PETROLOGY AND GEOCHEMISTRY OF UNGROUPED DUNITIC ACHONDRITES NORTHWEST AFRICA 12217 AND 12562. Z. Vaci[1], J. M. D. Day[2], M. Paquet[2], C. B. Agee[1], [1]Institute of Meteoritics, University of New Mexico, Albuquerque, NM, USA, [2]Scripps Institution of Oceanography, La Jolla CA 92093 USA.

Introduction: The dunitic achondrite meteorites Northwest Africa (NWA) 12217 and 12562 are highly unusual monomict fragmental breccias (**Fig. 1**). They have petrological characteristics similar to brachinites and brachinite-like achondrites [1,2] and oxygen isotopes that plot in the region of the howardite-eucrite-diogenite (HED) meteorites, angrites, and brachinites [3]. Mineralogically they are unique, containing more magnesian olivine than any previously characterized dunitic meteorite. In this study, we report the petrology and geochemistry of these meteorites which are likely cumulate rocks from a highly differentiated planetary body.

Figure 1: *Hand sample of NWA 12217.*

Petrology and Major Element Geochemistry: Modal mineralogy was determined by greyscale analysis of BSE imagery for both samples. NWA 12217 consists of 93 mod% olivine, 4 mod% low and high-Ca pyroxene, and minor chromite, Fe-sulfide, FeNi metal, andesine plagioclase, alkali feldspar, merrillite, and silica. NWA 12562 consists of 87 mod% olivine, 9 mod% pyroxene, and minor chromite, Fe-sulfide, FeNi metal, and plagioclase. Both meteorites contain vermicular symplectites composed of chromite and low and high-Ca pyroxene (**Fig. 2**). The olivine compositions of NWA 12217 and 12562 are Fa9.1±2.3, Fe/Mn=32±2, n=90, and Fa14.7±5.0, Fe/Mn=40±3, n=60, respectively. Major mineral phases are unzoned in both rocks. Bulk rock major element compositions, determined by ICP-MS [4], are shown in Table 1.

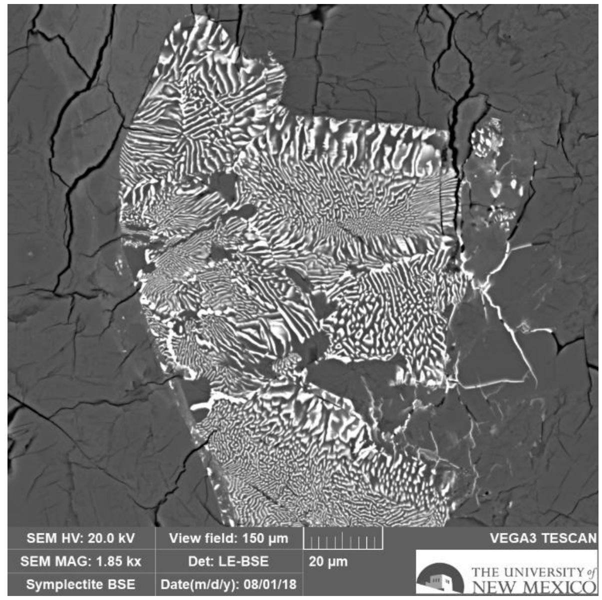

Figure 2: *BSE image of symplectite in NWA 12217.*

(in wt%)	NWA 12217	NWA 12562
SiO_2	41.8	41.3
TiO_2	0.01	0.04
Al_2O_3	0.11	0.99
Fe_2O_{3total}	8.99	15.9
MgO	47.9	40.0
CaO	0.52	0.79
Na_2O	0.02	0.09
K_2O	0.05	0.08
Cr_2O_3	0.33	0.53
MnO	0.21	0.31
P_2O_5	0.02	0.02
Mg#	0.82	0.68

Table 1: *Bulk major element composition of NWA 12217 and 12562.*

Trace Element and Isotope Geochemistry: Both meteorites contain between 2200-3400 ppm Cr, 50-260 ppm Ni, and chondritic to slightly below chondritic Rare Earth Element (REE) values (**Fig. 3**). NWA 12217 is more depleted overall, and both rocks show slight LREE enrichments, with the higher total REE concentrations in NWA 12562 likely because of its higher modal pyroxene content. The barium content is elevated for ultramafic rocks (~20 ppm for NWA 12217 and ~15 ppm for NWA 12562), likely due to terrestrial weathering.

Highly siderophile element (HSE) concentrations in NWA 12217 and 12562 are low (<0.002×CI chondrite), with the exception of Pd and Re contents in NWA

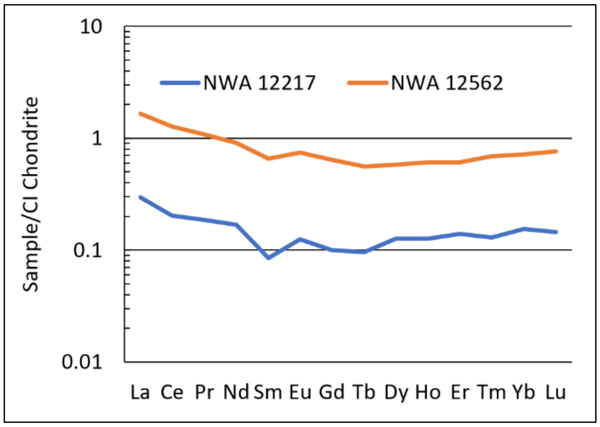

***Figure 3:** CI-chondrite normalized REE abundances for NWA 12217 and 12562, normalized to values in [5].*

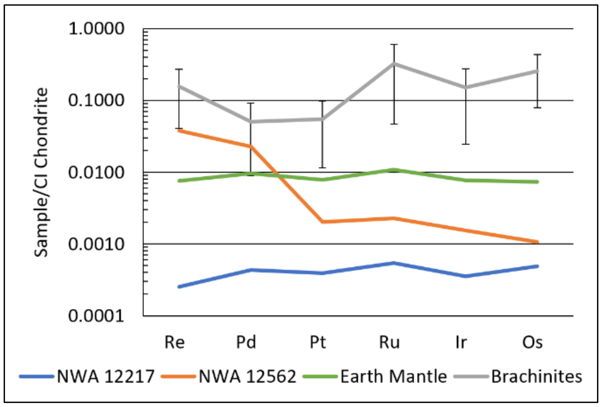

***Figure 4:** CI-chondrite normalized HSE abundances of NWA 12217, NWA 12562, brachinites [6], and the terrestrial mantle [4] normalized to values in [5].*

12562 (13 and 1.5 ppb, respectively) (**Fig. 4**). Osmium isotopic compositions for both rocks are suprachondritic and almost identical (0.136 for NWA 12217 and 0.134 for NWA 12562), though their $^{187}Re/^{188}Os$ values vary between 0.2 (NWA 12217) and 14.3 (NWA 12562) demonstrating that the enrichment in Re is due to recent modification, likely contamination during terrestrial weathering. The HSE patterns and Os isotopic compositions of NWA 12217 and 12562 are in generally chondritic relative proportions. Assuming a chondritic starting composition for their parent body, their HSE compositions imply genesis from a source that experienced metal-silicate equilibrium, followed by re-addition of a minor chondritic (late accretion) component.

Discussion: The overall compositions of NWA 12217 and 12562 are similar, with differences in major and trace element abundances largely attributed to greater modal pyroxene and recent modification of Re and Pd in NWA 12562. Their oxygen isotopic values are also similar ($\Delta^{17}O$ = -0.16 for NWA 12217; -0.22‰ for NWA 12562), suggesting that they are sourced from the same parent body, and possibly the same igneous source. While the two meteorites have oxygen isotopic compositions similar to brachinites, HED meteorites, and angrites, they are quite distinct from these groups in other respects. The two meteorites differ from the brachinites and brachinite-like achondrites both in olivine compositions, as brachinites have higher fayalite contents, and in HSE content; the NWA dunites have low HSE abundances more similar or lower than the terrestrial primitive mantle abundance. They are more similar to dunitic and harzburgitic diogenites, though they differ from the HED meteorites in their feldspar compositions and lower olivine Fe/Mn values (HED average Fe/Mn=47±5). While mineralogically similar to the dunitic angrite NWA 8535 [7], they differ in terms of their low olivine Cr and Ca contents and low Fe/Mn values. Importantly, the Fe/Mn values do not completely rule out potential parent body similarity.

Both NWA 12217 and 12562 are likely sourced from a differentiated planetary body in which HSE were depleted by the separation of metal and silicate. The flat HSE pattern of NWA 12217 suggests replenishment by late accretion, as found in diogenites and in the mantles of Earth, Mars and the Moon (e.g., [4]). The mineralogy and petrology of the two rocks attest to a formation as deep crust or mantle cumulates. While the olivines in brachinites, ureilites, and other primitive achondrites show near-constant Mn/Mg ratios, suggesting that they are residues formed by low degrees of partial melting of chondritic material, NWA 12217 and 12562 show constant Fe/Mn and variable Fe/Mg. This suggests that they were formed by high-degree partial melting and igneous differentiation, rather than partial melt extraction from a chondritic source.

The enrichment in LREE found in NWA 12217 and 12562 could be due to post-crystallization metasomatic processes. This hypothesis would be consistent with the symplectites found in both meteorites, which are similar to those found in lunar rocks. In particular, such inclusions in troctolite 76535 have been suggested to form by addition of a Cr-rich fluid, with the lunar examples containing plagioclase in addition to chromite and pyroxene [8]. The formation conditions of such fluids on planetary bodies is at this point unclear. The symplectites in NWA 12217 and 12562 most closely resemble those found in the ungrouped achondrite Queen Alexandria Range (QUE) 93148. The similar mineralogy and petrology of QUE 93148 also suggest that it could be related to these meteorites.

References: [1] Day et al. (2012) *GCA, 80,* 94-128. [2] Goodrich et al. (2017) *Meteoritics & Planet. Sci., 52, Nr 5,* 949-978. [3] Vaci et al. (2019) *LPS L* #1175. [4] Day et al. (2012) *Nature Geoscience* 5, 614-617. [5] Day et al. (2016) *RiMG vol. 81*, 161-238. [6] Day et al. (2012) *GCA* 81, 94-128. [7] Agee et al. (2015) *LPS XLVI* #2681. [8] Elardo et al. (2012) *GCA 87*, 154-177.