A CONCEPT FOR EXPLORING THE HISTORY OF LUNAR MARE DEPOSITS WITH THE AXEL EXTREME TERRAIN ROVER L. Kerber[1], I. Nesnas[1], J.W. Ashley[1], M. J. Malaska[1], C. Parcheta[1], K. L. Mitchell[1], R. C. Anderson[1] [1]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr., Pasadena, CA 91109 (kerber@jpl.nasa.gov).

**Introduction:** The lunar mare basalt deposits serve as natural probes into the lunar interior. Studies of the morphologies and spectral properties of exposed surface basalts have yielded major insights into the thermal history and chemical composition of the Moon [e.g., 1-3]. However, these surface basalts only represent the last volcanic event in each region. Still unknown are the compositional, petrologic, and thermal changes in each mare basin through time; information which can only be accessed through examination of their cross-sectional exposure. Recent images returned by the Kaguya and Lunar Reconnaissance Orbiter missions have revealed the presence of deep mare pits containing meter-scale layer stratigraphy exposed in their walls ([4-6], **Fig. 1**). A mission to a mare pit would address numerous top priority lunar science goals laid out in community reviews [7], the Decadal Survey [8], and the Lunar Exploration Roadmap [9] in the following ways:

(1) Characterizing chemical and mineralogical trends along a stratigraphic section of the mare would reveal how partial melting processes and mantle source regions evolved through time. Analysis of Apollo mare basalt samples has revealed significant compositional variety and implied source regions, even among basalts taken from a single landing site [10]. Analysis of an in-place stratigraphy would shed light on whether these basalts were extruded from one or multiple vents, and whether the lavas came from a long-lived magma source that evolved through time, or from unique magma sources.

(2) Documenting the thickness, flow textures, and petrologic textures of individual layers would yield information about the temperature, viscosity, and gas content of the lava when it was flowing and cooling, providing clues about source vent flux, gas content, and proximity. Volcanic textures of Apollo 11 samples vary from ophitic to intersertal, and are correlated with their chemical compositions [10].

(3) Accessing regolith layers potentially preserved between basalt layers would yield insight about the intermittency of mare eruptions and the timescales for regolith formation, which could help refine the link between surface crater dates and true chronological ages [7]. Preserved past regolith horizons could contain trapped solar wind particles and galactic cosmic ray information from long past epochs of Solar System history [7].

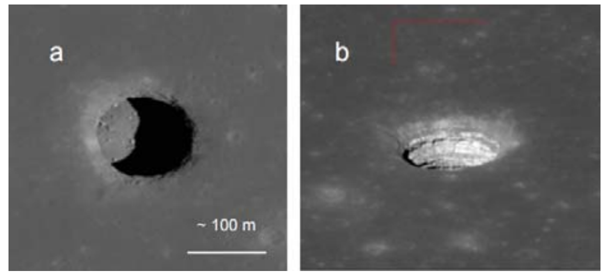


**Figure 1.** Two views of the Mare Tranquillitatis pit, (figures from [5]). LROC NAC images (a) M126710873R and (b) M144395745L.

(4) Investigating lava layers that were quickly buried would provide a way to sample rocks that were unaffected by space weathering, revealing more about the process of space weathering and how its effects can be disentangled from the Moon's primary chemistry and chronology [8-9].

(5) In some cases, lunar mare pits may open into subsurface void spaces or lava tubes [5,11]. Exploring and measuring these tubes would yield information about lava flux rates and the distances that insulated lava could flow from the vent. Information about lava tubes and caves is also highly sought after for the purposes of human exploration and habitation [12]. Human settlements located in lava tubes would benefit from a stable, benign temperature, and would be protected from cosmic rays and micrometeorites. The lunar pit shown in **Fig. 1** has ~47 m of lava layer stratigraphy overlying a ~60 m void space leading into the lunar interior [6].

For these reasons, lunar pits provide an exciting new target for lunar exploration. Before now, the desire to send a mission to these targets was tempered by the difficulty of reaching them given the mobility of traditional rovers. The Axel Extreme Terrain Rover [13], developed by the Jet Propulsion Laboratory in collaboration with Caltech, has the mobility necessary to approach, anchor, and rappel into this type of pit, revolutionizing our capability to access and explore in-place stratigraphy on the Moon.

**The Axel Rover:** The Axel rover consists of two wheels connected by a thick axle containing a winch and a tether [13]. Scientific instruments are housed inside the wheel well (**Fig 2**).


**Figure 2.** The Axel rover taking spectroscopic measurements on a slope of 40º (figure from [13]).

Currently integrated instruments include a microimager, a miniature spectrometer, a thermal probe, and a sampling drill [13]. Over flat terrains (for example, from the landing site to the investigation area), the Axel rover can traverse just like an ordinary rover. Across rough terrain, the Axel rover can maneuver across large rocks up to one wheel radius in height. Once it approaches a steep section, the Axel rover can set an anchor and rappel down the steep slope by letting out the tether stored inside the axle [13; **Fig. 2**]. Two Axels can be combined to form a "DuAxel" (**Fig. 3**), or one Axel can replace an axle on a more traditional rover body [13].

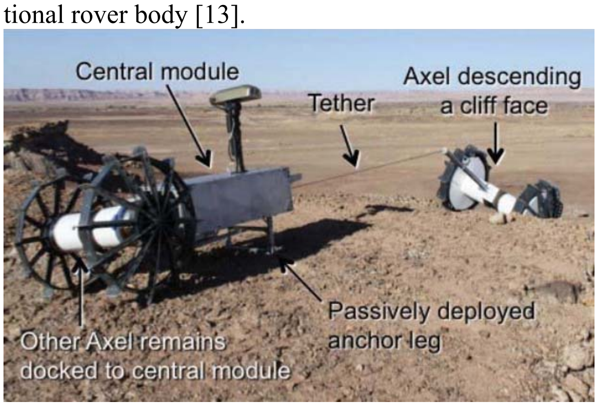


**Figure 3.** The DuAxel rover configuration at work in the field (figure from [13])

This functionality allows the rover to descend steep to vertical slopes (and ascend them again). The rover can even dangle in free space and continue to let out its tether.

The rover can communicate through its cable, alleviating common communication problems facing other cave-exploring robots. The rover can also receive power through its tether, meaning that it could leave a solar panel on the surface and still receive power to explore a dark cave below [13]. The functionality of this rover would allow a mission to examine and characterize lava layers exposed in the wall of a mare pit crater during abseil descent. Mineralogy (provided by the miniature spectrometer), texture (provided by the microimager), and measurements by additional instruments (housed by Axel's 6-8 instrument bays), or on the larger body of the DuAxel, would reveal changes in composition and morphology throughout the section. Axel's onboard cameras could record layer thicknesses and document the presence and characteristics of intervening soil layers.

Once on the floor of the pit, the Axel rover could continue to explore. If the pit opened into a lava tube or other subsurface void, the rover could attempt to negotiate the floor up to the length of its tether (currently 250-300 m, potentially up to 1 km; [13]). After exploring the pit, the rover could reel itself back up the wall and either continue roving across the surface or rappel down a different side of the pit.

Axel has undergone extensive testing in terrestrial desert environments on steep slopes and various rock types [13]. Future field trials could test Axel mobility in lunar pit analogs as a preparation for a mission to the Moon.

**Summary:** Lunar mare pits represent an exciting new opportunity for lunar exploration. The Axel rover provides enhanced mobility which would enable it to land, rove to a pit or cave, enter, explore with a suite of high-priority science instruments, and exit, all with existing or highly developed technologies. This approach would revolutionize our capability to access and sample not only lunar mare pits, but also pits in lunar impact melt [e.g., 5,6] and other previously inaccessible terrains on a variety of planetary bodies.

**References:**

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