NEW LUNAR METEORITE NWA 2996: A WINDOW INTO HIGHLAND PLUTONIC PROCESSES AND KREEP METASOMATISM C. N. Mercer and A. H. Treiman, Lunar and Planetary Institute, 3600 Bay Area Blvd., Houston, TX 77058; mercer@lpi.usra.edu

Introduction: The petrogenetic history of the lunar highlands is complex. Pristine examples of key plutonic lithologies are needed to elucidate the role of intrusive processes on the formation of the highlands. We have begun a detailed petrological and geochemical investigation of a recently found meteorite, NWA 2996, which provides fragments of several of these key lithologies.

Meteorite Northwest Africa (NWA) 2996 is a feldspathic breccia with prominent, coherent anorthositic clasts up to 3 cm in size [1]. Other clasts include medium-grained gabbros, anorthositic norites and troctolites, mineral fragments, shocked clasts, and devitrified glassy clasts [1]. We describe clasts from the polished thin section NWA 2996/TAL-1*.

In the context of a petrogenetic mixing model based on Apollo return samples, the bulk composition of NWA 2996 (and paired stone NWA 2995; 4.65 ppm Sm, 18.8 ppm Sc) suggests that this meteorite may represent a 2:1 mixture of feldspathic material and mare basalt with 5% KREEP [2]. This mixture could be representative of rocks near the margin of the Procellarum KREEP Terrane. Alternatively, NWA 2996 could represent a bulk composition unique to the South Pole-Aitken Terrane [2]. Bulk FeO_T (9.75 wt%) and Th (1.73 ppm) concentrations [2] compared with recent remote sensing data [3] imply an origin along the perimeter of the Procellarum KREEP Terrane or the South Pole-Aitken Terrane.

The aim of this work is to provide a detailed petrological and geochemical study of NWA 2996 to test whether it could have originated from either the margin of the Procellarum KREEP Terrane or the South Pole-Aitken Terrane, and to contribute to improving the understanding of lunar highland petrogenesis.

Methods: SEM imaging and EDS mapping were carried out at the Johnson Space center using a JEOL Field-emission JSM7600F SEM with a Thermo SDD EDS. Major and minor element analyses of minerals were performed using a Cameca SX100 at the Johnson Space Center and a Cameca SX50 at Texas A&M University. Clasts were analyzed with a 15 keV accelerating potential, 20 nA beam current, and 1-5 μm spot size, using natural and synthetic standards and peak count times optimized for each mineral.

Intrusive Lithologies: NWA 2996 clasts and mineral fragments are dominanted by medium- to coarse-grained (1) ferroan noritic/troctolitic-anorthosite, (2) mafic-rich (non-mare basalt) lithologies, and (3) KREEPy granophyric K-feldspar and quartz monzodiorite. The meteorite is notably deficient in basalt and granulite lithologies.

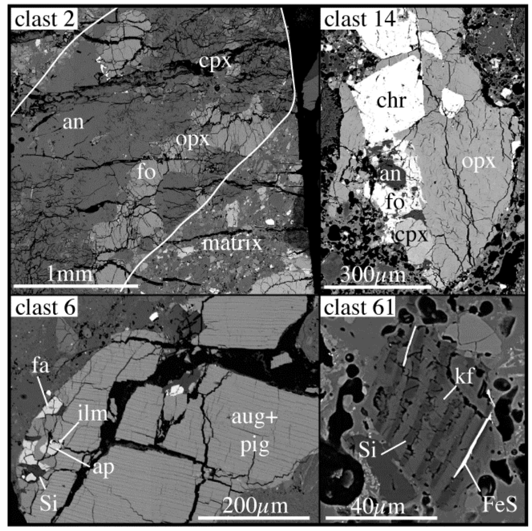

Figure 1. Example BSE images of ferroan noritic-anorthosite (clast 2), coarse mafic lithology (clast 14), and KREEPy quartz monzodiorite (clast 6) and granophyric K-feldspar (clast 61).

Ferroan noritic/troctolitic-anorthosite clasts are typically large (up to 3mm), with cumulus plagioclase grains that are coarse-grained (up to 1 mm) and equigranular (Fig. 1, clast 2). They contain 80-90% plagioclase with roughly equal amounts of intercumulus orthopyroxene and olivine, minor clinopyroxene, and accessory ilmenite. Plagioclase compositions (Fig. 2) range from $An_{96\text{-}98}$ while coexisting mafic phases range from $Mg_{64\text{-}78}$. Most pyroxenes are relatively homogenous, but some pyroxenes display fine, linear exsolution lamellae while others show irregular intergrowths. One large clast contains several clusters of apatite, ilmenite, and Fe-sulfide.

Mafic-rich lithologies include clasts that are rich in orthopyroxene, olivine, and clinopyroxene with 0-50% plagioclase ($An_{92\text{-}98}$), and minor amounts of chromite, spinel, or ilmenite (Fig. 1, clast 14). Mafic phases range in composition from $Mg_{60\text{-}80}$ (Fig. 2). Many of these clasts are coarse, relatively Mg-rich, and contain some heterogeneous pyroxenes, much like the mafic components of ferroan noritic-anorthosites, while others are medium- to fine-grained, resembling gabbronorites. One clast displays an inverted pigeonite texture.

KREEPy granophyric K-feldspar and quartz monzodiorite clasts and mineral fragments represent the "K-fraction" and "REEP-fraction" [4], respectively, in this meteorite. There are two grains (80-100 μm) of granophyric K-feldspar ($An_6Ab_{21}Or_{73}$) with intergrowths of smooth-edged, ovoid shaped silica glass (Fig. 1, clast 61). One clast contains Na-rich plagioclase (An_{65}) with similar granophyric intergrowths of silica glass. Quartz monzodiorites contain coarse-grained, Fe-rich ($Mg_{20\text{-}40}$) pyroxenes with well developed exsolution lamellae, fayalite ($Fo_{18\text{-}30}$), quartz or Si-rich glass, apatite, and ilmenite (Fig. 1, clast 6). Many coarse pyroxene and olivine fragments have similarly ferroan compositions (Fig. 2). Only one quartz monzodiorite clast contains coexisting alkali plagioclase (An_{86}), but there are many fragments of Na-rich plagioclase ($An_{68\text{-}77}$) that would be expected to correspond to Fe-rich mafic fragments, and together likely represent alkali suite lithologies (Fig. 2).

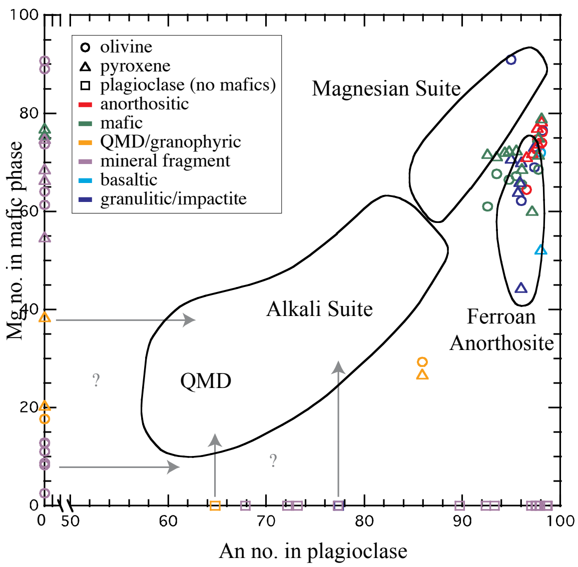

*Figure 2. Mg no. (100*molarMg/(Mg+Fe)) in pyroxene and olivine as a function of An no. (100*molarCa/(Ca+Na)) in coexisting plagioclase for clasts and mineral fragments.*

Rare lithologies. NWA 2996 distinctly lacks basaltic and granulitic lithologies. Only one clast out of the 65 analyzed thus far has a true basaltic texture. It is 300 μm in size and contains Ca-rich plagioclase laths (An_{98}), zoned pyroxene ($Mg_{23\text{-}60}$), olivine (Mg_{72}), and accessory ilmenite and chromite. Three relatively small (<300 μm) clasts display a granulitic texture while five others are very fine grained impactites. All of these lithologies contain a significant mafic portion (15-50%) in addition to plagioclase and accessory oxides.

Implications- A Window into Lunar Highland Intrusive Processes: The lack of both extrusive lithologies (e.g., basalt) and impact metamorphosed clasts (e.g., granulites), along with the abundance of relatively coarse-grained clasts, suggests that NWA 2996 preserves relatively unmetamorphosed, intrusive lithologies. Our preliminary results provide evidence for the physical mixing of three distinct intrusive lithologies that contribute to the overall geochemical character of NWA 2996.

The volumetrically abundant ferroan noritic/ troctolitic-anorthosites of NWA 2996 are relatively mafic-rich members of the lunar ferroan anorthositic suite and could be similar to the plutonic ferroan noritic-anorthosites of [5]. Further investigation of cumulus relationships within these clasts and trace element analyses will help to clarify the specific intrusive process leading to their generation.

Incorporation of mare basaltic material does not appear to be an important mafic component of NWA 2996. Instead, the mafic character comes from several intrusive mafic inputs, including mafic components that could be related to plutonic ferroan noritic/ troctolitic-anorthosites, and gabbronorites that could represent the base of deep seated, thick basalt flows or the "plumbing system" of basaltic magmatic systems (e.g., [6]). The occurrence of inverted pigeonite further implies a plutonic generation [7].

Preservation of more evolved, KREEPy granophyric K-feldspar and quartz monzodiorite is an important intrusive component that likely contributes to the moderately elevated incompatible element signature of NWA 2996. These lithologies also are evidence of silicate liquid immiscibility of a highly evolved melt [8]. These distinctive KREEP lithologies and their apparent occurrence within one ferroan anorthosite clast warrants further investigation into the process of KREEP metasomatism, which may be an important process in the generation of the lunar highlands [9].

Our preliminary petrographic evidence supports the Apollo petrogenetic mixing model and argues against the interpretation that NWA 2996 could represent a single unique South Pole-Aitken composition (e.g., Dhofar 961) [2]. However, it is not yet clear how distinct South Pole-Aitken Terrane compositions are from probable mixtures of lunar nearside rocks, and our evidence does not preclude an origin from the South Pole-Aitken Terrane.

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References: [1] Weisberg et al. (2009) *The Meteoritical Bulletin, 95,* 431-432. [2] Korotev et al. (2009) *Meteoritics and Planetary Science 44,* 1287-1322. [3] Gillis et al. (2004) *Geochimica et Cosmochimica Acta, 68,* 3791-3805. [4] Neal C.R. and Taylor L.A. (1989) *Geochimica et Cosmochimica Acta, 53,* 529-541. [5] Jolliff B.L. and Haskin L.A. (1995) *Geochimica et Cosmochimica Acta, 59,* 2345-2374. [6] Kiefer W.S. (2008) *GSA Abstracts with Programs, 40,* 114. [7] Papike J.J. and Bence A.E. (1972) *Earth and Planetary Science Letters, 14,* 176-182. [8] Jolliff et al. (1999) *American Mineralogist, 84,* 821-837. [9] Neal C.R. and Taylor L.A. (1991) *Geochimica et Cosmochimica Acta, 55,* 2965-2980.