ALLAN HILLS (ALHA) 81005 40 YEARS ON: NEW INSIGHTS FROM DUNITIC AND TROCTOLITIC MG-SUITE CLASTS.

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Introduction: At the time of writing, it has been just over 40 years since John Schutt and Ian Whillans sampled meteorite Allan Hills A81005 (hereafter referred to as ALHA81005) on the Antarctic icefield during the final day of the 1981-1982 Antarctic Search for Meteorites (ANSMET) expedition [1]. The year 2023 specifically marks 40 years since ALHA81005 became the first meteorite to be identified as lunar in origin. The original sampled mass weighed 31.39g and was characterized by a fusion crust which covered ~50% of its surface [2]. It is officially classified as an anorthositic (polymict) regolith breccia [3] but has also been referred to as an anorthositic gabbro [4] and a glassy, olivine-rich regolith breccia [5]. Within it, a wide variety of clast types have been documented including high- and low-Ti basalts, anorthosites, norites, troctolites, in addition to impact melts and brecciated clasts (granulitic and cumulate). Collectively, clasts comprise ~40% of ALHA81005 [6]. A rare pink spinel-rich clast was identified in 2011 in sample split -9 and remains today the only documented occurrence of this lithology both within ALHA81005 and throughout the lunar meteoritic and returned sample collection [7].

In this study, we report results from a detailed textural, mineralogical, and geochemical study of ALHA81005,92. We report the occurrence of a spinel-bearing dunite clast in addition to several pink spinel-bearing troctolitic clasts.

Methods: Initial back-scatter electron (BSE) imaging of ALHA81005,92 was completed at the Center for Advanced Microscopy and Imaging (CAMI) at Miami University using a Zeiss Supra 35 Variable Pressure Field Emission Gun-Scanning Electron Microscope (VP FEG-SEM). Qualitative X-ray spectra and initial elemental data were collected on a Bruker Xflash 5010 Energy Dispersive X-ray Spectrometer (EDS). Additional BSE images complemented the acquisition of major and minor element analyses on select mineral grains using a Shimadzu EPMA-1720HT electron probe microanalyzer at the Shimadzu Center for Environmental, Forensic, and Material Science at the University of Texas at Arlington.

Results: Figure 1A shows the studied dunite clast in cross polarized light (XPL). Figure 1B shows two distinct pink spinel grains within a clinopyroxene-bearing leucotroctolite clast in plane polarized light (PPL).

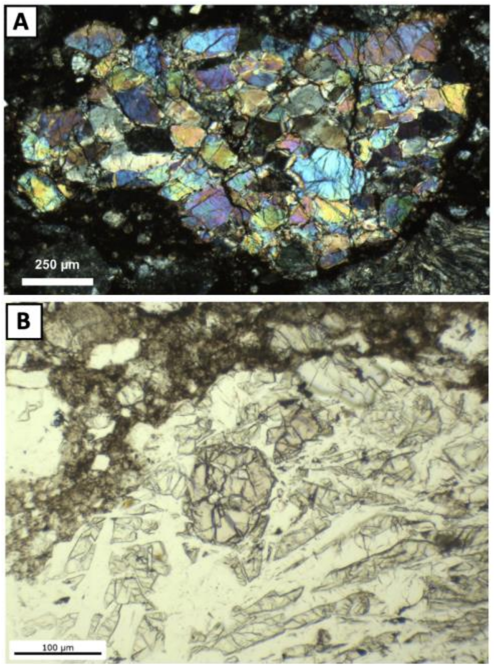

Figure 1A: Dunite clast in ALHA81005,92, shown in XPL. **1B**: Two pink spinel grains within a leucotroctolite clast, shown in PPL.

Olivine compositions within the dunite clast exhibit a narrow compositional range from Fo_{88} to Fo_{83} (avg=$Fo_{87.6}$±2.4, 2σ; median = $Fo_{87.9}$). Spinels within the dunite clast (figure 2A,B) are anhedral and are, in part, associated with a Fe-Ni-Co-Cr alloy: 70% Fe, 25% Ni, 3% Co, 2% Cr by weight.

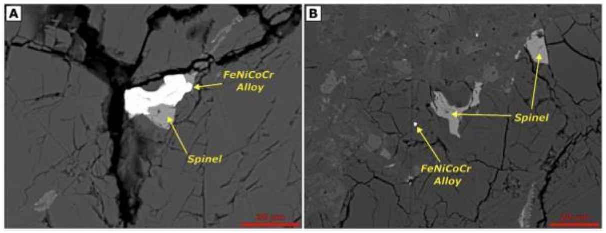

Figure 2A,B. BSE images of olivine-hosted spinel within the dunite clast.

With respect to Mg# (100 x Mg / Mg + Fe^{2+}), dunitic spinels range from 45.1 to 52.5 with corresponding Cr# (100 x Cr / Cr + Al) ranging from 72.5 to 75.7.

In figure 3, x-ray element maps of three spinel-bearing clasts are shown. In fig. 3A,B clast Spn-1 is a leucotroctolite with 75.4% plagioclase, 19.4% olivine, and 5.2% spinel. In fig. 3C,D clast Spn-2 is a clinopyroxene-bearing leucotroctolite with 67.6% plagioclase, 23.6% olivine, 5.8% clinopyroxene, and 3% spinel. In fig. 3E,F clast Spn-3 is an olivine leuconorite with 65.5% plagioclase, 15.3% olivine, 18.3% orthopyroxene, and 1% spinel.

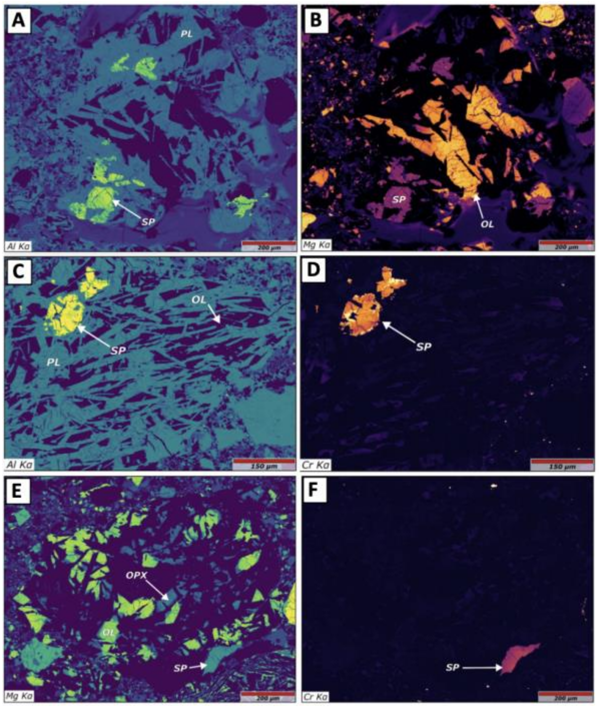

Figure 3. X-ray elemental maps of 3 spinel-bearing clasts (Spn-1: A,B; Spn-2: C,D; Spn-3: E,F).

Collectively, plagioclase compositions across all three clasts range from $An_{94.9}$ to $An_{98.7}$. In clast Spn-1, spinels are euhedral to subhedral, exhibit Mg# from 78.4 to 83.6 and corresponding Cr# from 8.3 to 1.7. In clast Spn-2, spinels are also euhedral to subhedral with a limited range in Mg# from 80.2 to 81.0 and Cr# from 4.7 to 5.5. Clast Spn-3 is easily distinguished from Spn-1 and Spn-2 by the presence of orthopyroxene and two distinct plagioclase morphologies; i) tabular, elongate grains and ii) larger, blocky grains. Spinel grains are anhedral and exhibit a limited range of Mg# from 85.4 to 85.7, with corresponding Cr# from 4.9 to 5.6.

Discussion: lunar dunites are often associated with the Moon's intrusive Mg-suite which has been proposed to represent mafic crust development following crystallization of a primordial lunar magma ocean. Within the Mg-suite itself, dunites (and gabbros) are rare [8]. Throughout the lunar sample collection (Apollo, Luna, Chang'e), dunites are also one of the rarest rock types with examples proposed to exist in the following lunar samples: 14304, 14321, 72415-72418, 74275, and Northwest Africa (NWA) 11421. With this work, ALHA81005 is added to this list. Considering olivine Fo, wt. % CaO, and Cr (ppm) contents, the ALHA81005 dunitic olivines are consistent with a Mg-suite origin (Fig. 4A). In addition, they exhibit low Cr abundances at high Fo and their Cr/Mn systematics are distinct from compositions that would be expected for LMO cumulates [9].

Figure 4B summarizes the Mg# vs. Cr# systematics for all sampled spinels in this study. For comparison, spinels from previous studies of Mg-suite lithologies are also shown (e.g., dunites, gabbronorites, norites, spinel troctolites, and troctolites). As shown, ALHA81005 dunitic spinels are consistent with Mg-suite dunites while ALHA81005 spinels within the troctolitic (and noritic) clasts are similar to those in Mg-suite spinel troctolites at relatively high Mg# and low Cr#.

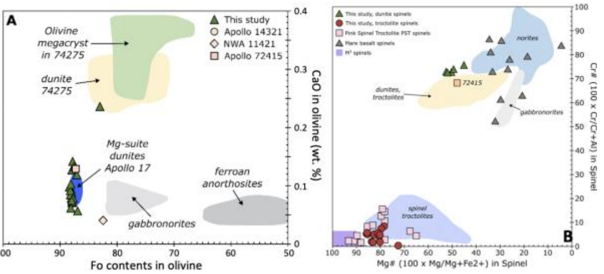

Figure 4. A: Fo vs. wt. % CaO in olivine (dunite clast). B: comparison of sampled spinels in this study of ALHA81005 with spinels in Mg-suite lithologies.

It is further noted here that sampled spinels within ALHA81005 are also compositionally distinct from the spinel-rich lithologies which have been identified on the lunar surface via remote sensing (e.g., from the Moon Mineralogy Mapper (M^3); Fig. 4B) [10]. It is therefore highly likely that the pink spinel troctolites that exist within the lunar sample collection do not represent sampling of the locations identified by M^3.

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References: [1] Righter K. (2007) *Lunar Meteorite Compendium*. [2] Righter K. (2018) *Lunar Meteorite Compendium*. [3] Korotev et al. (1983) *GRL*, v.10; 829–832. [4] Laul et al. (1983) *GRL*, v.10; 825-828. [5] Ostertag & Ryder (1983) *GRL* v.10; 791-794. [6] Mason B (1983). *AMN* v.6(1). [7] Gross & Treiman (2011) *JGR* v.116; E10009. [8] Shearer & Papike (1999). *Am Min* v.84; 1469-1494. [9] Elardo et al. (2011). *GCA* v.75; 3024-3045. [10] Sun et al. (2017). *EPSL* v.465; 48-58.