in pyroxene, spinel and ilmenite, confirmation of the pairing with EET96008 based on petrologic characteristics should now be possible.

References: [1] Boesenberg J. S. and Delaney J. S. (1992) LPSC XXIII, 127-128. [2] Arai T., Shimoda H., Kita N. and Morishita Y. (2005) NIPR XXIX, 1-2. [3] Arai T., Takeda H. and Warren P.H. (1996) MaPS 31, 877-892. [4] Herzberg C. T., Baker B. B., and Wendlandt R. F. (1982) Contrib Mineral Petrol 80, 319-323.