**DISCOVERY OF A NEW MARTIAN METEORITE TYPE: AUGITE BASALT - NORTHWEST AFRICA 8159.**

C. B. Agee[1], N. Muttik[1], K. Ziegler[1], F. M. McCubbin[1], C. D. K. Herd[2], P. Rochette[3], J. Gattacceca[3], [1]Institute of Meteoritics, University of New Mexico, Albuquerque NM, agee@unm.edu, [2]Department of Earth and Atmospheric Sciences, 1-26 Earth Sciences Building, University of Alberta, Edmonton, Canada, [3]CEREGE Aix Marseille Université/CNRS, France.

**Introduction:** We report here the discovery of a new type of martian meteorite, Northwest Africa (NWA) 8159 augite basalt, that has characteristics that make it distinct from other martian meteorite types.

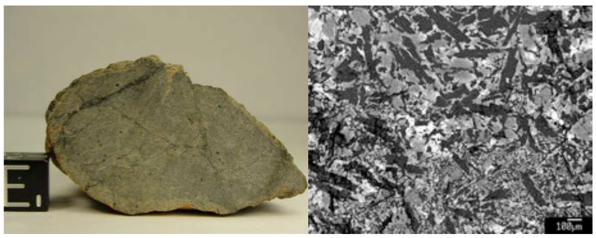

Fig. 1A (left). Saw cut of the NWA 8159 main mass, dark melt veins present, scale cube 1 cm. Fig. 1B (right). Backscatter electron image (BSE) of typical basaltic microtexture, scale bar 100 microns. Dark laths: plagioclase, medium gray zoned crystals: augite, light gray: olivine, brightest phase: magnetite.

**History and Physical Charateristics:** NWA 8159 was purchased by Brahim Tahiri from a Moroccan meteorite hunter and sent to his partner Sean Tutorow for classification in 2012. The specimen is a single stone, 149.83 grams, with a weathered, yellow-brown patina exterior, and light colored desert soil coating on one side. Saw-cuts reveal a very fine-grained, gray-green interior, with a few small melt veins present, but one vein was up to 1 mm thick, lithology offsets at vein boundaries suggest slight brecciation (Fig.1A).

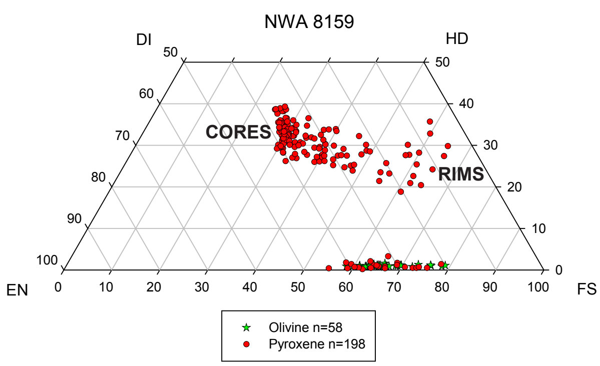


Fig 2. Pyroxene quadrilateral showing the augite, orthopyroxene, and olivine compositions in NWA 8159. Augite crystallization trend is unique among martian basalts. Orthopyroxenes are reaction products of olivine and melt and both have similar Mg#.

**Petrology:** NWA 8159 is a fine-grained basalt with intergranular augite (~50%) plagioclase + maskelynite (~40%), olivine (~5%), magnetite (~3%), orthopyroxene (~2%) (Fig.1B). Minor phases include ilmenite, merrillite, Cl-apatite, Cr-spinel, and secondary alteration minerals. Pyroxene compositions in NWA 8159 are unique relative to known martian basalts (Fig. 2). The dominant pyroxene is zoned augite that becomes increasingly ferroan-rich from core to rim. The only pyroxenes in martian meteorites that have a compositional resemblance to NWA 8159 augites are found in nakhlites -- in particular the zoned augites in MIL03346 [1,2]. However, while nakhlite augites are relatively coarse-grained cumulates, the augites in NWA 8159 occur as fine-grained, rapidly-cooled, intergranular crystals. Ferroan orthopyroxene (Fs56-80) is a relatively minor phase in NWA 8159 and occurs exclusively with magnetite mantling olivine (Fig. 3). Olivines range in composition from Fa61-76, having similar Mg# to the orthopyroxene. We propose that the orthopyroxene is the product of the reaction:

$$6Fe_2SiO_4\ (ol) + O_2 = 2Fe_3O_4\ (mt) + 6FeSiO_3\ (opx) \quad (1)$$

suggesting that the NWA 8159 magma possessed a relatively high oxygen fugacity ($fO_2$)during crystallization.

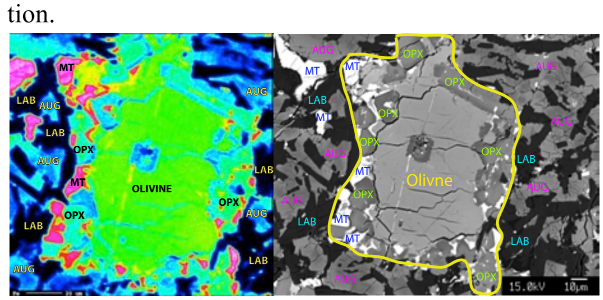


Fig 3. An example of olivine mantled by orthopyroxene and magnetite. Left is a false color iron map, right is a BSE image, scale bar 10 microns.

Magnetite is relatively pure with low $TiO_2 = 0.22\pm0.13$ wt% (n=29), in contrast to oxides in other martian meteorites, which are predominantly titanomagnetites. Application of the Fe-Ti oxide oxybarometer of [3] to an ilmenite-magnetite pair yields an $fO_2$ of over 4 log units above the Quartz-Fayalite-Magnetite (QFM) buffer – although poorly constrained, this is the highest known $fO_2$ for any Martian meteorite lithology. The above reaction is observed as a peritectic reaction in the system olivine-magnetite-silica at high $fO_2$ [4]. Thus the observed texture in NWA 8159 is due to reaction of olivine with a oxidized melt, either as a peritectic reaction involving cognate olivine phenocrysts, or the reaction of olivine xenocrysts after incorporation into the much more oxidized melt.

**Magnetic Properties:** NWA 8159 appears to be the second most magnetic martian meteorite, with a saturation remanence about one third of that of NWA 7034 [5] and twice the most magnetic nakhlite and shergottite [6]. Nearly pure magnetite (based on Curie point, and Verwey transition, fig. 4) dominates, but a significant amount of maghemite (like in NWA 7034) is also identified by the irreversible drop in susceptibility at 350°C (fig. 4). This new lithology is thus more oxidized than the usual SNC lithologies and another candidate for explaining the origin of the strong crustal magnetizations on Mars.

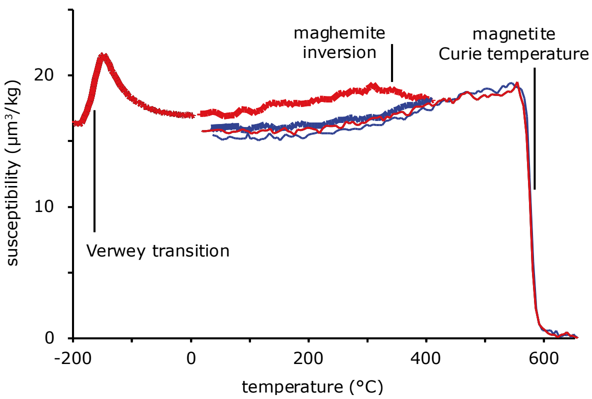


Fig.4. Magnetic susceptibility vs. temperature for NWA 8159. The experiment starts at low temperature and includes one temperature cycle between 450 and 20 °C (red=warming, blue=cooling).

**Shock Pressures = Plagioclase + Maskelynite:** The feldspathic phases of NWA 8159 also appear to be unique relative to other martian basalts in that both plagioclase and maskelynite are present in the three sections we examined. Labradorite plagioclase (An54-65) occurs as shock-fractured prismatic laths up to 500 x 100 um, but many are smaller (~50 x 10 um). Approximately half of the plagioclase has been converted to maskelynite, and is observed as unfractured, glassy casts. Shock pressures in NWA 8159 only partially coverted plagioclase to maskelynite thus the peak pressures may have been lower than for shergottites which presumably reached shock pressures sufficient to convert all plagioclase to maskelynite. NWA 8159 shock pressures may have been similar to those experienced by Chassigny and some nakhlites which also possess both plagioclase and maskelynite. Interestingly, plagioclase compositions in NWA 8159 are more similar to shergottites than to nakhlites, and its low potassium labradorites are a near compositional match to maskelynite in QUE 94201.

**Evidence for Martian Origin:** NWA 8159 is classified as a martian meteorite based oxygen isotopes, Fe/Mn of augite and olivine, and An-content of plagioclase and maskelynite. Figure 5 shows our results for laser fluorination analyses of five acid-washed aliquots of bulk sample with values of $\Delta^{17}O$ = 0.247, 0.321, 0.336, 0.316, 0.280 (all linearized, permil). All of the measured values fall within the $\Delta^{17}O$ range for SNC meteorites, however one sample gave $\delta^{17}O$ and $\delta^{18}O$ values that extend the lower range of SNCs by a few tenths of a permil.

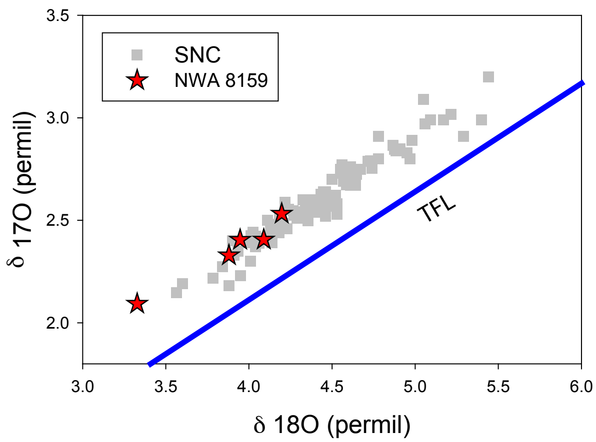


Fig 5. Triple oxygen isotope diagram showing data from NWA 8159 (red stars) compared to SNC meteorites.

**The Missing Link to the Nakhlites or is NWA 8159 a Singleton Martian Basalt?** The bulk composition of NWA 8159 is similar to the composition of the intercumulus melt from the MIL03346 nakhlite [7]; this and other similarities suggest a genetic relationship to the nakhlites, as discussed by [8]. Alternatively, NWA 8159 may be a martian basalt with no genetic link to nakhlites or other Martian meteorites, instead originating from an up-to-now unsampled (by meteorites) locality on the martian surface. Future work on the crystallization and cosmic ray exposure ages of NWA 8159, and other geochemical/isotopic data may shed further light on its origin.

**References:** [1] Day J. M. D. et al. (2006) *Meteoritics & Planet. Sci., 41,* 581-606. [2] McCubbin F. M. et al. (2013) *Meteoritics & Planet. Sci., 48,* 819-853. [3] Ghiorso M.S. and Evans B.W. (2008) *American Journal of Science, 308,* 957-1039. [4] McBirney A. R. (1984) *Igneous Petrology,* 504p. [5] Gattacceca J. et al. (2013) *AGU Fall meeting*, abstract #GP33A-01 [6] Rochette P. et al. (2005*) Meteoritics & Planet. Sci., 40*, 529-540. [7] Hammer J.E. (2009) *Meteoritics & Planet Sci. 44*, 141-154. [8] Herd, C.D.K. et al. (2014) This meeting.