DIFFERENT TYPES OF SPINEL SYMPLECTITES IN LUNAR DUNITE 72415 AND 72417. K. K. Bhanot[1,2], H. Downes[1,2], N. Almeida[2], C. M. Petrone[2], E. Humphreys-Williams[3] and B. Clark[3], [1]Dept. of Earth and Planetary Sciences, Birkbeck, University of London, Malet St. London, WC1E 7HX, UK (krishan.bhanot@rigaku.com), [2]Department of Earth Sciences, Natural History Museum, Cromwell Rd, London, SW7 5BD, UK, [3]Imaging and Analysis Centre, Natural History Museum, Cromwell Rd, London, SW7 5BD, UK.

Introduction: Spinel symplectites have been reported in lunar dunites from the Taurus–Littrow valley [1-6]. Samples 72415 to 72418 were taken from a 10 cm size clast from boulder 3, station 2. Sample 72417 yielded an age of 4.55 ± 0.1 Ga [7]. Hand specimens are brecciated and composed of pale-green, translucent olivine grains up to 10 mm in size, set in a fine-grained matrix. We have investigated Apollo 17 samples 72415,4 and 72417,9003 by electron microprobe analysis (TS 72415,53) and micro-CT.

Electron microprobe results: The sample shows a brecciated texture of angular to sub-angular fragments (Fig. 1) of olivine Fo_{86-89} ([1] in a matrix of smaller angular fragments, with rare diopside, anorthite, spinel and Fe-Ni metal. Olivine grains show shock features with undulose extinction and mosaicism. Fractures crossing olivine crystals are common.

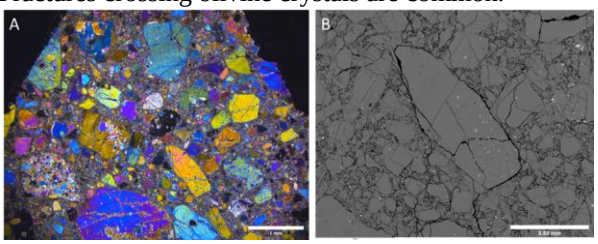

Figure 1. (a) Photomicrograph (cross-polars) of brecciated olivine fragments in TS 72415,53. Scalebar = 1 mm. (b) BSE image of angular to sub-angular olivine clasts in same sample. Scalebar = 0.5 mm.

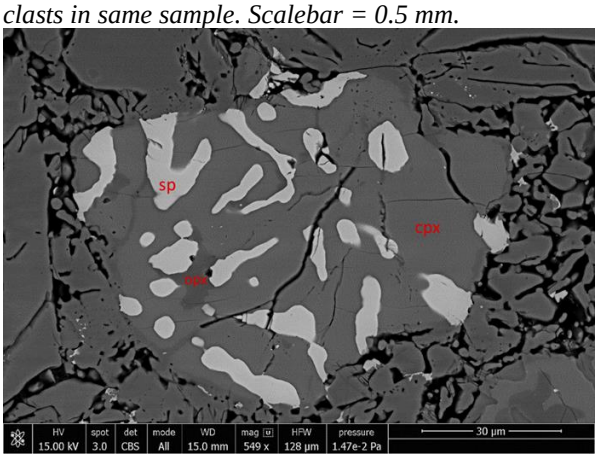

Figure 2. BSE image of a spinel + clinopyroxene + orthopyroxene symplectite (Type 1a) clast from TS 72415,53. Scalebar = 30 microns.

We have found three types of symplectite with different compositions of spinel. One symplectite (spinel Type 1a) is between spinel (sp) + diopside (cpx) ± enstatite (opx) (Fig. 2); another is between spinel + anorthite (an) (spinel Type 1b) and is closely associated with olivine (ol) (Fig. 3). Spinel in Type 1a intergrowths have Mg# = 48 and Cr# = 67, whilst spinel in Type 1b intergrowths have Mg# = 60 and Cr# = 49. A third type of symplectite (spinel type 1c) is much smaller (<30 µm in size), very abundant, only found inside single olivine clasts and is composed of spinel + diopside ± enstatite (Fig. 4). Type 1c spinel is intermediate in composition between Types 1a and 1b.

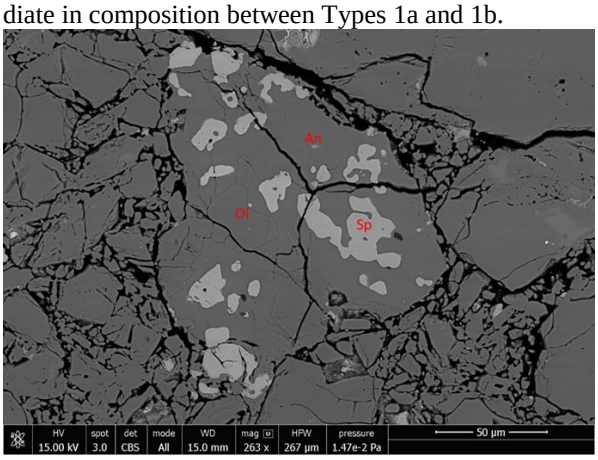

Figure 3. BSE image of a spinel + anorthite + olivine symplectite (Type 1b) clast in TS 72415,53. Scalebar = 50 microns.

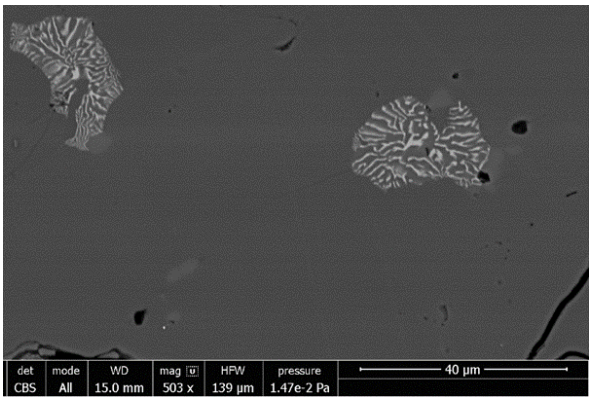

Figure 4. BSE image of spinel + diopside symplectite inclusions (Type 1c) in an olivine clast in TS 72415,53. Scalebar = 40 microns.

Micro-CT results: Micro-CT analysis of lunar dunites confirms that spinel forms complex structures of varying size, shape and texture (Fig. 5). Spinel type-1a forms randomly orientated elliptical (<0.6 mm)

structures with a highly vermicular texture in which spinel is wholly contained within a single grain. Individual spinel branches are in contact with each other and form a single crystal. Individual spinel structures have rounded edges but also include angular edges indicating fracturing. Spinel type-1b forms smaller structures which are elongate and flat, and formed around adjacent grains and thus is interstitial. Spinel type-1c cannot be imaged because of its small size.

A completely new large unfractured high density structure with many individual elongate branches is seen to form linear channel-like features (Fig. 5). These features often terminate at plate-like structures. Such structures have only be seen in the CT scans. We interpret this as a melt texture (here termed Type 2) but this requires further investigation to confirm that it is spinel or possibly troilite.

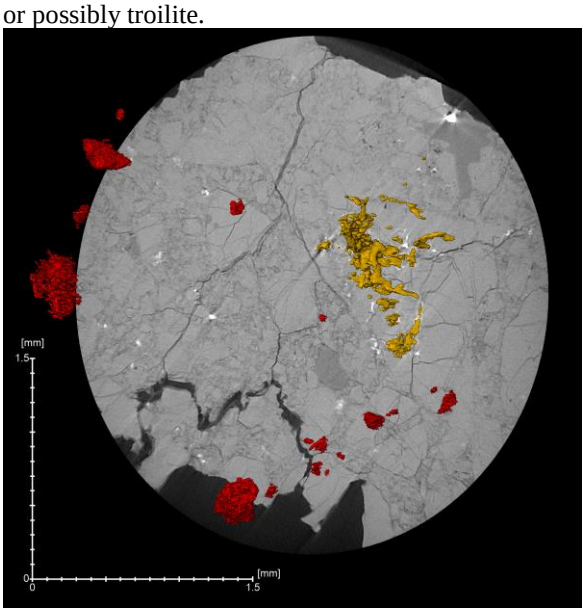

Figure 5. 3D rendered micro-CT image from lunar dunite 72417,9003 showing two contrasting textures: spinel type 1a and 1b (red) and type 2 (yellow). Scale-bar = 1.5 mm.

Discussion: EMPA data coupled with the micro-CT images have revealed that lunar dunite 72415 and 72417 have 4 distinct spinel textures, probably formed by different processes (spinel Types 1a, 1b, 1c, and structure Type 2 which may be spinel or troilite). Spinel 1 textures are symplectites including sp + cpx ± opx ± an, whereas the newly discovered Type 2 structure forms elongate veins and channels.

Several studies have discussed the origin of symplectites in lunar dunites. The interpretations fall into two major categories: shallow formation (crust) and deep formation (mantle). Based on the observation that the symplectites commonly occur along ol-plagioclase grain boundaries (our Type 1b), [2] suggested that the stability pressure for ol + plagioclase + spinel had not been exceeded, so crystallization was shallow. They proposed that the dunites are ol + sp cumulates and that late stage adcumulus ol growth was associated with crystallization of opx, cpx, an and Cr-sp as vermicular intergrowths. [5] proposed that variations in texture and phase assemblages reflect local variations in the trapped melt composition.

In contrast, [1] reported zones of sp symplectites (our Type 1a, 1b) and tiny ovoid inclusions in olivine (our Type 1c). The intergrowths were interpreted as existing prior to excavation and that the lunar dunite represents a very early differentiate derived from the upper mantle, i.e. a cumulate formed during early lunar differentiation and associated gravitational settling. [3] also reported eutectoid intergrowths of sp + pyx and occasional plagioclase (our Type 1a and 1b) and considered that the lunar dunite formed under high pressures and temperatures, and originally contained garnet because the microsymplectites (our Type 1c) have an idealized bulk composition of a garnet. [4] proposed that the symplectite intergrowths were the result of the breakdown of garnet. [8] supported the hypothesis of late overturn of magma ocean cumulates, and suggested that the related pressure release initiated decomposition of a high-pressure Cr-rich garnet present in the original deep mantle cumulates.

Based on texture and mineral chemistry of the spinels, we propose that Type 1a, b and c have different origins. The large sp + cpx symplectites (sp Type 1a) are formed from decompression of garnet, and the garnet was brought up from ~420 km depth by convective overturn. Type 1b have a shallower origin with interaction of ol and decompression melts forming ol + an + sp sympletitic textures. Type 1c have an exsolution origin, possibly as decompressed melt inclusions that cooled slowly and crystallised. Type 2 textures show no signs of fracturing and thus make this texture younger than all Type 1 spinel textures and most likely related to shock melting.

Acknowledgments: H. Schmitt for collecting the samples, R Zeigler (NASA) for providing the samples, NHM, Birkbeck. M. Hippler and M. Clarke at Rigaku Europe for supporting this project.

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