THE INNER SOLAR SYSTEM CHRONOLOGY *(ISOCHRON)* DISCOVERY MISSION: RETURNING SAMPLES OF THE YOUNGEST LUNAR MARE BASALTS.

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Summary: The Inner SOlar System CHRONology *(ISOCHRON)* Discovery mission concept is an automated lunar sample return mission to mare basalt units south of the Aristarchus Plateau that are estimated to be ~1.5–2.0 Gyr old. This mission will address fundamental questions about the composition of the lunar crust and the time-stratigraphy of lunar volcanic processes, with implications for all of the terrestrial planets. These goals address numerous key outstanding questions identified by several recent community assessments [1-3].

The primary science goal is to make high-precision radiometric age measurements on these relatively young basalts to fill the existing gap in age-correlated crater size-frequency distributions (CSFDs), thereby greatly improving this widely-used tool for estimating the ages of exposed surfaces on rocky bodies. This advance will improve the ability to understand the geologic histories of all cratered bodies in the inner Solar System. To the extent that lunar-based CSFD models have been extrapolated for outer Solar System applications, those as well stand to benefit from this result.

The returned samples will also allow us to address two secondary science goals. First, they will yield critical insights on the thermal and magmatic history of the Moon by providing, for these relatively young basalts, comprehensive compositional and mineralogical data for direct comparison with Apollo- and Luna-returned samples, the majority of which are older than ~3.8 Gyr. Second, material returned by *ISOCHRON* will shed new light on regolith dynamical processes owing to its formation substantially after the Moon's heaviest period of bombardment.

The age and compositional measurements to be performed on the returned samples cannot currently be duplicated by *in situ* instrumentation. In particular, dating the end of large-scale volcanic eruptions on the Moon requires the precision routinely achieved in terrestrial geochronology laboratories if it is to benefit all of inner Solar System chronology.

Background: The Moon preserves a geologic record erased from the other terrestrial planets, and is the only extraterrestrial body from which we have contextualized samples, yet critical unanswered questions remain. We lack important details of the Moon's early igneous history, the full compositional and age range of its crust, or the bulk compositions of the crust, mantle, and whole Moon. Lunar mare basalts formed through partial melting of the mantle and serve as probes of the structure and composition of the interior. However, the full range of mare basalt compositions and ages has not yet been sampled [4,5]. Knowledge of the duration of mare volcanism comes from (a) radiometric dating of Apollo and Luna samples and lunar meteorites and (b) CSFD analysis of mare surfaces (especially those correlated with returned samples) from remote sensing data. According to our present understanding, mare volcanism reached its maximum volumetric output between 3.8 and 3.2 Gyr ago but began as early as 4.3 Gyr ago and may have persisted until as recently as 1.2 Gyr ago [5,6] or even more recent times [7], and much remains to be learned about the dynamics of regolith formation [e.g. 8]. All of these questions can be addressed by targeted sample return.

Existing models for remotely determining the absolute age of a surface are calibrated by correlating measured ages of Apollo samples with the crater densities in the terranes from which they are thought to derive. Models are well-determined for ages >~3.5 Gyr, and reasonably constrained for very recent ages. But there is a ~2 Gyr gap in age coverage in these models (Fig. 1), because none of the Apollo or Luna samples have ages in that range. Thus the uncertainty on a surface's absolute model age of ~1.5 Gyr is also ~1.5 Gyr or even higher. Lunar-derived CSFD models are routinely applied to other rocky Solar System bodies (even beyond the asteroid belt), where this inherent uncertainty is compounded by the range of model adjust-

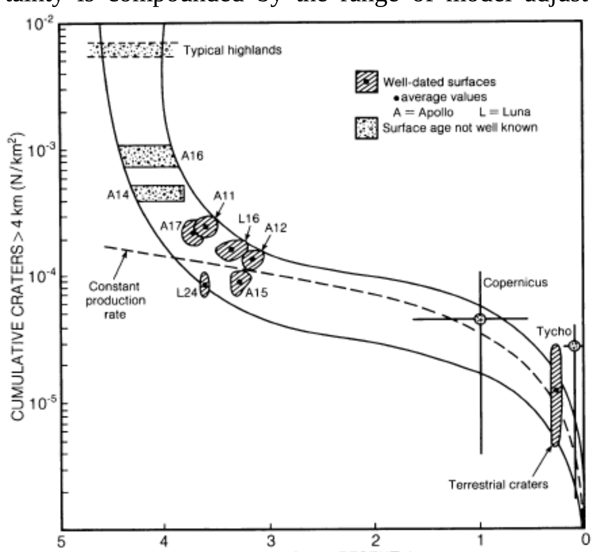

Figure 1. Summary of potential solutions to lunar CSFDs illustrating gap in data coverage (see text). From [9].

ments made in attempts to account for the different bolide flux and bombardment history that surely prevailed in the outer Solar System compared to the inner. Thus the accomplishment of the primary *ISOCHRON* science goal may also be a significant advance for an even wider range of planetary investigations.

Mission approach: *ISOCHRON* will be proposed to the 2019 Discovery mission call. Our team includes NASA and non-NASA institutions, commercial space firms, and an international partner. High-heritage system components will yield a strong concept with high chances of mission success.

The *ISOCHRON* mission comprises a single landed element with automated sample collection and return capabilities utilizing a novel, innovative, and highly effective sample acquisition system. Targeting a near-side landing site simplifies execution, with no relay satellite needed. *ISOCHRON* will collect and return ~150 g of regolith, consisting of ~1 cm rocklets plus bulk regolith/fines. Our acquisition system allows rocklets to be concentrated or “high graded” prior to delivery to the final sample return canister. Surface operations will be completed after ~100 hours, to avoid the temperature extremes of lunar noon and night. Landing will occur in the early lunar morning, with liftoff of the return vehicle before the sun reaches an elevation of 60 degrees from the local horizon.

Landing site: Crater size-frequency distributions suggest that some of the basalt flows on the Moon are significantly younger than are the youngest Apollo basalts [6]. Hiesinger et al. [10] mapped 60 spectrally homogeneous basalt units in Oceanus Procellarum. CSFD methods determined that five of these units have model ages ranging from ~1.5–2.0 Gyr. Unit P60 (Fig. 2), directly south of the Aristarchus Plateau, has the youngest average model age (1.2 +0.32/-0.35 Gyr). Recent work has independently confirmed P60 model ages ranging from 1.03 to 2.81 Gyr across the unit [11]. There are now sufficient data from the NASA Lunar Reconnaissance Orbiter to certify a safe landing site on P60 (within orange box, Fig. 2). The analysis of returned samples from the P60 region would accomplish the mission science goals by providing new compositional, mineralogical, textural, and geochronologic data.

Mission science: The *ISOCHRON* international science team includes deep experience in lunar investigations. Age determinations will be made by multiple techniques, including radiometric and noble gas analyses. Concordancy between these measurements will close the ~2 Gyr gap in our knowledge of lunar chronology and enable a major improvement to our ability to remotely estimate the timing of events across the Solar System. Investigations on petrology, mineralogy,

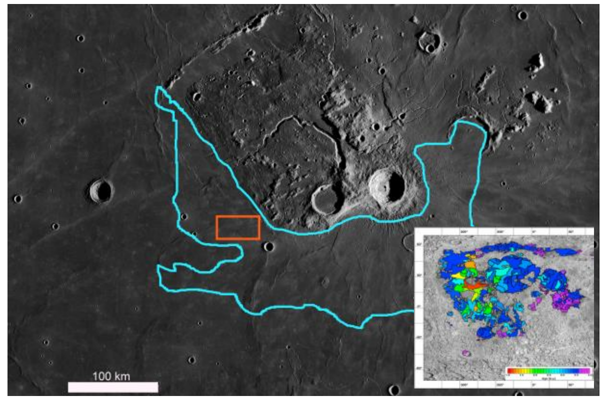

Figure 2. LROC WAC showing Aristarchus Plateau, P60 region (blue outline and in orange on inset from [9]), and targeted landing zone (orange box).

and regolith dynamics will be conducted using the same methodologies applied to Apollo & Luna samples and lunar meteorites, providing continuity with that immense body of knowledge. The majority of material returned by *ISOCHRON* will ultimately be added as a new collection to the Astromaterials Acquisition and Curation Office at NASA Johnson Space Center, from where they will be allocated to the community via CAPTEM in the usual way.

Conclusions: Return of samples of some of the youngest lunar basalts via *ISOCHRON* is straightforward, with clear goals and deliverables that will provide unambiguous science advances. It is cost-effective and addresses fundamental planetary science questions identified by the community as among the highest in priority. Minimal instrument development is required. It will establish US capability in automated powered descent to, and automated return from, an airless body. *ISOCHRON* results will yield important implications for all rocky bodies in the inner (and perhaps the outer) Solar System.

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