MOON DIVER: A DISCOVERY MISSION CONCEPT FOR UNDERSTANDING THE HISTORY OF THE MARE BASALTS THROUGH THE EXPLORATION OF A LUNAR MARE PIT. L. Kerber[1], I. Nesnas[1], L. Keszthelyi[2], J.W. Head[3], B. Denevi[4], P.O. Hayne[5], K. Mitchell[1], J.W. Ashley[1], J.L. Whitten[6], A.M. Stickle[4], M. Paton[1], K. Donaldson-Hanna[7], R.C. Anderson[1], D. Needham[8], P. Isaacson[3], L. Jozwiak[4], [1]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr., Pasadena, CA (kerber@jpl.nasa.gov), [2]USGS Astrogeology Science Center, Flagstaff, AZ, [3]DEEPS, Brown Univ. Providence, RI 02912. [4]Johns Hopkins Applied Physics Laboratory, Laurel MD 20723, USA, [5]University of Colorado, Boulder, CO. [6]CEPS, Smithsonian Institution, MRC 315, Washington, DC 20013, [7]AOPD University of Oxford, UK, [8]NASA Marshall SFC, Huntsville, AL.

Introduction: Images returned by the Kaguya and Lunar Reconnaissance Orbiter missions revealed deep pits exposing tens of meters of layered stratigraphy in their walls [1-3]. Moon Diver (**Fig. 1**), a Discovery-class mission to a mare pit, would address numerous top-priority lunar science goals laid out in community reviews [4], the Decadal Survey [5], and the Lunar Exploration Roadmap [6], as follows:

(1) Virtually all mare basalt samples were collected as float rocks, without knowledge of which part of the lava flow was being sampled [6]. Lava flows, especially thick, slow-cooling flows, can differentiate or become contaminated both before their eruption onto the surface and as they flow or cool [7]. Exploring the variations in chemistry and mineralogy of an intact flow cross-section would provide vital context, and improve assessments of the probable parent melt [8]. Access to tens of meters of stratigraphy made up of numerous intact lava flows would allow intra- and interflow variability to be characterized, and could help determine whether the chemistry of the magma source(s) changed over time.

(2) The large areal extents of the mare basalts, together with their flat morphologies and sparsely identified flow fronts prompted the hypothesis that they were emplaced as "flood basalts": quickly, with voluminous amounts of low viscosity lavas [7]. Over the last few decades, closer examination of long lava flows in Hawaii, as well as thick continental flood basalt flows, have demonstrated a large role for insulated and inflated flows [9-10]. Documenting the thicknesses and internal structures of individual mare basalt flows would illuminate whether the mare basalts were emplaced quickly or more gradually as complex flow fields with tubes and inflated sheets. In-depth characterization of the chemistry and flow textures of the layers would provide vital temperature and rheological parameters for cooling models of lunar lavas.

(3) The average mature lunar regolith differs in composition from the average basaltic lunar rock, suggesting the presence of up to 20% non-local material, as well as a greater component of agglutinates and glass [7]. A mare pit with steep walls provides access to both the regolith and its underlying basalts, allowing a direct comparison between their compositions.

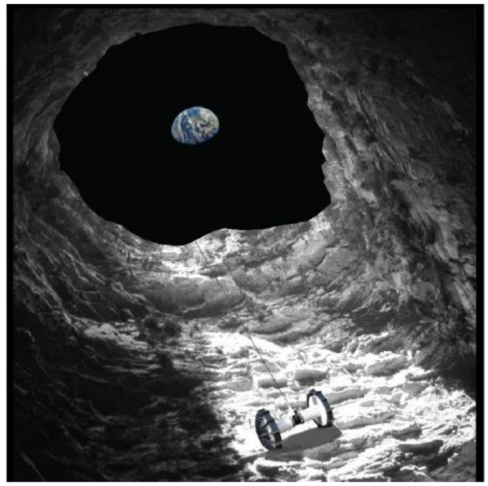

Figure 1. A representation of the Axel rover rappeling into a lunar pit as part of the Moon Diver mission. This mission's exploration of mare pits with potential subsurface void spaces would address numerous top-priority lunar science goals.

(4) Potential paleoregolith layers were identified in the wall on the far side of Hadley Rille at the Apollo 15 landing site, but it was not possible to observe them up close [7]. Accessing ancient regolith preserved between basalt layers would yield insight about the intermittency of mare eruptions and the timescales for regolith formation [4].

(5) Bombardment during early Solar System times is thought to have created a deep layer of fractured bedrock blocks in the lunar highlands known as the megaregolith [11]. In the mare, a shorter exposure time and dwindling impact population have retarded megaregolith formation, yielding up to ~10 meters of fine regolith on top of seemingly coherent basalt layers [7]. Mare pits permit access to the mare regolith/bedrock interface, where the details of regolith formation, including fractures in the bedrock and compositional changes with distance from the interface, can be examined first hand.

(6) In some cases, lunar mare pits may open into subsurface void spaces or lava tubes [1-3]. 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 [12-13]. Human settlements located in lava tubes would benefit from a stable, benign temperature, and would be protected from cosmic rays and micrometeorites.

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 limitations of the vertical mobility of traditional rovers. The Axel Extreme Terrain Rover [14], developed by the Jet Propulsion Laboratory in collaboration with Caltech, has the mobility necessary to approach 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 [14]. Scientific instruments are housed inside eight deployable bays housed in the wheel wells (**Fig. 2**), which rotate independently of the wheel.

Figure 2. The Axel rover taking spectroscopic measurements on a slope of 40º (figure from [14]).

Over flat terrain (for example, from the landing site to the pit), it has mobility similar to a traditional rover. Once it reaches the pit, it can rappel down by letting out the tether stored inside its axle [14; **Fig. 2**]. This functionality allows the rover to descend and ascend steep vertical slopes. The rover can even dangle in free space and continue to let out its tether.

Axel communicates through its cable, alleviating common communication problems facing other cave-exploring robots. The rover can also receive power through its tether, meaning that it can use a solar panel on the surface to power its exploration in the dark cave below [14]. 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. Payload capability would include: morphologic measurements (provided by a camera system), mineralogy (provided by a reflectance spectrometer), texture (provided by a microimager), and elemental chemistry (provided by an X-ray spectrometer). 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 [14]).

Axel has undergone extensive testing in terrestrial desert environments on steep slopes and various rock types [14]. Future field trials will test Axel mobility in volcanic settings with appropriate lunar pit analogs as 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, and explore with a suite of high-priority science instruments, with existing or highly mature technologies. The lessons learned by Moon Diver about the mare basalts would be relevant to flood basalt processes across the terrestrial planets., and its mobility technology could be easily modified to accommodate future missions in extreme terrains across the solar system.

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