IN SITU CHEMICAL CHARACTERIZATION OF MINERAL PHASES IN LUNAR GRANULITE METEORITE NORTHWEST AFRICA 5744.

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Introduction: Northwest Africa (NWA) 5744 meteorite is a granulitic and troctolitic lunar breccia which may represent nearly pristine lunar crust (Fig. 1). NWA 5744 is unusually magnesian compared to other lunar breccias, with bulk [Mg/(Mg+Fe)] ~ 0.79 [1, 2]. Inspection shows impactor content is likely to be very minor, with low Ni content and a lack of metal grains. Some terrestrial contamination is present, evidenced by calcite within cracks. NWA 5744 has notably low concentrations of incompatible trace elements (ITEs) [2]. The goal of this study is to attempt to classify this lunar granulite through analyses of *in situ* phases.

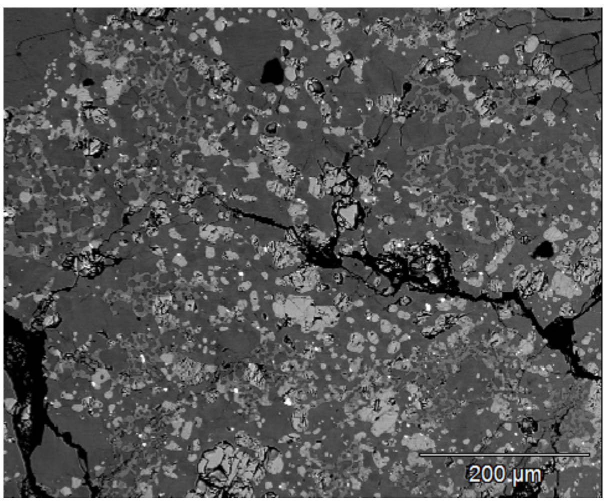

Figure 1: BSE image of a typical portion of NWA 5744. Plagioclase/maskelynite matrix with darker pyroxene schlieren, lighter-colored olivine, and white specks of Ti-chromite.

Methods: Major element concentrations of all principal mineral phases within NWA 5744 were measured using electron probe micro analysis (EMPA) on a Cameca SX100 electron microprobe at NASA-Johnson Space Center. Trace element concentrations were determined by laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) at the University of Houston on a Varian *810* ICP-MS with a Photon Machines *Analyte.193* excimer laser. Trace element measurements were performed on the same mineral phases measured by EPMA, and their Mg and Ca concentrations were used as internal standards. X-ray Computed Tomography (CT) was done on an XTECH (Nikon) XT H 225 machine at Shell BTC Research Facility. Raw data were compiled into a 3D volume using Nikon Metrology CT Pro 3D XT software. Volumetric rendering was done with VGStudioMAX.

X-ray Computed Tomography: A CT scan was performed on a slab of NWA 5744 approximately 1.5 cm x 1 cm x 2 mm in dimension (Fig. 2). This was done prior to any destructive analyses, and produced a 10.4 µm resolution 3D volumetric density map that can be manipulated to reveal subsurface sutructure, texture, fracture patterns, and grain boundary information not visible from surface imaging. This volume can also be used to improve the accuracy of modal phase estimates, to select desirable ablation locations, and to quantify whether or to what extent grain boundaries were breached during ablations. X-ray CT may be an invaluable future tool for non-destructively assessing rare specimens and preserving some character of them even after destructive tests are performed.

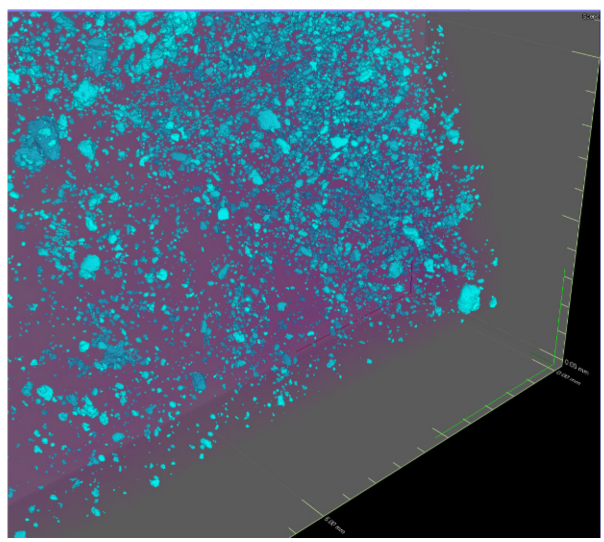

Figure 2: 3D density volume of a slab of NWA 5744, obtained by X-ray CT scan. Rendered with opacity settings to display only high density grains in blue, such as olivine and chromite. The tick marks on each scale are 500 µm.

Shock Features: NWA 5744 has similar shock features to NWA 3163 [3], including pyroxene and olivine schlieren within maskelynite (Fig. 1). Although present, mafic schlieren in maskelynite are not ubiquitous within NWA 5744. Some larger relict grains (80+ µm) of each major phase can be observed with subangular, identifiable crystal faces, and some large relict plagioclase crystals exhibit mild compositional zoning from rim to core (eg. Mg depletion in the rim), possibly indicative of diffusion during metamorphism. Pyroxene grains larger than 40 µm are rare, but those present often exhibit nanometer scale lamellae similar to those observed in Apollo 17 granulite sample 77017 [4].

Results: *In situ* analysis of olivine, pyroxene, and/or plagioclase/maskelynite allows more detailed classification of NWA 5744 than whole-rock alone. Figure 3 clearly distinguishes this granulite as a member of the magnesian suite with olivines of largely uniform Mg'. Anorthite content of plagioclase is considerably more variable, but interestingly appears confined within the range of expected FAN values. However, other granulite clasts within lunar meteorites Allan Hills 81005 and Dhofar 309 display a different trend, with Mg' in olivine varying more than An in plagioclase (Fig. 3) [5]. NWA 5744 plagioclase rare earth element (REE) abundances (Fig. 4) are all depleted in comparison to magnesian granulite Dho 309, and similar to or lower than ALH 81005 [5, 6].

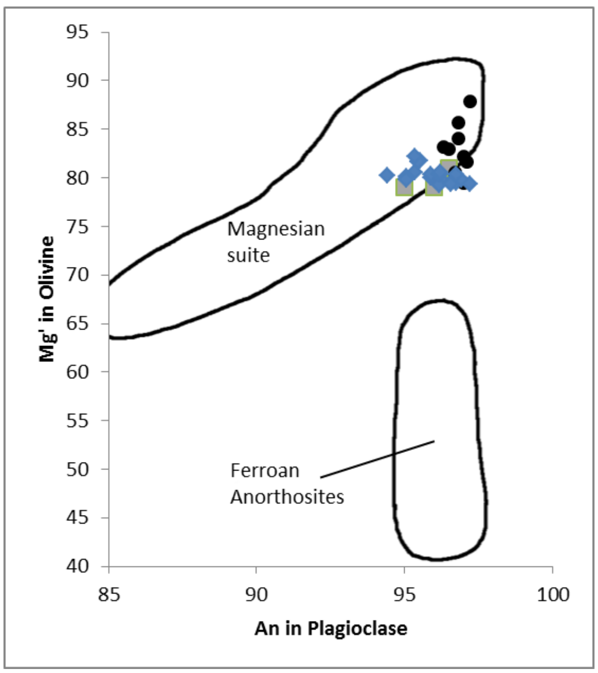

Figure 3: Blue diamonds represent individual EPMA measurements of NWA 5744 olivine crystals vs. plagioclase matrix, within 25 µm. Black circles are magnesian granulites within ALH 81005 and Dho 309 [5, 6]. Gray squares are Apollo magnesian granulites 67415, 67955, and 72275 [7, 8]. Mg' = [Mg/(Mg + Fe)]; An = [Ca/(Ca + Na)]. The points fall within the magnesian suite with little variation in olivine Mg', while plagioclase An covers the full range of FAN plagioclase. Fields reproduced from Treiman et al. (2010) [5] and Goodrich et al. (1984) [6].

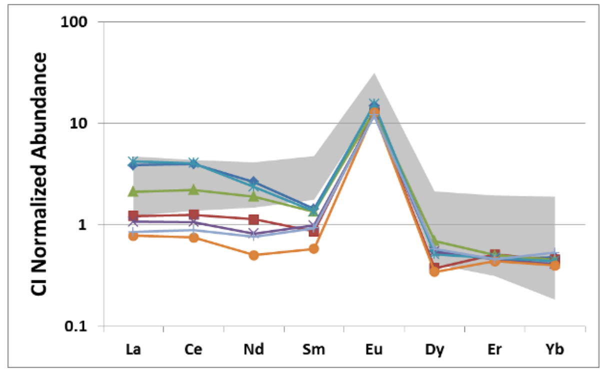

Figure 4: CI chondrite-normalized REE profile of individual plagioclase crystals within NWA 5744, determined via LA-ICP-MS. Shaded region is the range between REE profiles in plagioclase of granulites Dho 309 (upper bound) and ALH 81005 (lower bound) [5].

Pyroxene Thermometry: Four distinct examples of coexisting orthopyroxene and clinopyroxene were identified. The Fe-Mg two pyroxene thermometer of Gasparik [9] indicates a recrystallization temperature in the range of approximately 750 to 800 ^{o}C depending on the pressure of equilibration from near surface to ~13 kbar, respectively. Only OPX and CPX in direct contact were used as thermometers, and all four observed instances yielded the same result.

Conclusions: NWA 5744 is a magnesian granulite with chemical characteristics similar to some other known granulites (Fig 3), but with key differences as well. Anorthite content may indicate a history linked to FAN materials despite magnesian composition. The range in Mg' and anorthite don't match ALH 81005 despite some similarities in REE content, and neither match with Dho 309. Whole rock analyses could miss differences between NWA 5744 and other magnesian granulites such as ALH 81005 and Dho 309 that are revealed by *in situ* examinations. NWA 5744 may correspond more closely with some Apollo granulites, but overall these chemical differences indicate a diversity of origins among magnesian lunar granulites as a whole.

References: [1] Weisberg M. K. et al. (2009) *Meteoritics & Planet. Sci., 44,* Nr 9, 1355-1397. [2] Kuehner et al. (2010) *LPS XLI,* #1552. [3] Shafer et al. (2011) *LPS XLII,* #1508. [4] Hudgins J. A. et al. (2011) *American Mineralogist, 96,* 1673-1685. [5] Treiman A. H. et al. (2010) *Meteoritics & Planet. Sci., 45,* Nr 2, 163-180. [6] Goodrich C. A. et al. (1984) *Journal Geophys. Res., 89,* C87-C94. [7] Lindstrom and Lindstrom (1986) *Journal Geophys. Res., 91, B4,* D263-D276. [8] Salpas et al. (1988) *LPS IIXX,* 11-19. [9] Gasparik T. (1984) *Contrib. Mineral. Petrol., 87,* 87-97.