Testing the Terminal Cataclysm Hypothesis with Samples from the South Pole-Aitken Basin. B. L. Jolliff[1], D. A. Papanastassiou[2], and B. A. Cohen[3]. [1]Department of Earth and Planetary Sciences, Washington University, St. Louis, MO 63130 <blj@wustl.edu>, [2]M/S 183-335, Jet Propulsion Laboratory, Pasadena, CA 91109, [3]Institute of Meteoritics, University of New Mexico, Albuquerque NM 87131.

Introduction: A fundamental question of planetary science is what happened in the Solar System, and the Earth-Moon system in particular, during the interval of 4.5 to 3.8 Ga ago. The first billion years of solar system history and the processes that occurred during this epoch and propelled the evolution of Earth and the other planets were identified by the Decadal Survey as a scientifically broad, crosscutting theme for planetary exploration. A specific top level issue was the question of how the impactor flux decayed during the solar system's youth, and in what ways this decline influenced the timing of life's emergence on Earth.

According to the record derived from the study of lunar rocks, the Earth and Moon – and possibly the entire inner Solar System – were intensely bombarded by asteroid-sized objects, which formed impact basins. Remnants of these are visible today on the Earth-facing surface of the Moon. Similar impacts on Earth would have caused global changes in geology and climate that surely played a key role in the development and stability of habitable environments for the origin and early development of life. Evidence in the lunar rocks suggests that the heavy bombardment was confined to a relatively narrow interval of time, aptly named the "terminal cataclysm" [1,2].

Whether the heavy bombardment was confined to such an interval [*e.g.,* 3] or simply represented the waning stages of a prolonged planetary accretion [4] is fundamentally important to understanding the evolution of the early Solar System. If such a bombardment occurred during a confined interval, what caused it and what were the effects on the early Earth? Recent dynamical modeling suggests that a shift in the orbits of the outer planets could have caused the ejection of objects from the primordial trans-planetary belt into the inner solar system at about 600 my following planetary accretion [5-8]. This remarkable model result has tremendous implications for the early evolution of the Solar System.

Finding rocks to test the Cataclysm hypothesis: The ancient rocks needed to test the cataclysm hypothesis are extremely scarce (or do not exist) on Earth because erosion and tectonic processes have erased most of the ancient rock record from those times. However, such ancient rocks and geologic terrains do exist on the Moon and are accessible to test the hypothesis. The approach advocated here involves the collection and return of rock samples to Earth for geochemical and petrologic analysis and radiometric age dating. The location of samples needed to address the issue is the giant South Pole-Aitken (SPA) Basin on the lunar far side, so named because it stretches from the South Pole to the Aitken crater near the equator (Fig. 1). A sample return from this region of the Moon would provide not only a means to test the cataclysm hypothesis, but also would provide new data to understand the evolution of the Moon and processes that occurred during the formation of giant impact basins.

During the collision of an asteroid with a planetary surface, an enormous quantity of kinetic energy is deposited. The impactor is largely vaporized and rocks in the target region are melted. The explosion resulting from the impact ejects rocks and molten debris from the impact crater and distributes them around the planet, forming thick deposits in regions proximal to the rim of the basin. As the impact melt crystallizes, it locks in radiogenic elements that can be used to measure the crystallization age. In the case of the SPA Basin, the impact would have penetrated into the lower crust, if not the upper mantle.

The interior of the SPA basin retains its compositional signature despite the occurrence of numerous smaller and younger impact basins within it. Concentrations of Fe and Th, determined from orbit, show the signature of the basin deposits (Fig. 1). The deposits are significantly richer in FeO than most of the lunar highlands, consistent with a deep crustal or upper-mantle origin. They have somewhat elevated Th, but not nearly as high as on the lunar near side in the Procellarum-Imbrium region. Two conspicuous Th highs occur in the northwestern part of the basin. Materials from the interior of the basin, where the compositional signature is strong, provide the best chance of obtaining SPA impact melt. Materials excavated from deep within the impact site would be distributed in the ejecta deposits along or beyond the rim of the basin, where they would be mixed with pre-existing upper-crustal substrate.

Ideally, a field geological expedition might explore a broad region and sample large rocks of known geologic formations from multiple locations in and around the SPA basin to find basin impact-melt rocks and deep-seated materials. However, a more feasible and better approach is to take advantage of the vertical and lateral mixing provided by the post cataclysm impacts, of lesser intensity and, therefore, more likely to have preserved the earlier chronologic record. The goal is to collect a diverse sample composed of small rock fragments that are ubiquitous and abundant in the regolith. From Apollo experience, the bulk of these small rock fragments are representative of the larger rocks that occur in a given location [9]. Experience from Apollo also taught us how to relate regolith samples to local site geology. Using regional remote sensing and knowledge of the variety and relative abundance of rock types from such samples, the rock distribution can be related to remotely sensed site geology. From the diversity of materials found in a regolith sample, coupled with observations from orbital remote sensing and from descent and surface imaging, the effects of local and regional geologic features, especially impacts, can be understood. The range of ages, and intermediate spikes in the age distribution, as well as the oldest ages, are all part of the definition of the absolute age and impact history recorded within the SPA Basin.

Geochronology: Of critical importance to SPA science goals is the capability to determine precise ages of small and, in most cases, complex (breccia) samples. The goal of assigning an absolute age to the SPA event can be attained with varying degrees of confidence by direct and indirect means. The goal can be achieved directly by dating a sample of the original crystalline SPA impact melt. Such a sample may be preserved within SPA or may be preserved as clasts of crystalline impact melt, incorporated into later-formed breccias. Such clasts can be extracted and dated [10]. Crystalline impact melt produced by post-SPA basins (*e.g.,* Fig. 1) can be dated to provide additional constraints. Petrologic and geochemical information will help to confirm that the oldest event in a distribution of ages is indeed the SPA event.

We propose to use multiple isotopic dating systems and to compare results from systems that are prone to resetting (and may thus reflect events more recent than the terminal cataclysm) and systems that are less easily reset (and may thus reflect the terminal cataclysm and events preceding the terminal cataclysm, if SPA formation predates the 4.0-3.9 events). Judging by mature Apollo regolith samples, 1 kg of rock fragments greater than 2 mm would (conservatively) yield some 10,000 2-4 mm particles, over 3000 4-10 mm fragments, and a significant number of rocklets >1 cm. The key is that we now have the sensitivity to measure such small samples, in our labs, and take advantage of the diversity in chemistry and processes of formation that they provide.

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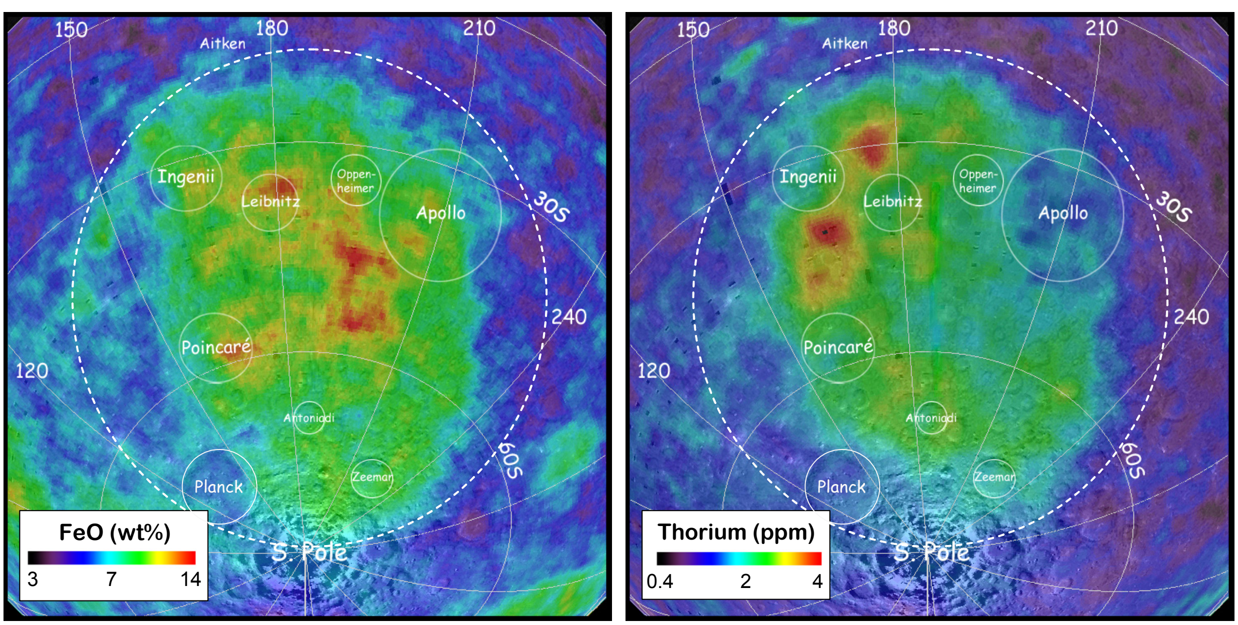

Figure 1. Compositional images of the South Pole-Aitken Basin superimposed on merged shaded relief and Clementine 750 nm base images. FeO and thorium are half-degree resolution from the Lunar Prospector gamma-ray spectrometer data [13-14]. Locations of South Pole, Aitken crater, and some of the large craters and basins interior to the SPA basin shown for reference.