40 YEARS OF STUDYING ALLAN HILLS (ALHA) 81005: WHAT ELSE COULD WE POSSIBLY LEARN? PLENTY!

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Introduction: Happy 40-year anniversary to Allan Hills (ALHA) 81005! ALHA 81005 was recovered from Antarctica in early 1982 and has been under the microscope ever since. Nearly a year after it was recovered, ALHA 81005 was given the distinction of being the first meteorite recognized as lunar in origin and classified as an 'anorthositic regolith breccia' potentially representing material not sampled by Apollo or Luna missions [1, 2, 3]. ALHA 81005 was also significant evidence in the argument that material from the Moon and Mars could be delivered to Earth after an impact on their parent body [4, 5]. Of note from recent work on ALHA 81005 is the identification of material whose petrogenesis may be related to the magnesian suite. Material originating from the magnesian suite is rare outside of the Imbrium basin ejecta. This has significant implications for early lunar differentiation [6]. This study aims to build on previous work through a detailed petrographic and microgeochemical investigation of the clasts, mineral grains, and accompanying textures present in three thin-sections: -23, -80, and -92. Results will be used to assess the lithological homogeneity and heterogeneity of ALHA 81005 as well as differentiated rocky objects within our Solar System more broadly. In addition, we aim to conduct a chronological study of dateable mineral phases (e.g., apatite) using long-lived chronometers: the U-Pb system. This component of our work aims to provide constraints on the timing of events which led to the petrogenesis of ALHA 81005 within the context of the Moon's geological history.

Methodology: Guided by optical microscopy, clast and mineral grain maps were generated for each thin section (**Figure 1**). Accompanying backscattered electron (BSE) images (**Figure 2)** and elemental maps were acquired on a Zeiss Supra 35 Variable Pressure Field Emission Gun-Scanning Electron Microscope (VP FEG-SEM) at Miami University's Center for Advanced Microscopy and Imaging (CAMI). Initial elemental maps were captured at a pixel size of 512x512 for 15 minutes to broadly assess mineralogical and elemental distribution throughout each thin-section. Clast 27 (Figure 2) is basaltic containing laths of anorthite with a glassy background of pyroxene compositions (augite & pigeonite). From these initial maps, individual clasts and mineral grains which collectively represented the variability present in each thin section were chosen to be mapped at a pixel size of 2048x1536 for 1 hour. Acquired images guided selection of sites for *in-situ* major element analysis via electron probe microanalysis (EPMA) at Louisiana State University

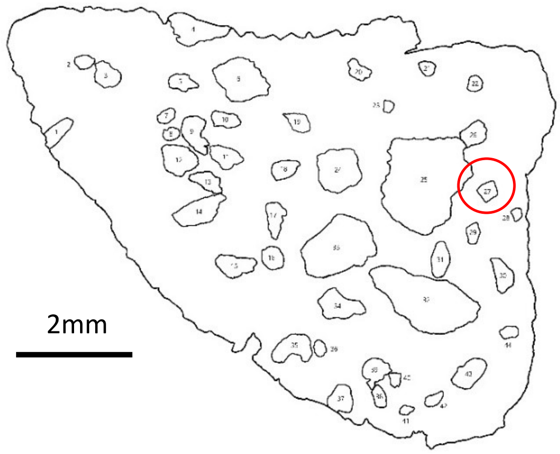

Figure 1: Clast map of thin-section 23. Red circle indicates clast 27 in Figure 2.

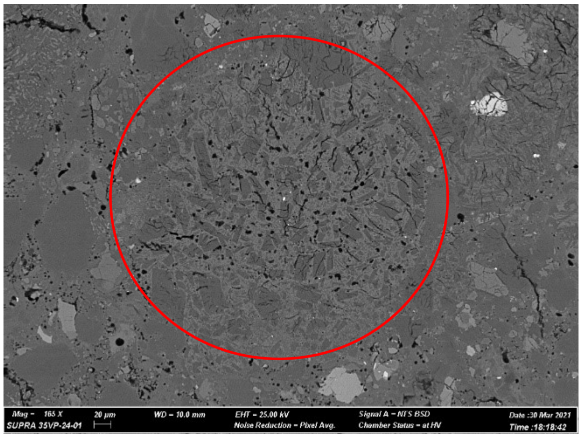

Figure 2: BSE image of clast 27 in thin-section 23. Red circle indicates extent of clast 27.

and trace element analysis via laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) at the University of Arkansas. The SEM-EDS approach follows similar work presented in previous studies [6, 7], but has been adapted for the instrumentation and software available at CAMI.

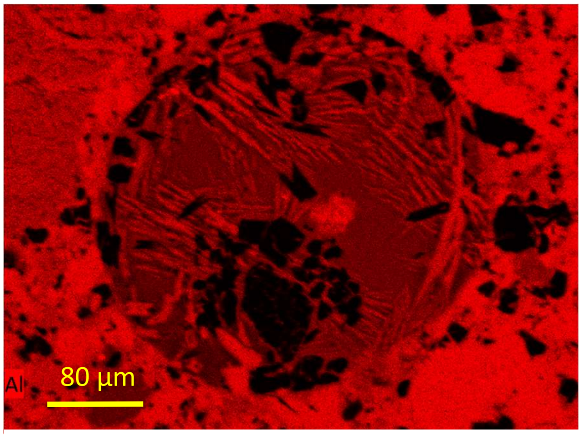

Figure 3: Aluminum (Al) element map of region 21, section -80: crystalline spherule.

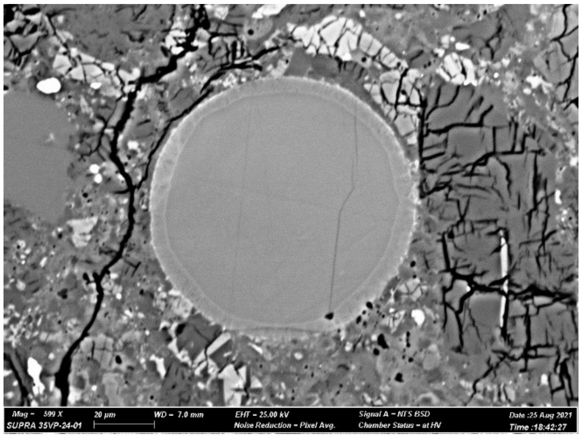

Figure 4: BSE image of a melt pocket, section -80.

Petrography: Phases identified across all three thin sections include olivine, pyroxene (ortho- and clino-), plagioclase, taenite, troilite, spinel, silica, and calcium phosphate. Norite and troctolite dominate the clast population, in addition to anorthosite. Crystalline spherules and melt pockets were observed in thin sections -23 & -80 (**Figures 3 & 4**). Three calcium phosphate grains were found in sections -23 and -80. Although two are too small to analyze via LA-ICP-MS for their U-Pb systematics, there is one present in section -23 that is ~26x32 µm which is large enough for LA-ICP-MS.

Results: Thin-section -92 includes a prominent dunite clast with a range of olivine compositions (**Figure 5**). From 21 analyses, forsterite contents range from Fo_{60} to Fo_{88} with an average of Fo_{85}. From sections -23 and -80, plagioclase compositions are dominated by anorthite (average = An_{94}; n=142). Several compositions consistent with bytownitic plagioclase and K-Spar were also identified. Pyroxene (Avg Mg# = 69) compositions include: Mg-Pigeonite, Fe-Augite, Mg-Augite, Fe-Diopside, Fe-Enstatite, Mg-Hedenbergite, and Mg-Ferrosillite. Olivine compositions in thin-sections -23 and -80 range from Fo_{51} to Fo_{91} (average Fo_{78}; n=76). The three calcium phosphates from -23 and -80 were identified as fluorapatite. Mg content for olivine across -23 and -80 is (average = Mg# ~78; n=76).

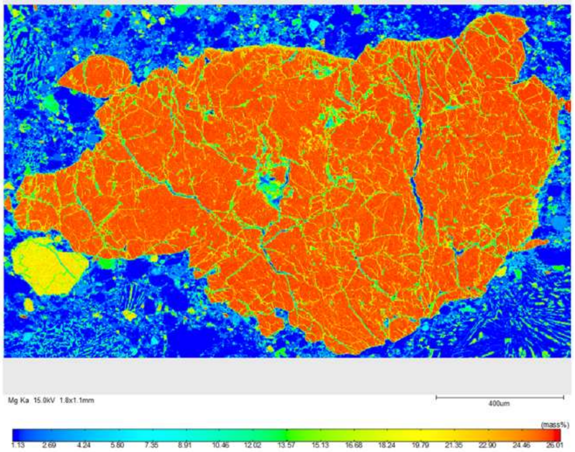

Figure 5: Mg map of dunite clast #41, section -92.

Discussion: After 40 years, ALHA 81005 still holds value in the lunar and meteoritic communities. The Mg# in the clasts of -23 and -80 is similar to Clast U in thin section -9 (Mg# ~80) [5]. With this similarity, Mg-suite related material may exist in ALHA 81005. When chronological data is collected and interpreted from the apatite, it will expand on ALHA 81005's poorly constrained ages [8]. Considering apatite's U-Pb closure temperature, this will provide insight into ALHA 81005's impact history and early lunar evolution.

References: [1] Mason (1982); [2] Kallemeyn (1983) 14th *LPSC*, #6006; [3]Kurat & Brandstatter (1983) 14th *LPSC*, #6008; [4]Lunar Meteorite Compendium (2010); [5]Treiman & Gross (2015); [6]Joy, K. H., et al (2011) *GCA,* 75 ; 2402-2452; [7]Niihara et al., (2013) 44th *LPSC,* #2083; [8]Eugster et al., (1989) SoAM, 2; 25-35.