ENDURANCE: LUNAR SOUTH POLE–AITKEN BASIN TRAVERSE AND SAMPLE RETURN ROVER. James Tuttle Keane (Jet Propulsion Laboratory, California Institute of Technology, james.t.keane@jpl.nasa.gov), Sonia Tikoo (Stanford University, smtikoo@stanford.edu), John Elliott (Jet Propulsion Laboratory, California Institute of Technology, john.o.elliott@jpl.nasa.gov), and the Endurance concept study team.

Over the past decade, new ideas have emerged about the timing and nature of planet migration and bombardment. Simultaneously, new geologic evidence has suggested that our existing models of planetary bombardment—which are constrained by determining the formation ages of impact-produced returned samples from the Moon—may be incomplete. Finally, exploration of worlds across the Solar System have revealed the prevalence of giant, planetary-scale impacts, motivating questions for how these impacts shaped planetary bodies.

The lunar farside and the gigantic (~2,500-km diameter) South Pole–Aitken (SPA) basin provide a unique opportunity to address this confluence of problems. SPA is the largest and most ancient (undisputed) impact basin on the Moon. As the oldest basin on the Moon, SPA is a critical datum constraining Solar System history. Determining the age of SPA, and the other large basins superposing it, would provide critical new constraints on the Earth and Moon's bombardment history during the time when life first emerged on Earth, providing unparalleled insights into the formation and evolution of a habitable worlds that would serve as our touchstone to the emergence of life elsewhere in the Solar System. Moreover, determining the age of SPA would singularly revolutionize our ability to calibrate with exceptional certainty the timing of events across the Solar System, including migration of the giant planets. Additionally, SPA almost certainly excavated the lunar mantle. Studying samples from the mantle would provide a window into the early thermochemical evolution of a rocky world. For these reasons, SPA sample return and exploration has been a priority in the last three Planetary Science and Astrobiology Decadal Surveys.

Endurance is a mission concept developed by the most recent Decadal Survey that would address these high priority planetary science questions by exploring and ultimately collecting, caching, and returning samples from SPA. Endurance has five science objectives:

1. **Determine the age of the largest and oldest impact basin on the Moon, South Pole-Aitken (SPA)** to anchor the earliest impact history of the Solar System.
2. **Determine when post-SPA farside basins formed** to test the giant planet migration and terminal cataclysm hypotheses, and to better constrain the inner solar system impact chronology used to date the surfaces of other planetary bodies.
3. **Determine the age and mineralogical and geochemical composition of deep and crustal materials exposed in SPA** to understand the bulk composition of the Moon, its primordial differentiation and geologic evolution, and the significance of chronologic measurements completed on nearside samples for timing lunar solidification.
4. **Determine the age and nature of volcanic features and compositional anomalies on the lunar farside** to characterize the thermochemical evolution of terrestrial worlds and constrain the origin of the Moon's nearside-farside asymmetry.
5. **Determine the geologic diversity of the SPA terrane** to provide geologic context for returned samples, ground truth for orbital measurements, and characterize the surface processes that shape planetary bodies.

To address these science objectives requires collecting a diverse set of samples and other in situ data from across SPA.

The Endurance rover design is an evolution of the Intrepid planetary mission concept study (Robinson et al. 2020), and is capable of traversing nearly 2,000 km of lunar terrain in under four years, owing to a high degree of pre-planning and automation. As Endurance progresses across this terrain, it will collect scientific measurements along the traverse using a suite of remote sensing instruments, with hundreds of stops for investigating the local geology, geochemistry, and geophysics. Along its journey, Endurance would collect a large mass (up to 100 kg) of samples from 12 key, pre-identified locations across SPA. The rover would then deliver these samples to Artemis astronauts at the lunar south pole, who could analyze and triage the samples, and return a subset to Earth for analyses in terrestrial laboratories, enabling transformative advances in the understanding of solar system chronology and planetary evolution.

The Decadal Survey highly prioritized Endurance for implementation as a medium-sized (i.e., New Frontiers class) strategic mission within NASA's Science Mission Directorate, and the highest priority for the Lunar Discovery and Exploration Program. The Decadal Survey noted that "Endurance rover mission is a superior approach for acquiring abundant samples across diverse terrains to address multiple top-level science questions for the Moon and the solar system" and that "Return of Endurance samples by Artemis astronauts is the ideal synergy between NASA's human and scientific exploration of the Moon, producing flagship-level science at a fraction of the cost to PSD through coordination with Artemis." Endurance is effectively an SPA sample return campaign (akin to the Apollo sample return campaign), in one mission.

The key technology development enabling Endurance is autonomy. As currently formulated, Endurance incorporates a high level of autonomy for everything from the traverse, to dealing with faults, and some science operations. The autonomy development builds on the current capabilities of Mars rovers, but will require significant advancement. Additional challenges with operating on the Moon, including harsh thermal and dust environments—spanning the mid-latitudes to the south pole —will also need to be addressed.

There are substantial opportunities to infuse new science and technologies into Endurance. For example, alternate mobility systems may allow for new traverses, or larger sample collection masses. There may be a variety of new and innovative instruments that could provide transformative science from along a long traverse. Additionally, Endurance may survive well beyond its primary mission, opening up exciting opportunities for extended missions—particularly if serviced by Artemis astronauts. Finally, there may be opportunities for community partnerships, given recent developments for the Artemis Lunar Terrain Vehicle (LTV).

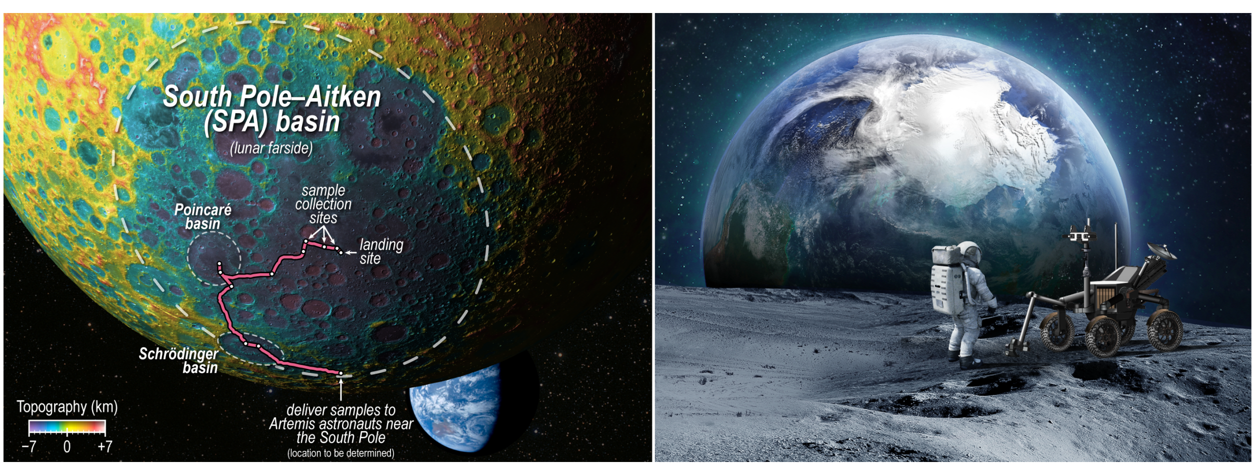

Figure 1: The Endurance concept. Left: the baseline Endurance traverse. The rover would traverse ~2,000 km from the center of SPA to the south pole, collecting ~100 kg of samples from 12 key sites along the traverse. Right: An artist concept of the rover rendezvousing with Artemis astronauts at the south pole. Figures adapted from the Endurance concept study report. The full Endurance report is publicly available: tinyurl.com/2p88fx4f.