

## THE ROAD TO ENDURANCE: OUTCOMES FROM THE ENDURANCE SCIENCE WORKSHOP.

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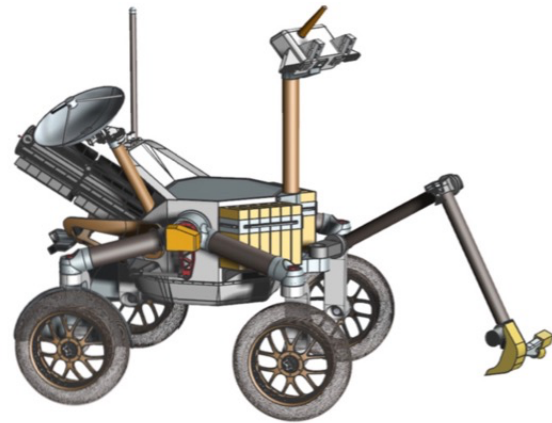
**Introduction to Endurance:** Endurance is a mission concept for a long-range, highly autonomous lunar rover (Fig. 1) designed to explore the farside of the Moon and the largest and oldest (undisputed) impact crater in the Solar System: South Pole–Aitken basin (SPA) (Fig. 2). Endurance would traverse nearly 2,000 kilometers, acquiring a large volume of in situ data, and a large mass of samples (up to 100 kg of material from 12 sites), before rendezvousing with Artemis astronauts at the south pole of the Moon. The Endurance concept was developed during the recent *Origins, Worlds, and Life* Planetary Science and Astrobiology Decadal Survey [1–2], which recommended Endurance as the highest priority new strategic mission for NASA’s Lunar Discovery and Exploration Program. Since the release of the Decadal Survey in 2022, NASA has been further studying this concept, and investigating the range of implementation options [3–5].

**The Endurance Science Workshop:** In August 2023, JPL/Caltech hosted the first public Endurance Science Workshop, with logistical support from LPI [6] (Fig. 3). The goal of this workshop was to go beyond the Decadal Survey and bring together the broader planetary community to discuss all aspects of this mission and to help further develop the mission concept. While this workshop was focused on the science to be accomplished by Endurance, there was also discussions of the various engineering challenges for this concept.

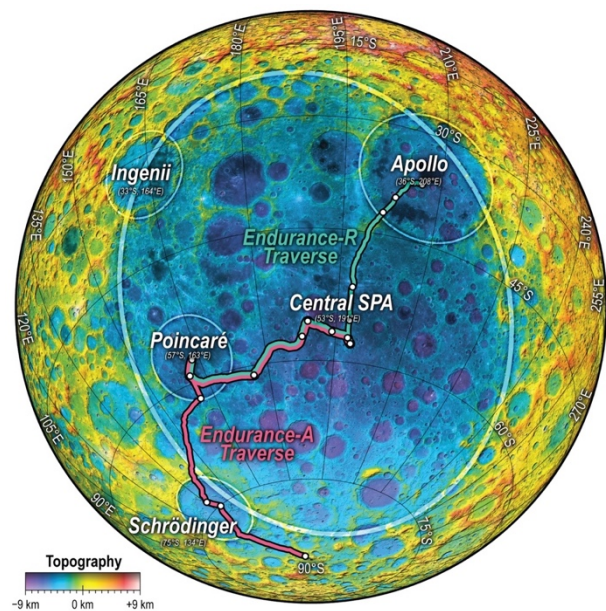
The workshop was hybrid, with both in person and virtual speakers, panels, and discussion sessions. In total, >160 people participated.

**Findings from the Endurance Science Workshop:** The Endurance Science Workshop science organizing committee synthesized findings and is drafting a final report. Here we summarize a subset of the major findings:

*Endurance is an exciting concept that would address long-standing planetary science questions, and the lunar community has already done a lot of the necessary enabling work. SPA sample return has been highly prioritized in the last three Decadal Surveys, the focus of several previous mission proposals, and the subject of several hundred peer reviewed publications. Much of the fundamental scientific groundwork for this mission (such as the development of testable hypotheses) has already been accomplished. Exploring this basin and returning samples in the Artemis era will be of great value; crewed missions will enable transformative science, but will likely lack the capability to access high-priority*



**Fig. 1:** Artist concept of the Endurance rover, as designed in the Decadal Survey concept study [2].



**Fig. 2:** The South Pole-Aitken (SPA) basin, and the scale of the Endurance traverse (colored lines). This map shows two traverse options (Endurance-A and Endurance-R). The current baseline is Endurance-A. Figure adapted from [2].

locations within SPA.

*Endurance’s sample science objectives are achievable, although they would require coordinated analysis techniques and numerous, diverse samples. Coordinated analyses with multiple analytical techniques (e.g., multiple chronometric systems, petrologic analyses, etc.) are essential to confidently address Endurance’s*

science objectives, particularly with respect to understanding early Solar System chronology. While there have been substantial advancements in analyzing small samples, larger samples—particularly rocklets larger than ~25 mm—are the particularly desirable for many analyses. To acquire such rocklets from lunar regolith, Endurance would likely require a sieve.

*Geologic context is essential for addressing Endurance's science objectives.* To understand Endurance's samples, it is necessary to acquire geologic context at a range of scales—from the scale of the sample (~centimeter scale) to the scale of the sample site (meters to kilometers), to the scale of the entire basin (hundreds of kilometers). This geologic context could be accomplished with a range of in situ instrument (e.g., color cameras, hyperspectral instruments, particles/fields measurements, etc.), and more work needs to be done to determine which measurements are necessary and how they should be prioritized.

*While Endurance's objectives center on sample return, Endurance's long traverse would enable a variety of other transformative science investigations.* Endurance's 2,000 km traverse across the farside would be unprecedented. There are multiple scientific investigations that would be uniquely enabled by such a long traverse. For example, consider how a traverse from the mid-latitudes to the poles could shed light on surface volatiles (e.g., water) and their evolution. A long traverse would also likely result in surprising scientific discoveries. For example, consider the unexpected discovery of the orange soil on Apollo 17. As Endurance is developed, it is important to not diminish the opportunity afforded by

having such a capable in situ robotic explorer.

*As Endurance is developed, the project should strive to include more diverse perspectives in its formulation—particularly from early-career scientists and engineers who would ultimately operate the rover and analyze the returned samples.* Endurance is in the earliest stages of development, with flight anticipated in the early 2030s. Now is the time to get early-career scientists and engineers involved. Endurance has the potential to provide a long-term, continuous scientific exploration of the Moon (plausibly including extended missions), and its samples would be studied for generations.

**Next steps for Endurance:** Endurance is in the earliest stages of mission formulation. The next major activity will likely center on more formal definition of the science requirements for this concept (perhaps through a Science Definition Team). Note: this is pre-decisional information, for planning and discussion purposes only.

**References:** [1] NASEM, *Origins, Worlds, and Life: A Decadal Strategy for Planetary Science and Astrobiology 2023-2032*: <https://nap.nationalacademies.org/catalog/26522/>. [2] Keane et al., Endurance Mission Concept Study Report: <https://tiinyurl.com/2p88fx4f>. [3] NASA's Initial Response to the Decadal Survey: [https://smd-cms.nasa.gov/wp-content/uploads/2023/05/Initial90\\_daywritten\\_responsetothe20232032PlanetaryScienceandAstrobiologyDecadalSurvey.pdf](https://smd-cms.nasa.gov/wp-content/uploads/2023/05/Initial90_daywritten_responsetothe20232032PlanetaryScienceandAstrobiologyDecadalSurvey.pdf). [4] Elliott et al., LPSC 2024. [5] Nesnas et al., LPSC 2024. [6] Endurance Science Workshop: <https://www.hou.usra.edu/meetings/endurance2023/>.



**Fig. 3:** Top: the banner for the Endurance Science Workshop. Bottom left: a photo of a hybrid panel discussion at the Endurance Science Workshop. Bottom right: a photo of Endurance Science Workshop participants congregating around an Astrolab lunar rover testbed that was showcased at the workshop.