NORTHWEST AFRICA 11444: A LUNAR BRECCIA WITH A HIGH ABUNDANCE OF IMPACT-DERIVED METAL AND A SEARCH FOR PGE ALLOY MICRONUGGETS

S.S. Russell*, N. V. Almeida, T. Salge, W. Brownscombe, C. Broderick, and J. Spratt. Natural History Museum, Cromwell Road, London, SW7 5BD, UK. *sarr@nhm.ac.uk.

Introduction: Northwest Africa (NWA) 11444 (Fig. 1) is a lunar melt breccia [1], or lunar fragmental breccia using the new lunar meteorite nomenclature scheme [2]. While it has not yet been studied in detail, it has been tentatively linked to a large pairing group of lunar breccia finds from Northwest Africa- the Northwest Africa 8046, or "Algerian Megafind" clan [3] that may originate from the lunar farside [4]. A notable characteristic of NWA 11444 is that it contains relatively abundant iron-nickel metal grains [1]. Such components may be candidates for *in situ* resource utilization of the lunar surface.

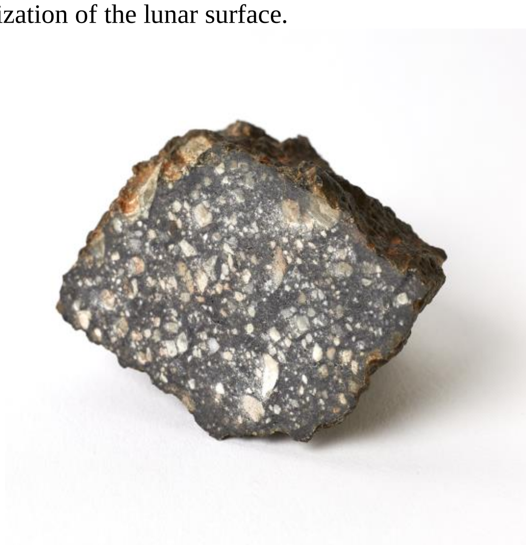

Figure 1. Lunar meteorite NWA 11444, approximately 8x6 cm. © Trustees of the NHM.

We investigated a polished section of NWA 11444 to provide an initial description of this important sample, investigate possible pairings and to particularly characterize its metallic components. We searched in detail for refractory platinum group element alloy micronuggets (PGMs), which have been shown to be a component of chondritic samples and especially the carbonaceous chondrites [5] that may account for a significant proportion of the impact flux to the lunar surface [6]. Since PGMs are highly refractory and resilient, if they were contained within any impactors then they may survive their sojourn on the lunar surface intact.

Techniques: We analyzed BM.2017,M3 section P23253, which has as a dimension of approximately 16 x 10 mm. Large area elemental mapping has been carried out using an Oxford Instruments AZtec EDS system. A ZEISS Evo LS15 SEM has been used to map the complete sample (20 kV, 2.2 µm pixel resolution, ~34 mega pixels), and two smaller regions were mapped with a ZEISS Ultra FE-SEM (12 kV, 160 nm pixel resolution, 33 and 28 megapixels). The sample was then mapped using the TIMA SEM-EDX system at 25 kV and 13 nA at 2 µm pixel size for 10.5 hours acquiring 3.4M spectra. It was then scanned at 0.2 µm pixel size, on phases >50% brightness and the surrounding 3 µm, for 15 hours acquiring 36M spectra. Mineral compositions were obtained using the JEOL JXA-8530F electron microprobe at 20kV.

Petrological and Mineralogical Description: The sample is a polymict breccia, composed of angular to sub-rounded clasts up to ~8mm across of many compositionally and texturally diverse rock types, held together by a largely recrystallized feldspathic glass. Clasts include basalt, anorthosite, gabbro, impact melt, and many isolated mineral grains of olivine and pyroxene. A modal analysis by the TIMA suggests the main components to be anorthite (32%), glass (~27%) and An_{85} (19.5%). Ilmenite and chromite are significant component of many of the clasts. Carbonate rich veins are abundant and cross cut the clasts, especially on one side of the section; these are likely produced by terrestrial weathering as are occasional baryte grains. The section contains many grains of sulfide (troilite) and of Fe-Ni metal (the latter being more typically a minor or rare component of lunar samples), but the metal is not evenly distributed across the section; one melt clast in particular is especially rich in both metal and sulfide, with one sub-rounded metal grain within the clast ~200 µm in size (Fig. 2).

Plagioclase compositions are invariably anorthositic, ranging from An_{88} to (more commonly) An_{98}. Olivine compositions, in contrast, are highly variable, with some clasts having Fo_{77-81}, and others more Fe-rich (Fo_{43-44}). One large (~500 micron) fayalitic grain within a gabbroic clast has a Fo_{10-11}. Pyroxenes are also highly variable; they occur in most of the clasts and range from orthopyroxene (typically Fs_{20-50}) to augite ($Fs_{30}Wo_{41}$). Clear exsolution textures are common both in clast derived pyroxenes and in isolated grains.

Discussion: *Comparison of silicates to those in other lunar samples:* The composition of silicates, especially olivine and pyroxene, varies greatly between clasts making comparisons to other lunar meteorites challenging. Some clasts have olivine compositions around Fo_{80}, with anorthite compositions around An_{95-97}. This composition falls within the gap between typical lunar ferro- anorthosite (FAN) and Mg suite rocks, similar to clasts reported from NWA 11303 [7], strengthening evidence for a pairing relationship between these meteorites.

A feature of the Algerian Megafind meteorites is that they typically contain olivine with a mean value of Fa_{33} (range Fa_{20-42})[3]. The range of olivine compositions we observe in NWA 11444 is much broader, from Fo_{10} to Fo_{88}, with a value of around Fo_{44} the mean value. The difference may, however, be a random effect due to the wide diversity of clasts in this and other lunar breccias.

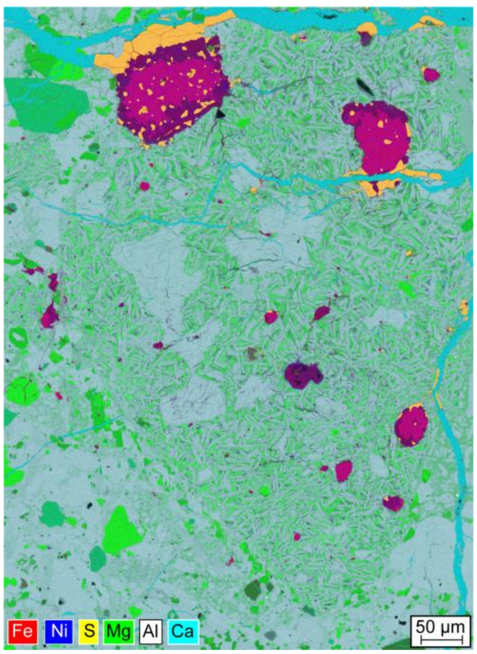

Figure 2. Net intensity elemental map of a melt clast rich in Fe-Ni grains (purple). Metal is associated with sulfides (orange). Carbonate veins cross cut the clast (light blue).

Origin of metal: Metal in lunar samples can either crystallize from a highly reduced melt [8, 9] or can be meteoritic in origin [9, 10, 11]. Endogenous lunar metal has a wide range of compositions, with up to 3 wt% or more Co, and > 50 wt% Ni [e.g. 8, 11]. Exogenous meteoritic metal has a more constrained composition, with between 5-15% Ni and 0.2-1.0% Co [9] and a Ni/Co ratio similar to the cosmic value of 20. All the metal grains analyzed in NWA 11444 have a composition compatible with a meteoritic origin (Figure 3), consistent with an interpretation of consolidation of the breccia near the lunar surface, where it was available to acquire a high impact flux. Such grains are a testament to the record of bombardment the lunar surface has experienced, and can be used to help constrain the nature of the flux of planetary materials to the Moon [10].

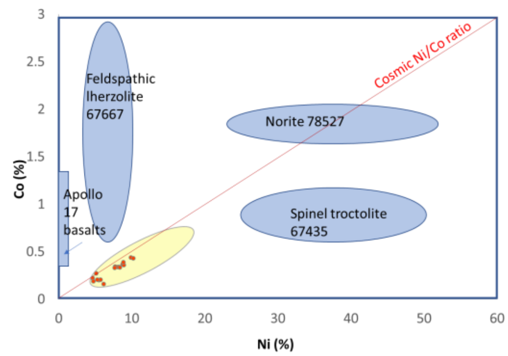

Figure 3. Co and Ni abundance of Fe-Ni metal grains. Data from NWA 11444 shown as red dots. The meteoritic field defined by [9] is given as a yellow range and the cosmic Ni/Co is also shown. Various lunar lithologies from the literature are shown as blue fields. The metal from NWA 11444 is most plausibly meteoritic rather than endogenous lunar in origin. Diagram after [11].

Search for PGMs: Given the significant abundance of meteoritic metal in NWA 11444, we anticipated it would be a good candidate for a detailed search for PGMs. However, despite the search as detailed above, no nuggets were located with a size > 1 μm. This may imply either that the impact flux of nugget-bearing meteorites to this rock was not sufficiently high to allow detection, or that the nuggets were subsequently destroyed by impact processes. Future work will study other lunar impact breccias for comparison.

Conclusions: NWA 11444 may be a part of the Algerian Megafind pairing group, though further work is needed to confirm this. If so, this may mean that the pairing group originated close to the lunar crust, enabling it to assimilate impact derived debris.

References: [1] Gattecca et al. (2019) Meteoritical Bulletin; [2] Ziegler R. et al. (2022) "A New Lunar Meteorite Naming Nomenclature" NIPR abstract; [3] Korotev R. Website: https://sites.wustl.edu/meteoritesite/items/lm_nwa_08046_clan [4] Fu, X., et al. (2021) Meteorit Planet Sci, 56: 1829-1856. [5] Daly L. et al., GCA [6] Barnes J. J. et al. (2016) *Nature Commun.* 7, doi:10.1038/ncomms11684; [7] Lunning N. and Gross J. (2019) LPSC #2407; [8] Reid A.M. et al. (1970) EPSL, 9, 1-5.; [9] J. I. Goldstein, H. Yakowitz, Abstracts of the 2nd Lunar Science Conference (1971), p. 177; [10] Joy, K.H. et al. (2016) Earth Moon Planets 118, 133–158; [11] Wittman A. and Korotev R. (2013) Lunar Plan Sci. Conf. #3035.