DEVELOPING A STRATEGY FOR GEOCHRONOLOGIC SAMPLING OF THE SOUTH POLE-AITKEN BASIN BASED ON EXPERIENCES WITH LOW-TEMPERATURE THERMOCHRONOLOGY OF TERRESTRIAL CRATERS.

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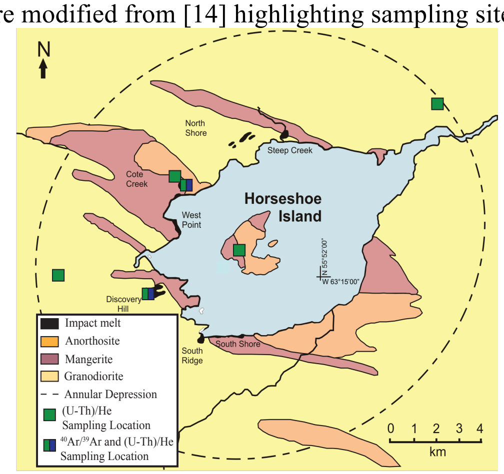
Introduction: The South Pole-Aitken Basin (SPA) has long been a feature of interest when studying the lunar surface. First examined and classified in the 1970s [1,2], the feature is ~2,500km in diameter [3] and 8km deep [4,5], making it the largest, deepest, and oldest impact basin on the Moon. While it is widely accepted that SPA represents the oldest preserved basin-forming event on the Moon, the absolute age of the structure is unknown, and its determination is one of the highest priority science goals for the Inner Solar System [6]. Sampling SPA is challenging due to the several billion years of subsequent impact events and volcanic episodes that have modified and displaced SPA-derived impact melts [7]. Younger, smaller structures such as Schrödinger Basin and Zeeman Crater (which lie within SPA) have previously been highlighted as potential sampling sites for displaced SPA material [8-10]. Here we discuss sampling strategies for structures like Schrödinger and Zeeman in the context of thermochronology results collected from a lunar analog crater here on Earth, the Mistastin Lake impact structure. Results of this comparison are also applicable to other central peak craters and peak-ring basins.

Low Temperature Thermochronology: While higher temperature thermochronologic techniques have been used to date impact structures and lunar samples in the past, there are factors that complicate the application of these techniques to impact dating. The resetting temperatures of systems such as U-Pb, Rb-Sr, etc., are high enough that these systems are not uniformly reset in impact events, where temperature and pressures, though very high, are fleeting [11]. This study uses the (U-Th)/He low-temperature thermochronologic technique, chosen because of to its low resetting temperature. It should be noted that (U-Th)/He is not a technique likely to be used on lunar samples due to the lack of necessary accessory minerals. However, the same principles and sampling lessons learned apply for any low-temperature system, such as $^{40}Ar/^{39}Ar$.

The Mistastin Lake Impact Structure: The Mistastin Lake impact structure (~28km diameter) is located in Labrador, Canada. It has long been considered a good lunar analog due to its similar target lithologies, which are dominated by anorthosite and also contain mangerite and granodiorite [12-15]. Extensive impact melt deposits are found throughout the Mistastin structure.

Sampling Mistastin: All three target lithologies were sampled and the impact melt was sampled in two locations. We separated thirty-four zircons from nine samples obtained from six locations (Fig. 1). Six zircons were isolated from two clast-poor impact melt rocks taken from Cote Creek (CC). Twenty-one zircons were isolated from mangerite samples collected at four sites: Discovery Hill (DH), the west rim of the structure, Cote Creek, and the central uplift at Horseshoe Island. Nine zircons from this subset were isolated from two large mangerite boulders entrained in the DH impact melt. The samples were collected from <1m from the edge of each boulder. Four zircons were isolated from the CC mangerite, specifically at a site ~400m away from the CC impact melt samples. Five zircons were isolated from a mangerite outcrop located near the west rim of the crater. Finally, three zircons were identified from an outcrop of mangerite from Horseshoe Island, which is thought to represent Mistastin's central peak. Six zircons were also dated from samples taken at two sites on the rim.

Figure 1: Map of the Mistastin Lake impact structure modified from [14] highlighting sampling sites.



The (U-Th)/He Technique: The (U-Th)/He technique capitalizes on the decay of ^{238}U, ^{235}U, and ^{232}Th to Pb. This decay process produces ^{4}He alpha particles, which, due to their mobility and low resetting temperature, can evacuate a crystal system rapidly upon opening due to the introduction of high temperatures such as those produced in an impact event. All (U-Th)/He analyses were conducted at Arizona State University in the Group 18 Laboratories.

(U-Th)/He Results from Mistastin: Table 1 shows the various modes in the (U-Th)/He Mistastin data. The dates generally fall into three modes, with a primary mode of 15 zircons from Cote Creek impact melt samples and two mangerite boulders entrained in the Discovery Hill impact melt. We applied the Hampel outlier identifier to the inverse-variance weighted residuals of the dates from the inverse-variance weighted mean and in doing so identified two outliers, accounting for the analytical precision in detecting them. The remaining 13 grains give an inverse-variance weighted mean age of 35.76 ± 0.33 Ma (2σ, MSWD=21.17), which we quote as the (U-Th)/He age for the structure.

High-magnification visible light microscopic examination of all of these grains indicated nothing that would explain this age range.

Rock Type	n	Age Range
ALL	32	1338±42 to 29.9±1.1 Ma
CC melt and DH mangerite boulders	15	47.3±1.5 to 29.9 ± 1.1 Ma
CC melt and DH mangerite w/o outliers	13	35.76±0.33 Ma mean age
Central uplift	3	1316±41 to 1228±47 Ma
Older rim granodiorite and mangerite	7	1338±42 to 936±35 Ma
Younger rim granodiorite and mangerite	3	374±18 to 318.2±8.7 Ma
Mangerite ~400m from CC	4	1336±46; 354±10 to 298±15 Ma

Table 1: Date distribution of all modes of data identified from Mistastin. It is notable that some of the oldest ages are found in the central uplift.

Discussion: Our (U-Th)/He results from Mistastin indicate that 100% of grains dated from the impact melt, or from boulders completely entrained in melt, yielded the impact age. However, grains isolated from target lithologies collected as close as ~200m away from melt locations were only partially reset and did not yield ages within error of the impact age. Samples dated from farther away yielded ages that were even farther from the impact age.

Perhaps most interestingly in this case was the fact that some of the oldest grains dated were collected from Horseshoe Island, or Mistastin's central uplift. These ages were only slightly younger than the initial crystallization ages, indicating that it is possible that these samples were deposited as part of the last stage of exhumation in the structure's uplift, when much of the high initial impact temperatures had dissipated.

Sampling Implications: Our (U-Th)/He results have potential implications for collecting samples from other planetary surfaces, namely the Moon and Mars.

Sampling Younger Craters: If the goal of a sampling mission is to collect samples to date a crater stratigraphically at the top of a site of interest, our results show that the highest priority samples should come from clast-rich impact melt produced during the impact or from shocked target rocks in very close proximity to larger melt deposits.

Sampling SPA: Many studies have highlighted the potential for the central peaks of younger craters to contain materials excavated from great depths [i.e. 8, 16, etc.]. Yamamoto et al., [8] in particular identified two structures and their central peaks (Schrodinger and Zeeman) that contain olivine-rich materials thought to have been excavated during the SPA event. Numerous other studies have also identified Schrodinger as an ideal place to sample SPA-derived materials [9,10,17,18].

Our results also highlight the potential for sampling SPA-derived materials in the central peaks of craters like Schrodinger or other central peak craters. At Mistastin, samples dated from the central uplift showed little to no resetting from the original protolith crystallization age. In the SPA context, this would mean that SPA-derived materials yielding unreset ages could be exhumed in the central peaks of craters large enough to penetrate deep enough into the lunar surface to excavate this SPA material, but not beneath the impact melt layer. Future missions designed to sample SPA should certainly keep these lessons learned in mind when selecting possible landing sites.

References:

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