LUNAR MANTLE ROCKS IN DHOFAR 1528.

A. Wittmann[1] and R. L. Korotev[2]
[1]LeRoy Eyring Center for Solid State Science, Arizona State University, axel.wittmann@asu.edu,
[2]Department of Earth & Planetary Sciences, Washington University in St. Louis, korotev@wustl.edu.

Introduction, Sample & Methods: Lunar Mg-rich spinel and Al-rich orthopyroxene assemblages are candidate mantle rock lithologies [1]. We present additional observations on such assemblages in lunar meteorite Dhofar (Dho) 1528 [2] and compare them to impact basin ejecta and the four other known samples that contain similar fragments [1, 3–5]. Using optical microscopy and electron microprobe analysis at the LeRoy Eyring Center for Solid State Science of Arizona State University, we analyzed a new 126 mm^2 thin section of Dho 1528.

Results: We found 24 assemblages of variably Mg-rich spinel. One assemblage is a melt clast with ~10 µm zoned, euhedral to skeletal spinel crystals ($Mg_{0.93}Fe_{0.11}Al_{0.92}Cr_{0.06}$). The other 23 spinel assemblages ($Mg_{0.88–65}Fe_{0.38–0.14}Al_{0.95–0.81}Cr_{0.18–0.04}$) are anhedral to euhedral crystals 25 to 250 µm in size. Most of them occur as isolated, strongly deformed fragments but a few are intergrown with plagioclase ($Ab_{5.4–1.8}An_{98–94}Or_{1.0–0.0}$), olivine ($Fo_{93–70}$) and orthopyroxene ($En_{85–75}Fs_{23–12}Wo_{5.0–0.8}$) that contains up to 8.5 wt% Al_2O_3. Ten of these spinel crystals show ~0.01–1 µm inclusions of TiO_2 and one spinel grain in contact with vitric impact melt is intergrown with a ~10 µm cordierite crystal. Thermodynamic modeling [3,6] yields minimum depths of equilibration of 14–37 km for the Mg-rich spinel assemblages. However, more recent thermodynamic data gives minimum depths of equilibration on average 8 km deeper [1].

Discussion: *Phenocryst spinel.* The most Mg-rich lunar spinel crystals occur as phenocrysts in impact melt clasts. A few of these spinel crystals have compositions that match the criteria for "pink spinel anorthosites" (PSA, e.g. [7]). However, impact melt-phenocryst spinel is typically associated with more mafic components than defined for PSA.

Cumulate spinel. A sub-group of 10 annealed cumulate spinel crystals has compositions enriched in Fe and Cr that suggest re-equilibration at temperatures >900ºC and depths ≤25 km. The remaining spinel crystals indicate equilibration at depths ≥25–37 km and temperatures <900ºC. Their compositions fall within the range of the other lunar spinel assemblages for which depths of equilibration ≥25 km have been determined [1–5]. Considering that the most recent estimate for the average thickness of the lunar crust is ~34 km [9], and that several lunar impact craters excavated the lunar mantle [8], minimum depths of equilibration of ~25–37 km (or 33–45 km [1]) for the spinel assemblages in Dho 1528, suggests a more likely origin of the Mg-rich assemblage of spinel, orthopyroxene and olivine in Dho 1528 in the upper mantle of the Moon than in its crust.

Dho 1528 vs Luna 20. The bulk rock composition of Dho 1528 indicates the chemical character of a magnesian feldspathic breccia [24 wt% Al_2O_3; mol% Mg/(Mg+Fe) = 73] with a slight enrichment in incompatible elements (e.g., 1.4 pm Th) [10]. Compositionally, Dho 1528 is very similar to Luna 20 soil, breccia components and impact melts that are interpreted as ejecta from the 740 km Ø Crisium impact basin [11–14], which excavated the lunar mantle [8]. Although no Al-rich orthopyroxene (~4 wt% Al_2O_3) was found in Luna 20 samples and none of the abundant Mg-rich Luna 20 spinel grains [e.g., 15] matches the compositions of lunar spinel for which depth estimates ≥25 km have been derived [1–5], it is still plausible that Luna 20 spinel grains represent impact-processed lunar mantle components.

Summary & Outlook: Dho 1528 is the first lunar meteorite that contains Mg-rich spinel, Al-rich orthopyroxene, Mg-rich olivine, and cordierite. These spinel assemblages record equilibration at depths ≥37–45 km, possibly deeper than 100 km in the Moon [2], and probably below the on average 34 km thick lunar crust [9]. This challenges the assumption that all pristine magnesian lunar rocks formed in the crust [17] and supports the notion that the lunar mantle is a heterogenous pile of mafic cumulates [16].

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