THE GEOLOGIC CONTEXT OF MAJOR LUNAR MARE PITS.

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Introduction: In 2009, the Kaguya spacecraft discovered several large pits in the lunar surface [1]. Later Lunar Reconaissance Orbiter Camera (LROC) images captured these pits in greater detail, revealing that some of them expose tens of meters of in-situ lava bedrock cross-sections in their walls [2,3]. Such exposures offer tantalizing natural drill-holes through the regolith and into the lunar maria. In particular, the pits provide the opportunity to examine maria deposits from the top of the regolith, through the regolith/bedrock interface, and finally to exposed in-situ bedrock layers [4].The exploration of such an exposure would allow for the investigation of several key questions, including (1) how the regolith is generated from the original rocky surface [5], (2) how the mare lavas were emplaced (the true thickness of indivudual lava flow units and indications of their instantaneous flow velocities) [5], and (3) the effects of flow and in-situ fractionation on our understanding of the compositions and petrologic origins of the mare basalts [5].

While these three processes could be investigated at any mare pit having steep walls with exposed layering, the variation in exposure and geologic context among the pits means that each would provide additional, unique information about a specific region of the Moon. In this contribution, we discuss the geologic context for six of the larger pits, including pit geometry, regional geologic setting, and regional mare composition and expected exposure. We use this information to assess the exploration potential of each pit, and make suggestions about the potential contributions that each would offer to lunar science.

Lunar Pits: While analysis of the lunar surface has revealed 15 mare pits [3, 6] we focus here on six pits that show potential for significant cross-sectional exposure of mare layers: Lacus Mortis, Central Mare Fecunditatis, SW Mare Fecunditatis, Mare Ingenii, Marius Hills, and Mare Tranquillitatis (the pits do not presently have IAU approved names, and are instead canonically referred to using the name of the larger geologic region within which each pit is located [3]).

Lacus Mortis: The Lacus Mortis pit is the widest mare pit so far identified on the Moon, with dimensions of 140 x 110 m [3]. The north and south sides of the pit have a rounded regolith surface leading into exposures of layered wall units. The east and west sides of the pit are dominated by regolith slumping and talus features that extend into the pit, forming inclined surfaces [7]. It is unclear whether the pit leads to a subsurface void [3]. The pit is located a few kilometers to the west of the Rimae Burg graben, and could be related [7]. Compositionally, the pit is located in a deposit of low- to very low-Ti and high Al_2O_3 lavas that extend from Lacus Mortis across the larger Mare Frigoris region [8]. The Lacus Mortis region itself is a small, semi-circular mare deposit to the south of Mare Frigoris, and appears to be composed of a single basaltic unit [8]. The Lacus Mortis pit would provide access to 5-6 layers of undersampled Al-rich lavas [8]. While the layers may represent several flow events, they may not expose different flow compositions.

Central Fecunditatis: Mare Fecunditatis, a non-mascon pre-Nectarian impact basin [9], contains two mare pits, one in the central region of the basin and a second to the southwest. The basin contains predominantly low- to intermediate-Ti basalts [10].

The larger of the two Mare Fecunditatis pits has a similar geometry to the Lacus Mortis pit in that mare basalts are partly exposed in three-quarters of the pit walls while one quarter of the pit wall is dominated by a large slump of regolith material that extends from the surface regolith to the bottom of the pit. The pit itself is 130 x 110 m, while the outer funnel is 190 x 160 m. Shadow measurements indicate the pit has a total depth of ~45 m [3]. It does not lead to a sublunarean void. The surrounding region is relatively flat, almost equidistant between Messier B crater and a wrinkle ridge ~14 km to the east. The regolith surrounding the pit is likely contaminated by the ejecta of Messier and Messier B. The pit is located in a more Ti-rich region of the basin, with intermediate-Ti values.

SW Fecunditatis: While SW Fecunditatis is smaller, with a central pit opening of only 16 x 14 m, it is comparable in central pit depth (~35 m vs. ~30 m) to Central Fecunditatis. The total depth of the SW Fecunditatis pit (central pit and funnel) is closer to ~75 m. This pit is located on a large hummocky kipuka at the edge of Mare Fecunditatis, east of several large graben (e.g., Rimae Gloclenius). Available LROC imagery indicate that there is a void space ~7 m beyond the edge of the pit [3]. The upper walls of SW Fecunditatis are predominantly covered with regolith, obscuring any exposures of mare basalts in the pit walls and reducing the exploration potential of this pit. Based on the LROC TiO_2 map [10], the basalts of SW Fecunditatis are considered low-Ti basalts.

Mare Ingenii: The Mare Ingenii pit is located in southern Mare Ingenii in Thomson M Crater, on the far side of the Moon.. The pit is 100 x 68 m, 45-65 m deep, and exposes a very low-Ti unit [3, 10]. Three separate basalt units were mapped in Thomson M by [11], and it is unclear how many discrete units may be exposed by the pit. Additionally, the pit is located within a lunar swirl [12]. Lavas exposed at Ingenii would be a good exploration target for investigating farside magmas as well as the potential three dimensional structure of a lunar swirl. However, the pit's location on the far-side makes this pit a logistically difficult target.

Marius Hills: The Marius Hills pit is located in one of the most volcanologically diverse regions of the Moon. The pit is located in the bottom of a sinuous rille, which may have contained some of the most turbulent lavas on the Moon [13]. This sinuous rille is surrounded by volcanic domes, which may represent the most viscous lavas on the Moon [e.g., 14]. The pit is approximately 58 m x 49 m, and 40 m deep with approximately 23 m of lava layers exposed in the walls [3]. The pit is located in intermediate-Ti lavas comprising the oldest regional stratigraphic unit [15], and the further location within a sinuous rille make it possible that the entire exposed stratigraphy was emplaced during the same event as the sinuous rille. The Marius Hills pit leads to a void with a significant overhang (12 m; [3]), and has been the subject of several studies trying to determine the presence and extent of a large subsurface void [16-17]

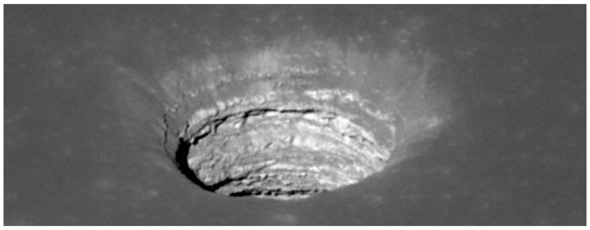

Fig. 1. An oblique view of the Mare Tranquillitatis Pit (100 x 88 m) showing the layers exposed (LROC image M144395745L)

Mare Tranquillitatis: The final pit is located in southeast central Mare Tranquillitatis (100 x 88 m and 105 m deep, with a ~20 m overhang; [3]). Mare Tranquillitatis is well known for titanium-rich lavas, sampled by Apollo 11 and Apollo 17 [17]. Multi-spectral analysis of the basin using Clementine data divided the basin lavas into four [19] or five [20] units, varying from low-Ti to very high Ti The pit is located right on a boundary where very high-Ti lava embays a kipuka of older, high-Ti lava. Because it is so close to the boundary, the pit should expose both units, which are compositionally distinct (high-Ti compared with very high-Ti) and significantly different in age (3.67 Ga compared with 3.85 Ga [19]). This age difference increases the likelihood that a paleoregolith layer would be encountered. The total depth of the lavas in this region of the basin was recently estimated to be ~200-400 m [21], meaning that a 111 m pit would sample a significant way through the total depth of the mare layers in this region.

Analysis and Implications for Exploration: Out of all of the pits, the Tranquillitatis pit provides the most compelling case for exploration. First, the surrounding flood basalts display a "classic" morphology, forming flat plains without clear flow boundaries or unusual morphologies. In this way the morphology can be considered "representative" of flood basalts broadly across the Moon. Second, the pit would provide a way to test theories of lateral regolith mixing, since it is distant from the highlands, but close to an internal mare boundary between two lava types. Third, since the pit it is located where one flow embays enother, the lateral location of the cross-section within the top flow is known, making interpretations of its morphology more straightforward. Finally, both of the pit's likely exposed lava types have been spectrally linked to basalt fragments in the Apollo 11 sample collection [19]. This means that as each lava was identified, it could be directly compared to an existing returned sample, multiplying the benefits of the in-situ payload by combining the original emplacement context of the lavas with the in-depth sample analysis done on the Apollo 11 samples [22].

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