THE MOST SPINEL-RICH SAMPLE FROM THE MOON: A FIRST LOOK AT PINK SPINEL ANORTHOSITE (PSA), PINK SPINEL PYROXENITE (PSP), AND SPINEL-CORDIERITE ASSEMBLAGES (SCA) IN NORTHWEST AFRICA (NWA) 16400.

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Introduction: The first "ground truth" occurrence of mm-sized pink spinel anorthosite (PSA) clasts in lunar meteorite Northwest Africa (NWA) 15500 that fit the diagnostic criteria imposed by remote sensing observations [1] has provided important constraints into a genetic relationship existing between PSA and the lunar highlands Mg-suite [2]; textural and chemical similarities observed between PSA clasts in NWA 15500 with Apollo pink spinel troctolites (PST) favor a petrogenetic model for the formation of PSA (and PST) from varying degrees of magma-wallrock interaction between plagioclase-undersaturated Mg-suite parental melts and assimilated anorthositic crust [3-4].

Despite recent advancements in our understanding of the interaction between early lunar mantle melts produced during lunar mantle overturn of olivine-rich lunar magma ocean (LMO) cumulates and anorthositic crust to produce the observed spinel-bearing Mg-suite lithologies (e.g. PSA, PST) [5-6], it is not obvious what the exact spatial/temporal relationship is between these lithologies and spinel-bearing lithologies containing Al-bearing orthopyroxene and/or cordierite (i.e. spinel cataclasites) [7-8]. Prior work investigating the petrogenesis of spinel cataclasites using thermodynamic equilibrium calculations and experimental modelling have yielded mixed interpretations; these include the formation of spinel cataclasites either within the deep lunar crust (> ~12 km) or in the lunar mantle [7-10], and the formation of cordierite either from decompression of spinel cataclasites to shallower depths or by interaction of spinel with surficial impact melt [9-12]. However, these studies were conducted on incomplete, broken up fragments that may not be representative of the correct mineral modal abundances; to properly evaluate the formation mechanism(s) of Mg-spinel on the Moon, it is desirable to have an intact sample on a mm-sized scale or larger.

Here, we report on the petrology of a diverse suite of mm-sized, intact spinel-rich clasts found within Northwest Africa (NWA) 16400 (Fig. 1), by far the most spinel-rich lunar meteorite (and sample) from the Moon [cf. 13]. This sample contains a lithology (Lith B) comprised of ~51 vol. % spinel (Fig. 2); clast types derived from Lith B include a) PSA and b) other spinel-rich clast types not previously identified in lunar samples: 1) spinel and Al-bearing orthopyroxene-rich clasts (here called "pink spinel pyroxenites" (PSP), and 2) spinel and cordierite-rich assemblages (SCAs).

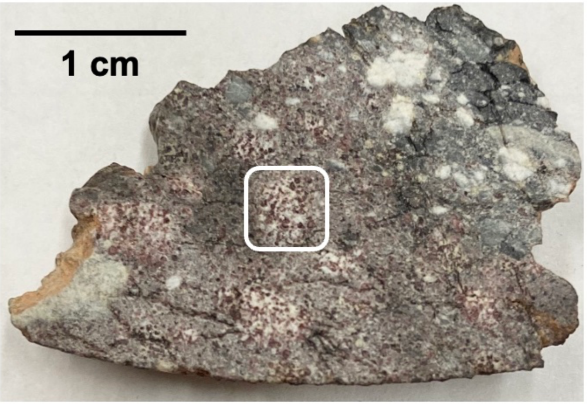

Fig. 1: *Hand specimen image of NWA 16400 slice with visible pink spinel anorthosite (PSA) clast outlined.*

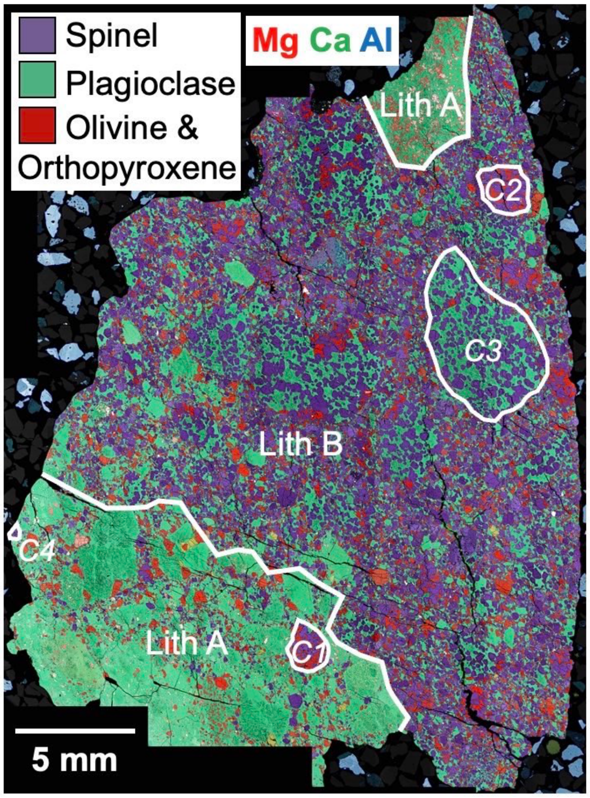

Fig. 2: *False color RBG (Mg, Ca, Al) EDS+BSE chemical map of NWA 16400. Lithologies A and B, and clasts C1-C4 are outlined. Mineral phase color key is displayed. Lith A- polymict fragmental breccia, Lith B- spinel-rich breccia. Lith B comprises ~51 vol. % spinel.*

Results: *Pink Spinel Anorthosite (PSA):* PSA clasts (e.g. C3, Fig. 3c) comprise the largest clast lithologies (up to 6 mm) and are predominantly made up of subhedral, equant spinel (Av. ~ 0.2 mm) and partially amorphized plagioclase (An95.9±0.5); olivine (Fa9.3±0.5) comprises a minor component (~3-8 vol. %). Spinel grains are largely unzoned and compositionally plot in the same Mg# and Cr# field as PSA clasts in NWA 15500 [2] (Fig. 4). Applying the Ol-Sp Fe-Mg geothermometer equation of [14] to multiple PSA clasts (including C3) yields equilibrium temperatures between 1165-1202 °C.

Pink Spinel Pyroxenite (PSP): PSP clasts (e.g. C1-C2, Fig. 3a-b) are comprised of roughly sub-equal proportions of subhedral, unzoned spinel and equant Al-bearing orthopyroxene (Fs11.8±0.4 Wo0.7±0.1, Al_2O_3 = 6.2±1.4 wt. %); PSP C1 contains anhedral cordierite (Mg# = 94.6±0.2, occurring as rims along spinel grains), and accessory plagioclase (An91.1±0.9) and olivine (Fa8.2±0.4). Spinel compositions from PSP clasts have a similar Cr# to PSA clasts, but a slightly lower Mg# (Fig. 4). Applying the thermodynamic equilibrium calculations of [7-8] to PSP C1 yields an equilibrium temperature and pressure between 963-970 °C and 648-842 bars respectively; assuming a lithostatic gradient of 50 bars/km [7], this yields an equilibrium depth between 13-17 km.

Spinel-Cordierite Assemblages (SCAs): SCAs (e.g. C4, Fig. 3d) display granoblastic to porphyritic textures comprised of polygonal, unzoned spinel, anhedral cordierite (Mg# = 93.8±0.3), and minor, partially amorphized plagioclase (An93.9±0.9) joined at 120° triple junctions. Spinel compositions have a lower Mg# and Cr# than both PSA and PSP clasts (Fig. 4).

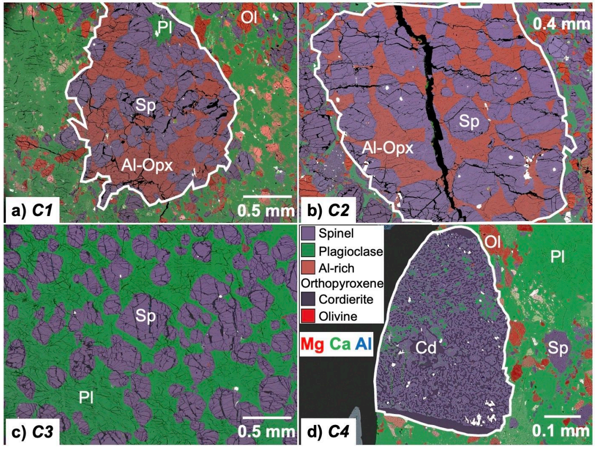

Fig. 3: *False color RBG (Mg, Ca, Al) EDS+BSE chemical map of clasts C1-C4. Mineral phase color key is displayed. C1/C2- PSP; C3- PSA; C4- SCA.*

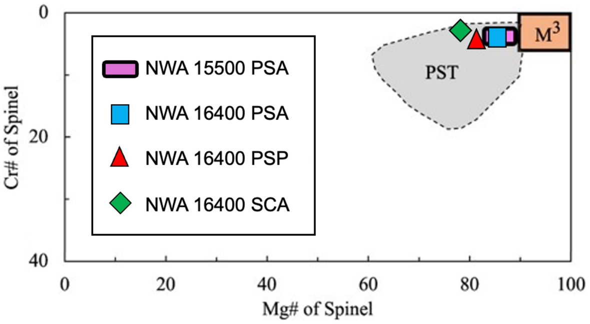

Fig. 4: *Spinel Mg# (Mg/(Mg+Fe)*100) vs. Cr# (Cr/(Cr+Al)*100) for spinel grains from PSA, PSP, and SCAs in NWA 16400, and from PSA in NWA 15500 [2]. Shaded regions indicate spinel compositions from PST, and PSA by remote sensing using M^3 data [1,3,15].*

Discussion: The simultaneous occurrence of PSA and PSP clasts in NWA 16400 may be indicative of a spatial/temporal relationship existing between deep-seated PSP and PSA parental melts. As spinel is not expected to crystallize as a major phase in LMO crystallization models [16], this could favor the formation of PSP by assimilating anorthositic crust into a parental Mg-suite melt with a relatively lower Ca/Al ratio and Mg# than that which produced PSA and PST.

The occurrence of cordierite within PSP C1 that is not in contact with matrix impact melt supports models involving the formation of cordierite from decompression of spinel to shallower depths due to impact excavation [9,11]. Here (~13-17 km), the PSP clasts may have been mixed with or intruded by later forming PSA, and the entire assemblage subsequently excavated by a later impact event onto the lunar surface.

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