PETROLOGY OF LUNAR UNBRECCIATED MARE BASALTIC METEORITES NORTHEAST AFRICA 039 AND NORTHWEST AFRICA 16286. J. S. Boesenberg[1] and A. J. Irving[2], [1]Dept of Earth, Environmental and Planetary Sciences, Brown University, 324 Brook Street, Providence, RI 02920 (joseph_boesenberg@brown.edu). [2]Dept. of Earth & Space Sciences, University of Washington, Seattle, WA.

Introduction: Lunar mare basalts constitute roughly 16% of the lunar surface [1]. Low-Ti mare basalts are the most common based on orbital reconnaissance mission data [2], representing roughly 80% of the mare basalts [3]. The large compositional range of Ti found in mare basalts is thought to mostly reflect the compositional heterogeneity within the upper-mantle cumulate source regions, as well as more complex magmatic processes within the Moon [4]. Here we describe and investigate two recently recovered low-Ti, unbrecciated mare basaltic meteorites, Northeast Africa (NEA) 039 and Northwest Africa (NWA) 16286, and compare them to the low-Ti Apollo 12, 14 and 15 samples, the Luna 16 samples, and other low-Ti lunar mare basaltic meteorites.

Results: The two basaltic meteorites are different in appearance and have very different grain sizes (Fig. 1 and 2). NEA 039 has an ophitic igneous texture, composed of stubby ~0.5 mm prismatic grains of zoned olivine (Fa $_{34.4-64.3}$, FeO/MnO = 78-106) (Fig. 3) and pigeonite (range: Wo $_{9.8-20.0}$ Fs$_{29.3-84.0}$, FeO/MnO = 43-86), subcalcic augite (range: Wo $_{20.1-34.5}$ Fs $_{23.3-77.1}$, FeO/MnO = 46-91), and augite (range: Wo $_{35.0-37.6}$ Fs $_{22.1-25.1}$, FeO/MnO = 48-55) (Fig 4). All plagioclase has been converted to maskelynite (An $_{84.8-90.4}$ Or $_{0.2-0.7}$) laths (up to 1 mm long). Accessory phases include blade-like ilmenite, low-Ti chromite, ulvöspinel (Fig. 5), troilite, fayalite, and a silica polymorph. Shock pockets composed of "swirly" glass plus some thin cross-cutting shock veinlets are present. Also within NEA 039 are a series of microfractures. The largest one found, with a pronounced convex down shape, can be seen in the bottom half of Fig 1. Obviously generated post-crystallization and cooling, they show offsets in both strike-slip, as well as, thrust motion directions. It appears impact processes have assisted in the rotation of some fragments relative to one another.

NWA 16286 is an olivine-phyric basalt composed of zoned subhedral olivine (Fa $_{42.1-60.7}$, FeO/MnO = 90-114) (Fig. 3) phenocrysts (up to 0.3 mm long), smaller, zoned, anhedral clinopyroxene grains composed of pigeonite (range: Wo $_{12.4-19.6}$ Fs $_{39.7-81.7}$, FeO/MnO = 55-90); subcalcic augite (range: Wo $_{20.2-35.0}$ Fs $_{24.3-71.2}$, FeO/MnO = 48-83) and augite (range: Wo $_{35.1-40.9}$ Fs $_{22.0-39.4}$, FeO/MnO = 54-72) (mean size ~0.2 mm) (Fig. 4) accompanied by thin laths of maskelynite (An $_{73.3-80.4}$ Or $_{0.7-3.0}$) (mean length ~0.2 mm) plus accessory acicular ilmenite, high-Ti chromite (Fig. 5) and interstitial glassy mesostasis with quench crystallites. All plagioclase in NWA 16286 has also been converted to maskelynite.

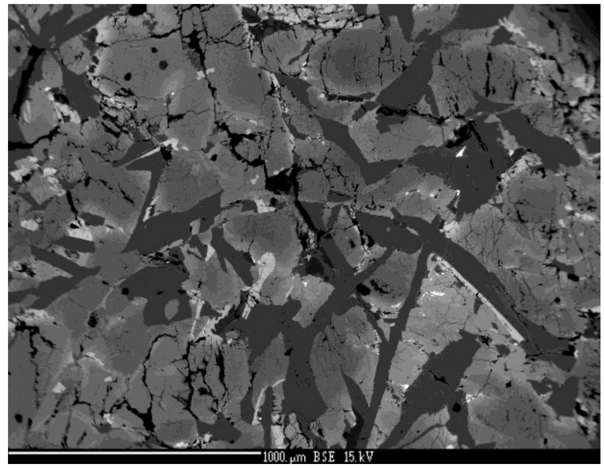

Figure 1: Backscattered electron image of NEA 039 with dark maskelynite, medium gray zoned olivine and pigeonite, bright ilmenite, ulvöspinel, and chromite. There are also a half dozen microfaults within the image that show offsets both in strike and slip directions.

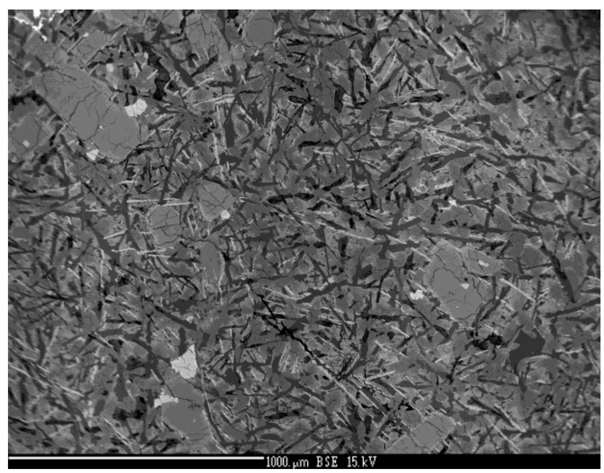

Figure 2: Backscattered electron image of NWA 16286 with dark maskelynite, dark to medium gray zoned olivine and cloinopyroxene, bright acicular ilmenite, and bright, but more equant-shaped, chromite. Note the dramatic grain size difference with NEA 039 in Fig.1.

Discussion: NEA 039 and NWA 16286 both appear to represent single fractionation sequences, similar to those documented in the Apollo 12 basalts. However neither meteorite contains the very low-Ca, Mg-rich pigeonite measured in some of the Apollo low-Ti basalts (Fig. 4). NEA 039 is more Mg-rich, relative to NWA 16286, but is more Ca- and Ti-poor. NEA 039 contains approximately half the Ti concentration of NWA 16286 (estimated ~1.5 vs ~3 wt% TiO2). The two basalts can be related to one another primarily through olivine fractionation. With both basalts containing <5 wt% TiO2, both could easily have formed by partial melting of olivine and orthopyroxene cumulates, as was demonstrated experimentally by [7].

Based on the pyroxene quadrilateral distribution of analyses and published analyses of olivine and pyroxene, NEA 039 appears to be remarkably similar to NWA 4734, and to lesser degrees, LAP 02205 (and its pairings) and NWA 032. All three meteorites show dominant pyroxene compositions that run along the ~Fs_{40} tie line joining pigeonite, through subcalcic augite into augite. Like NEA 039, both NWA 4734 and LAP also trend into more Fe-rich subcalcic augite [8].

NWA 16286 does not appear to have an obvious match among the other 20 known lunar basalt meteorites, though NWA 14526 and NWA 14137 certainly appear close. Both NWA 14526 and NWA 14137 have similar TiO_2 concentrations (14526: TiO_2 4.1 wt% and 14137: TiO_2 2.7 wt%), but contain more Fe-rich olivine (14526: Fa $_{60+/-16}$, 14137: Fa $_{57+/-21}$, respectively) than NWA 16286. These three specimens also have only partial overlapping pyroxene compositional ranges. NWA 16286 has pyroxene compositions that trend into Fe-rich pigeonite (Fig. 4), whereas the others, at present, appear to have a restricted range to more Mg-rich subcalcic augite compositions. However, NWA 14526 and NWA 14137 have not been extensively studied yet, and their full pyroxene compositional ranges are not yet known.

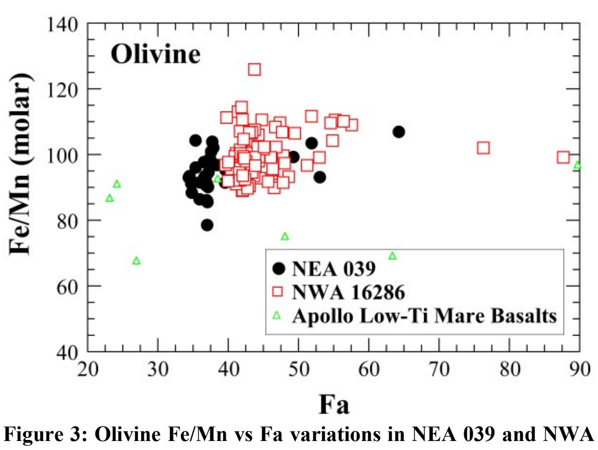

Figure 3: Olivine Fe/Mn vs Fa variations in NEA 039 and NWA 16286 compared to some published Apollo low-Ti basalts. Apollo data from [5,6].

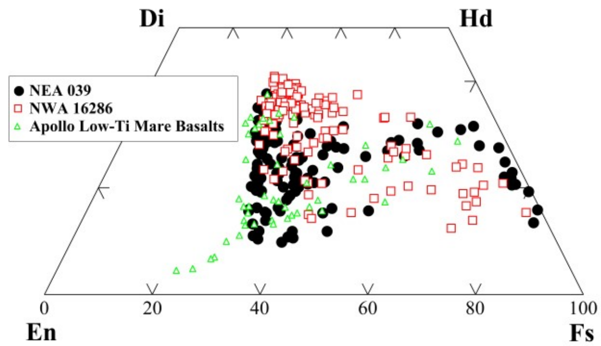

Figure 4: Pyroxene quadrilateral showing the range of compositions in NEA 039 and NWA 16286 compared to Apollo low-Ti basalts. NWA 16286 is more calcic and Ti-rich relative to NEA 039. Apollo data from [5,6].

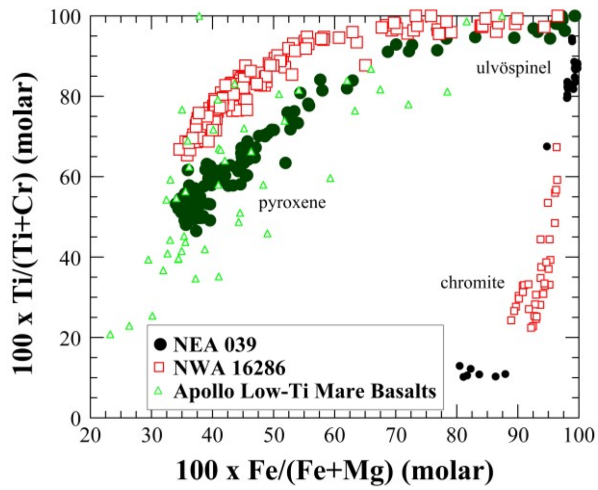

Figure 5: Ti/(Ti+Cr) vs Fe/(Fe+Mg) plot showing typical low-Ti fractionation trends for both NEA 039 and NWA 16286. Very low-Ti basalts would plot as steeper-sloped trends, whereas high-Ti basalts would plot as shallow, horizontal trends across the diagram. Apollo data from [5,6].

References: [1] Vaniman D. et al. (1991) In *Lunar Sourcebook* (eds. G. H. Heiken et al.), pp. 5-26. Cambridge Univ. Press. [2] Prettyman, T.H. et al. (2002) *Lunar Planet. Sci. XXXIII*: 2012 (CD-ROM). [3] Giguere, T. A. et al. (2000) *MaPS* 35, 193-200. [4] Delano, J. (2009) In *Elements*, Vol. 5, No.1, MSA, pp. 11-16. [5] Papike, J., Taylor, L. and Simon, S. In *Lunar Sourcebook* (eds. G. H. Heiken et al.), pp. 121-181. Cambridge Univ. Press. [6] BVSP (1981) *Basaltic Volcanism on the Terrestrial Planets*. Pergamon Press, 1286 pp. [7] Longhi J. (1992) *GCA* 56, 2235-2251. [8] Elardo S. M. et al. (2014) *MaPS* 49, 261-291.