

APOLLO 17 SAMPLE 72415 - A FRAGMENT OF THE LUNAR MANTLE? K. K. Bhanot^{1,2}, H. Downes^{1,2}, E. Jennings¹, S. Wotton¹. ¹Department of Earth and Planetary Sciences, Birkbeck University of London, Malet St, London WC1E 7HX UK (h.downes@ucl.ac.uk); ²Department of Earth Sciences, Natural History Museum, Cromwell Rd, London SW7 5BD UK.

Introduction: An unresolved problem of lunar science is the nature and composition of the lunar mantle. Many models have been published on the composition of the lunar mantle, resulting in a range of possible Mg#s of the bulk rocks and forsterite (Fo) compositions of the constituent olivine. Here we discuss a sample which is a possible fragment of the lunar mantle brought to the surface of the Moon by the Serenitatis impact and collected by Apollo 17 astronauts from the Taurus-Littrow valley.

Lunar mantle: No samples of the lunar mantle have yet been unambiguously identified in the Apollo sample collection or the lunar meteorite collection, although [1] described a dunite clast in a brecciated meteorite which may be part of the lunar mantle. However, the lunar mantle has been extensively studied through indirect means. Electromagnetic and seismic data sets place constraints on the interior profile that are consistent with the lunar mantle being composed primarily of olivine and orthopyroxene with lesser amounts of clinopyroxene and garnet.

Dunite clasts: Apollo samples 72415–72418 were chipped from a large clast in Boulder 3 at Station 2 in the Taurus-Littrow valley. Astronaut Schmitt recognized the clast as being composed of light pastel green material in a paler matrix and correctly suggested that it was "olivine and something". The samples were described as cataclastic dunites composed of 93% olivine (Fo₈₆₋₈₉), 4% plagioclase (An₈₅₋₉₇) and 3% pyroxene (En₈₄Wo₃Fs₁₀ and En₅₀Wo₄₂Fs₄). The dunites also display intergrowths of spinel and different minerals that may have formed as a result of either metamorphism or crystallisation. The dunites were determined to be 4.55 Ga old, and thus considered to be a product of primary lunar differentiation. It is these dunite clasts and their minute blebs of spinel "symplectites" which are the object of this study.

Petrological Study: In thin-section, the dunite is a breccia composed mainly of olivine clasts in a very fine-grained matrix (Fig. 1). Olivine clasts show a range of sizes, with the largest measuring 0.6–1.7 mm, smaller ones down to 0.1 mm and fine matrix clasts measuring ~50–100 µm. All olivines have approximately the same Fo (Mg/(Mg+Fe)) value of 88, which is at the lower end of the range of lunar mantle compositions suggested by modelling, and surprisingly similar to the Fo content of the terrestrial mantle.

Most of the olivine clasts are angular, but a few have more rounded edges. They often show fractures which terminate at their edges and do not continue into the matrix. These irregular fractures are probably due to impact shock. Some olivine grains show undulose extinction and mosaicism (Figure 1), also probably a result of shock metamorphism.

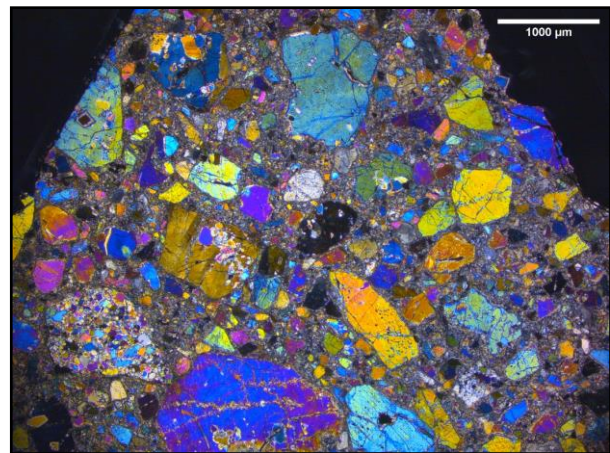


Figure 1. Photomicrograph (crossed polars) of brecciated olivine fragments in TS 72415, 53. 1 mm scale bar.

Spinel textural types: Four different textures involving spinel have been identified, varying in size, mineral associations and relative abundances (Figure 2). One common texture (**Type A**) is a ~0.3 mm symplectite of spinel + diopside ± enstatite ± Fe-Ni metal, with cpx >> opx. Type A occurs as individual clasts formed by clusters of spinel and pyroxene, in which spinel displays a strong vermicular texture with elongate branches. In contrast, **Type B** is an association between spinel + anorthite and is closely associated with olivine are large generally elliptical in shape with approximate dimensions of 1.4 x 1.3 x 0.5 mm. Spinel forms both blocky and elongate grains (Fig. 2). Abundant **Type C** textures are microsymplectites, only ~30 µm in size, found inside individual olivine clasts. They are composed of strongly vermicular spinel with diopside ± enstatite (Fig. 2). A fourth texture (**Type D**) is composed of composed of spinel and diopside, and is also only found inside olivine clasts either as linear channels or as spinel blebs isolated on the rims of olivine clasts where they form lobate arms. These spinel/pyroxene/olivine reaction rims are 75 µm in average diameter.

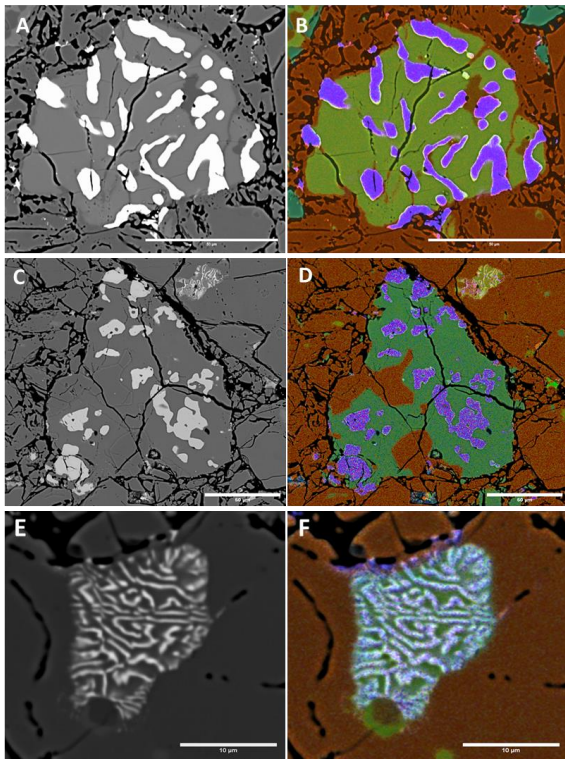


Figure 2. BSE and false-colour X-Ray maps of spinel textural types: (A,B) = Type A symplectite of $sp + cpx + opx$; (C,D)=Type B complex of $ol + an + sp + sp$; (E,F)= Type C microsymplectites of $sp + cpx + opx$. Figs A-D scalebar = 50µm. Figs E-F scalebar = 10 µm.

Micro-CT analysis: Investigations of the 3D interiors of the dunite fragments confirm that spinel occurs in distinct textural types. **Type A** spinel-pyroxene clusters are single grains with randomly orientated ellipsoidal intergrowths of highly vermicular spinel within pyroxenes. Individual clusters generally have rounded edges but can have angular margins, indicating fracturing. **Type B** clusters of spinel-anorthite-Fe-metal-olivine are highly complex intergrowths with blocky or elongate spinel. Spinel branches are elongate and form linear features which display a weak parallel orientation and often terminate in highly elliptical and very flat plate-like structures. In 2D slice images, the blocky spinel blebs appear as cross-sections of the linear spinels. **Type C** spinel-pyroxene inclusions inside olivines cannot be easily imaged in 3D by CT scanning because of their small size. However, 2D slice images show small high-density spinel inclusions randomly distributed in olivine grains. The very small **Type D** inclusions can also only be identified in 2D slices.

Interpretation: Type A spinel-pyroxene clusters originated at a depth of 420 km because they are the result of a metamorphic transformation of garnet

brought on by decompression following the solid state reaction of $ol + gt \rightleftharpoons cpx + opx + sp$ [2]. The reconstructed garnet composition is unusually Cr-rich. The garnet to spinel transition pressure (around 20 kbar) provides a minimum constraint on the ultimate depth of origin of the Type A symplectites. However, LMO crystallisation modelling indicates that garnet would only have fractionated much deeper, close to the lunar core-mantle boundary at 4 GPa. The presence of these symplectites at the Moon's surface therefore implies an overturn in the lunar mantle that has moved material through its entire depth. They were moved by the overturn to a depth of ca. 70 km, equivalent to 8 kbar pressure in the lunar mantle where anorthite is stable. Thus the anorthite-rich Type B clusters were probably formed at this depth, perhaps by melting during the Serenitatis impact. The origin of Types C and D microsymplectites is uncertain; they may be related to mafic or ultramafic melts that passed through the lunar mantle prior to excavation by the Serenitatis impactor.

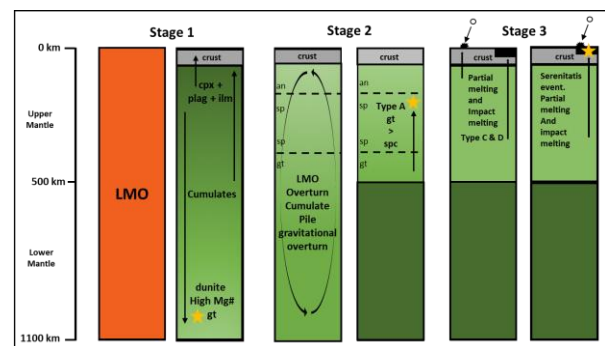


Figure 3. Diagram showing history of each spinel textural type in 72415. Stage 1: Formation and differentiation of LMO (4.46 Ga) with a crystallisation sequence of $ol \rightarrow opx \pm ol \rightarrow ol \rightarrow cpx \pm plag \rightarrow cpx + plag \rightarrow cpx + plag + ilm$ [3]. Crystallization of garnet at base of mantle. Stage 2: Conversion to Type A spinel-pyroxene cluster by mantle overturn. Type C and D melt inclusions related to impact melts and partial melting prior to the Serenitatis event. Stage 3: Type B spinel-anorthite melt inclusions related to melt generated during the Serenitatis impact event (3.97 Ga).

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References: [1] Treiman A.H. and Semprich J. (2019) 50th LPSC Abstract #1225. [2] Schmitt H. H. (2016) 47th LPSC Abstract #2339. [3] Shearer C. K. and Papike J.J. (1999) *American Mineralogist*, 84, 1469-1494.