

**EARLY LUNAR CHRONOLOGY: INSIGHTS FROM ALLAN HILLS (ALHA) 81005 METEORITE.** J. T.

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**Introduction:** Lunar meteorite Allan Hills (ALHA) 81005 holds a unique place in Earth's meteorite collection due to the fact that it was the first meteorite to be identified as being lunar in origin. Lunar samples (including Apollo, Luna, and meteoritic samples) not only provide windows into the mineral make-up of our nearest neighbor in space, but have proven to yield important insights and constraints on some of the earliest processes operating in our Solar System, such as the timing of planetary accretion and differentiation, as well as periods of bombardment [e.g. 1, 2, 3].

Sample ALHA 81005 has been classified as an Anorthositic regolith (polymict) breccia, [4]. To date, low- and high-Ti mare basalt clasts have been identified in addition to granulitic and cumulate breccia clasts, impact melt, clasts of anorthosite (the most common clast type in this sample), and clasts of norites and troctolites (see also, **Fig. 1**). Although ALHA 81005 was found and identified in the early 1980s, a comprehensive evaluation of its formation and chronology remains lacking. From previous work, the composition of ALHA 81005 is consistent with near-side highland rocks of the lunar crust which suggests that clasts within it are older than 4.0 Ga. To date, only 3 age-focused studies examining ALHA 81005 have been presented and these resulted in relatively poorly constrained Pb-Pb ages of 4.5-3.9 Ga [5, 6], and a poorly constrained K-Ar gas retention age of  $4.3 \pm 0.9$  Ga [7]. The primary goal of this study is to therefore examine the clasts within ALHA 81005 (starting with section 92) in order to improve our understanding of the timing of the meteorite's formation, but also the chronology and petrogenesis of its associated clasts.

**Methods:** Polarized light and backscatter-electron (BSE) images of thin section 92 have been collected (shown in **Fig. 1**). Acquisition of X-ray elemental maps (C, O, Na, Mg, Al, Si, P, S, Cl, K, Ca, Ti, Cr, Mn, Fe, Co and Ni) using the Zeiss Supra 35 VP FEGSEM located at the Center for Advanced Microscopy and Imaging (CAMI) is currently ongoing. This imaging approach is following similar work presented in previous studies [8, 9], but has been adapted for this instrument and the software that is available. Presently, acquired images (polarized light, BSE, and elemental maps) are being studied for minerals which will form the basis of a chronological investigation: zircon,

baddeleyite, and Ca-phosphates, and to a lesser extent, zirconolite, tranquillityite, and rutile. In the future, to better understand the crystallization history and the timing of potential impacts that have governed the formation of ALHA 81005, U-bearing accessory phases such as those named above will be dated by *in situ* U-Pb dating techniques.

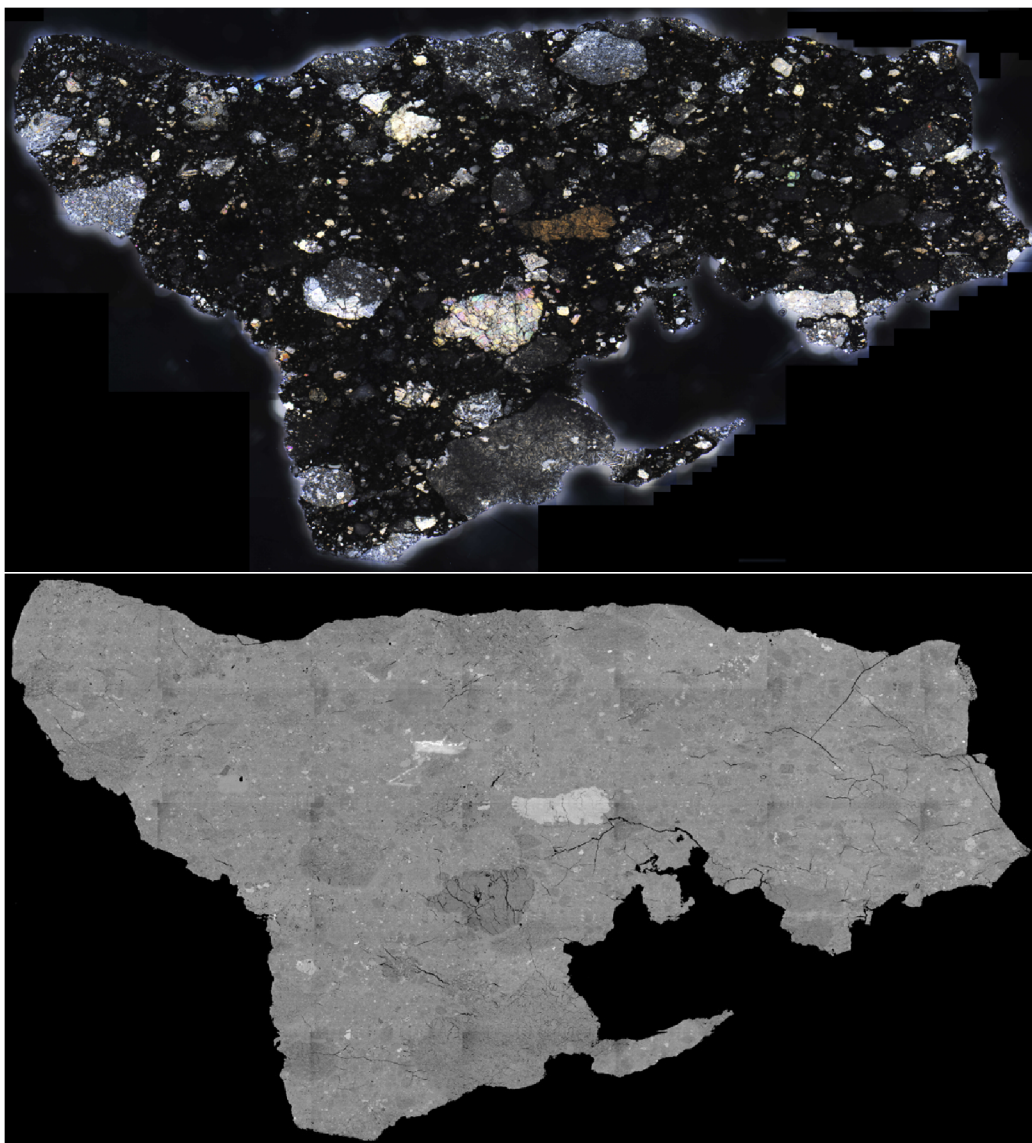
**Results:** The preliminary study of the polarized light and BSE image in **Fig. 1** reveals a range of clast types and sizes. The documented highly polymict nature of this meteorite is evident and potentially showcases the wide variety of lithologies that were present at the site of impact. Several clasts appear largely intact but are highly fractured from (likely) impact and resulting shock. Occasionally, zircon, baddeleyite, and rutile grains are as small as  $<10 \mu\text{m}$  in size while Ca-phosphate, zirconolite, and tranquillityite grains are less than  $25 \mu\text{m}$  in size. These are too small to be analyzed effectively and will therefore not be targeted for dating. The U concentration in the latter group can be significantly lower than in zircon, baddeleyite, and rutile – therefore, a larger laser spot (and thus a larger grain size) would be required to adequately measure U and radiogenic Pb. Acquired age data will be considered within the context of previously acquired age constraints and used to place the petrogenesis of ALHA 81005, and its associated clasts, within the overall framework of lunar evolution.

**Discussion:** With respect to the U-Pb systematics of the minerals present in this sample, the closure temperature of the U-Pb system in zircon and baddeleyite is high ( $> 900^\circ\text{C}$ ) and is therefore the most unlikely to be disturbed by impact events. This will allow us to potentially date the primary crystallization age of these minerals. The closure temperature of the U-Pb system in Ca-phosphates is lower ( $\sim 450\text{-}500^\circ\text{C}$ ) and is more likely to be disturbed. This therefore has the potential to record the timing of impacts events. Rutile, zirconolite, and tranquillityite have closure temperatures approximately between  $450\text{-}900^\circ\text{C}$ . By targeting these minerals, we can: 1) potentially date the crystallization/reset age of the variable clasts, and 2) better constrain the Moon's early impact history by extending a chronological study to include samples where no zircon or baddeleyite are present.

Future work will include additional study of ALHA 81005 sections 80 and 23 in addition to *in-situ*

electron microprobe analyses of major, minor, and accessory phases. Once target minerals have been located, they will be dated *in-situ* by Laser Ablation Inductively Coupled Mass Spectrometry (LA-ICP-MS) using a Thermo Scientific iCapQ quadrupole mass spectrometer coupled with a New Wave Research/ESI 193 nm excimer laser ablation system at the Trace element and Radiogenic Isotope Laboratory (TRAIL), University of Arkansas.

**References:** [1] Snape, J. F., et al. (2016) *EPSL*, 451; 149-158; [2] Michael, G., et al. (2018) *Icarus*, 302; 80-103; [3] Morbidelli, A., et al. (2018) *Icarus*, 302; 262276; [4] Treiman, A. H & Drake, M. J. (1983) *GRL*, 10(9); 783-786; [5] Chen, J. H and Wasserburg, G. J., (1985). 15<sup>th</sup> *LPSC*, #1032; [6] Nakamura, N., et al (1986). 17<sup>th</sup> *LPSC*, #1306; [7] Eugster, O., et al. (1986) *EPSL*, 78; 139-147; [8] Joy, K. H., et al (2011) *GCA*, 75; 2402-2452; [9] Niihara et al., (2013) 44<sup>th</sup> *LPSC*, #2083.



**Figure 1:** Section -92 (mounted section measures 1.6cm x 1cm) **Upper panel:** Cross Polarized (XPL) image in which the polymict nature of ALHA 81005 is evident. Lathe-like textures characterize several of the clasts (bottom-center, upper left for example). An olivine-rich clast is apparent in the center and is the only one of its kind identified in this particular section. **Lower panel:** Back-scattered electron (BSE) image of ALHA 81005. Bright spots are potential accessory minerals on which further *in-situ* analyses will be conducted.