UNDERSTANDING THE MAGNESIUM-SUITE LITHOLOGY AND LUNAR HIGHLANDS TERRAIN THROUGH A DETAILED INVESTIGATION OF LUNAR METEORITES NORTHWEST AFRICA (NWA) 10291 AND 11182.

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Introduction: The Apollo and Luna samples returned from the lunar nearside inform the large-scale petrogenesis and early history of the Moon. The current paradigm is that a Lunar Magma Ocean (LMO) cooled and differentiated to form a small, dense core, an inner mantle of Mg- and Fe-rich silicate minerals (like olivine and pyroxene), and an outer primary crust comprised of ferroan anorthosites (FAN). The last dregs of the crystallizing LMO are thought to produce residual, trace element-enriched KREEPy (Potassium, Rare-Earth Elements, Phosphorous) material. The Apollo Mg-suite and Alkali-suite plutonic rocks with a KREEP geochemical signature are thought to represent a secondary crustal-building process, intruding into the primary anorthositic (FAN) crust [1,2,3]. These lithologies and KREEPy materials are present in rocks collected from the Apollo sites; however, their global provenance is not well constrained.

Lunar meteorites provide a random sampling of the lunar surface that is not restricted to the sampled areas of the Apollo and Luna missions [5-6]. In this study, we investigate lunar meteorites NWA 10291 and 11182 to: 1) improve and expand our knowledge of lunar highland rock types; 2) understand the global provenance of these lunar rock types and; 3) analyze any potential connection to the Apollo Mg-suite and FAN rocks.

Samples: NWA 10291 and 11182 are feldspathic breccias recovered from northwestern Africa in 2015 and 2017, respectively. NWA 10291 is paired with NWA 10149 and pairs [6]. It contains a variety of feldspathic and mafic clasts in a finer grained matrix [7]. NWA 11182 contains mostly feldspathic clasts with some gabbroic clasts and shock melt [8].

Method: Geochemical data was obtained with the JEOL JXA-8200 Superprobe (EMPA) at Rutgers University using a 20 nA beam current, 15 keV accelerating voltage, and a focused beam (< 1 μm). Count times ranged from 20 to 40s on peak for major and minor elements. Na and K were analyzed for 10s. The MAN method was used for background determination.

Petrography and mineral chemistry: Both meteorites contain clasts of anorthosite, anorthositic gabbro, and gabbro. They also both contain ultramafic clasts and mineral fragments. Additionally, NWA 10291 contains clasts of anorthositic troctolite, gabbroic anorthosite, and troctolitic anorthosite, as well as symplectite clasts and glass beads.

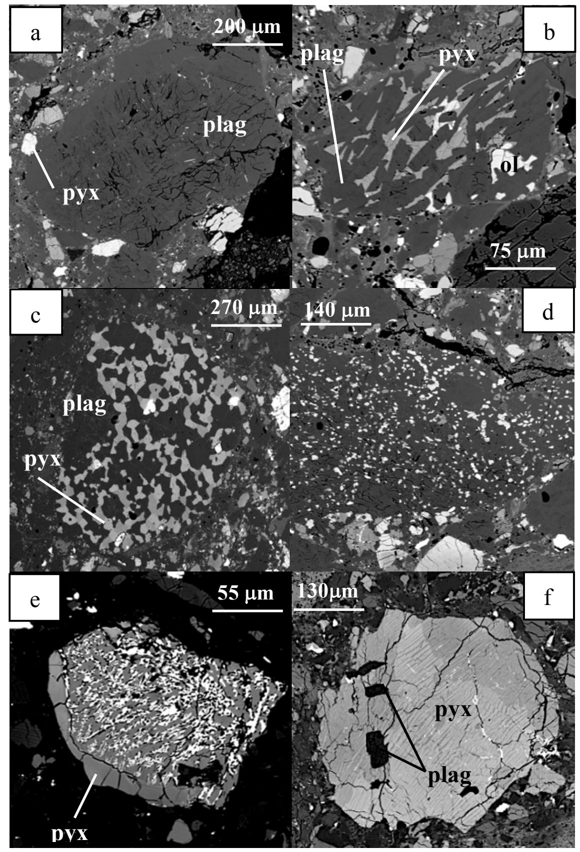

Fig. 1. Backscattered electron (BSE) images of clasts in NWA 10291 and 11182: a) NWA 10291 anorthosite clast composed of mostly anorthite with an iron-rich pyroxene inclusion; b) NWA 10291 gabbroic anorthosite clast with graphic pyroxene and olivine inclusions in plagioclase; c) NWA 11182 gabbro consisting of plagioclase with pyroxene inclusions; d) NWA 10291 granulite clast with granulitic olivine and pyroxene inclusions in plagioclase; e) NWA 10291 mafic clast exhibiting symplectitic intergrowth of pyroxene and iron-rich olivine; f) NWA 10291 mafic clast with pyroxene exsolution lamellae and anorthite inclusions.

Anorthosite: The anorthosites in each meteorite are fractured and contain small inclusions of mafic material (pyroxene or olivine) (Fig 1a). Some clasts in NWA 10291 contain laths of ilmenite. The pyroxene in NWA 10291 exhibits exsolution lamellae (Fig 1f). The olivine and pyroxene in these clasts range in Mg# (Mg/(Mg+Fe)) from 65 to 83 and 10 to 72, respectively.

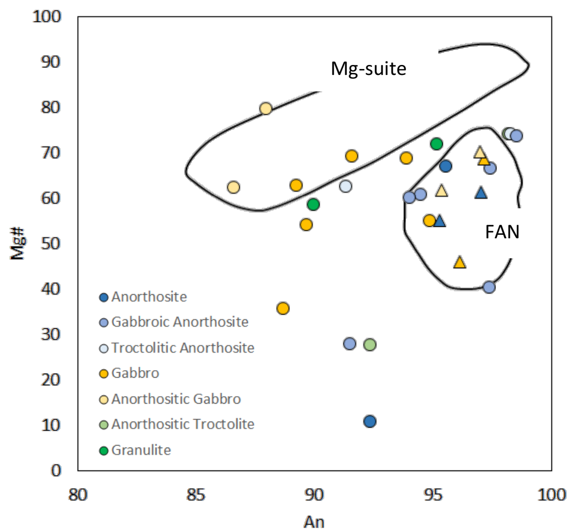

Fig. 2. A plot of An of plagioclase versus Mg# of a mafic. Color legend provided. NWA 10291 = circles; NWA 11182 = triangles.

The plagioclase ranges in An (Ca/(Ca+Na)) from 85 to 97.

Anorthositic gabbro: The plagioclase is fractured and contains laths of fractured pyroxene. The olivine and pyroxene range in Mg# from 67 to 70 and 61 to 79, respectively. The plagioclase ranges in An from 86 to 97.

Gabbroic anorthosite: Only NWA 10291 contains gabbroic anorthosite clasts. Plagioclase within these clasts is fractured and ilmenite is sometimes present. The pyroxene can exhibit exsolution lamellae and graphic textures (Fig 1b). The olivine and pyroxene range in Mg# from 60 to 61 and 65 to 73, respectively. The plagioclase ranges in An from 94 to 98.

Anorthositic troctolite: Only NWA 10291 contains anorthositic troctolite. The olivine and pyroxene crystals exhibit a granulitic texture set in plagioclase. The olivine and pyroxene in this clast range in Mg# from 72 to 74 and 27 to 55, respectively. The plagioclase ranges in An from 92 to 98.

Troctolitic anorthosite: Only NWA 10291 contains troctolitic anorthosite. Graphic pyroxene and olivine are set within fractured plagioclase. The olivine and pyroxene range in Mg# from 62 to 63 and 69 to 74, respectively. Plagioclase ranges in An from 91 to 98.

Gabbro: Both meteorites contain gabbro clasts (Fig 1c). Clasts in NWA 10291 contain graphic olivine and pyroxene inclusions in plagioclase, which can exhibit laths. The olivine and pyroxene in these clasts range in Mg# from 45 to 64 and 54 to 68, respectively. The plagioclase ranges in An from 88 to 97.

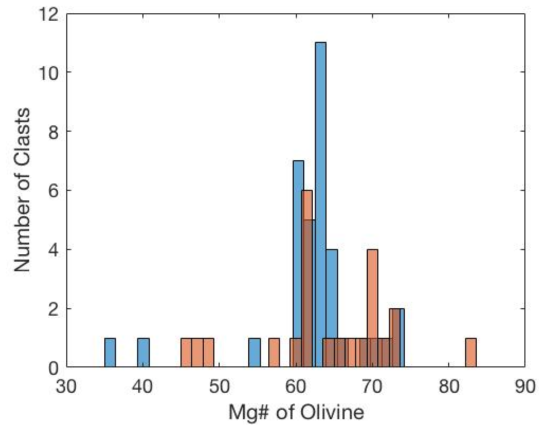

Fig. 3. A histogram of Mg# of olivine in NWA 10291 (blue) and NWA 11182 (orange).

Granulite: Only NWA 10291 contains granulitic clasts. Granulitic pyroxene and olivine are set within plagioclase (Fig 1d). The olivine and pyroxene range in Mg# from 58 to 61 and 58 to 71, respectively. The plagioclase ranges in An from 89 to 95.

Symplectite clasts: Only NWA 10291 contains symplectite clasts (Fig 1e). The clasts have iron-rich pyroxene and iron-rich olivine intergrown in a symplectitic texture. The pyroxene ranges in Mg# from 13 to 24, while the iron-rich olivine ranges from 6 to 7.

Discussion and Conclusions: The anorthosite in NWA 11182 is consistent with FAN, while anorthosite in NWA 10291 is more varied (Fig 2). Troctolitic anorthosites of NWA 10291 are almost entirely compositionally intermediate between Mg-suite and FAN. The anorthositic gabbro clasts in NWA 10291 are chemically consistent with Mg-suite gabbronorites, while the anorthositic gabbro clasts in NWA 11182 are chemically similar to FAN. The gabbros and anorthosites in NWA 11182 have a much narrower range in An-content than NWA 10291, and more closely resemble FAN. Olivine is chemically similar in both meteorites (Fig 3).

NWA 10291 may originate from the Procellarum KREEP Terrane due to elevated sodium and moderate thorium content [6]. Future work includes measuring the abundance of KREEP within NWA 11182 to constrain its origin and potential relationship to Apollo Mg-suite or FAN lithologies.

References: [1] Shearer, C.K. et al (2006) RMG. 60: 365-518. [2] Warren, P.H. (1993) Am. Min. 78: 360-376. [3] Shearer et al (2015) Am. Min. 100: 294-325. [4] Korotev, R.L. (2005) Chemie der Erde. 65: 297-346 [5] Joy, K.H. and T. Arai (2013) A&G. 54: 44.28–4.32. [6] Gross, J. et al. (2014) EPSL. 388: 318-328. [6] Korotev R.L. and Irving A.J. (2016) 47th LPSC #1358. [7] Met. Bulletin (2015) 104. [8] Met. Bulletin (2017) 106.