DIFFERENTIATING PIT STRUCTURES USING ORBITAL IMAGERY AS INFORMED BY EARTH ANALOGS. S. L. Loeffler[1] and K. G. Thaisen[2], [1,2]Department of Earth and Environmental Sciences, University of Minnesota Duluth, Heller Hall 229, 1114 Kirby Drive, Duluth, MN 55812-3036

Introduction: Pit structures are steep walled depressions at the surface of a planet that are not craters. These features offer insights into the geologic history of a region that is otherwise inaccessible to orbial observations. On the Moon, work on lunar pits has provided insights into the characteristics and timing of Mare volcanism [1]. Pits and their associated subsurface void spaces are key targets in astrobiological studies and are top candidates for future human outposts due to their radiation shielding and consistent internal temperature. [2]

This study explores the characteristics of pit structures on the Earth, Moon, and Mars in order to determine if geomorphological relationships can be used to determine pit structure origins. Several formation mechanisms have been proposed for pit structures on these bodies. These include lava tube ceiling collapse, sinkhole formations in karst and other environments, explosive igneous activity, and collapse into void space created by faulting.

Methods: Planetary imagery from the Lunar Reconnaissance Orbiter's Narrow Angle Camera (LRO NAC), The Mars Reconnaissance Orbiter (MRO) High Resolution Imaging Science Experiment (HiRISE) were acquired from the Planetary Data System (PDS) and subsequently processed in the Integrated Software for imagers and spectrometers (ISIS). Earth data was acquired via the USGS EarthExplorer system (LANDSAT), aerial photography and Google Earth.

The types of structures being differentiated between include impact craters, lava tube skylights, sinkholes, impact melt voids, pit chains, maars, and calderas. Each pit was assessed for diagnostic characteristics such as raised rims, ellipticity, whether the pit is infilled, has vertical walls, as well as associations with regional features such as rille systems, faults, ejecta, proximity to volcanic systems, and possible water interactions.

The selected Earth sites benefit from accessibility, and in some cases, high resolution lidar, internal structural maps, and detailed geologic information. These sites act as a control for our interpretations of the Moon and Mars sites

Earth sites: *Indian Lava Tube at Craters of the Moon National Monument, Idaho.* Young basaltic lava flows have created lava tubes, some of which have undergone ceiling collapse revealing a skylight. These pits are rimless due to lack of soil or regolith above the lava tube ceiling. Several skylights exist along the sinuous path of the lava tube with the largest being approximately 20 meters in diameter.

Figure 1. Series of skylights into Indian Lava Tube. (Google Earth)

Pit Crater Chain, NE Iceland. Dilational faulting created a pit crater chain in NE Iceland. These have been compared to pit chains found on Mars by [5].

Figure 2. Pit chains in Iceland created by dilational faulting from [6].

2010 Sinkhole, Guatemala. Approximately 20 meters across and 30 meters deep. This pit has vertical walls and a near circular shape. It formed due to water flow eroding volcanic ash, limestone and other pyroclastic deposits beneath the city.

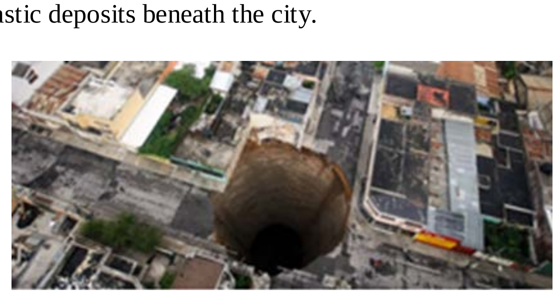

Figure 3. 2010 Guatemala sinkhole (National Geographic)

Lunar sites: *Marius Hills Pit, Marius Hills.* This pit is approximately 65 meters in diameter and 44 meters deep. It is located within a sinuous rille structure. There is a slightly sloping rim around the edge of the pit leading to vertical walls that show possible layering of mare flows. [4]

King Crater Arch, King Crater. Collapse feature of a lava melt pond. This feature has an oblong shape and central arch. Its depth ranges from 6 to 12 meters deep and the collapse structure at its widest is approximately 70 meters across.

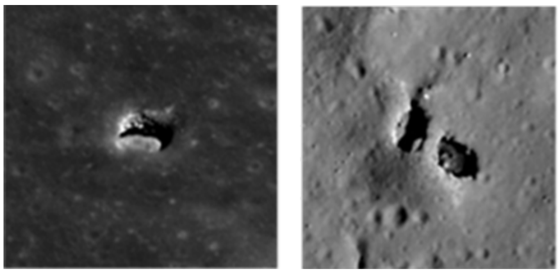

Figure 4. Left: Marius Hills Pit. Right: King Crater Arch. (NASA)

Martian sites: *Pair of rimless pits, Tharsis Region.* These pits are associated with a line of older, weathered collapse pits. Material appears to have been ejected from the interiors of these pits and deposited downwind in a dark, fan like shape. [5] The diameters of these pits are 180 and 310 meters with depths of 68 and 125 meters respectively.

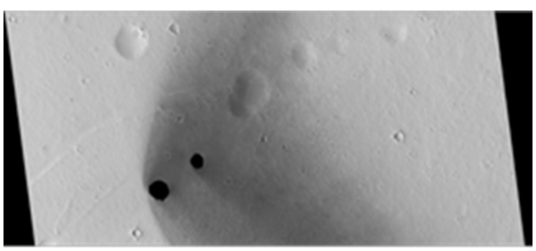

Figure 5. A pair of pits in the Tharsis Region with fan-shaped deposits. Filled pits trend to the NE. (HiRISE)

Pavonis Mons Pit, Pavonis Mons. This pit slopes at the angle of repose before dropping off at steep angle into a void. The hole is approximately 35 meters wide and 20 meters deep.

Analysis: We have compiled criteria of commonly observed features that are visible in satellite imagery and applied those to pits structures of known origin on Earth, then compared to Martian and Lunar features.

Earth site observations. Lava tube skylights of Indian Lava Tube were found to have circular to slight ellipsoid shapes, vertical walls, and were clustered in a sinuous path. Pit chains observed in Iceland showed sloped walls, circular shapes, and were repeated along a linear path controlled by the structure of the dilational fault. The sinkhole site showed vertical walls, circular shape, and was associated with subsurface water erosion.

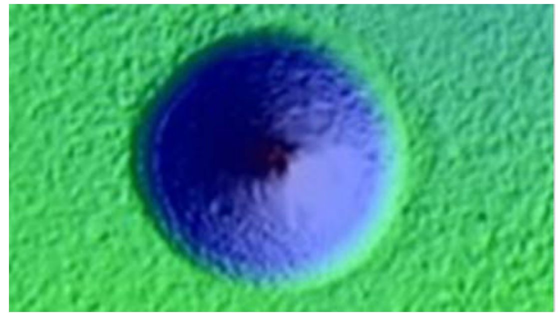

Figure 6. DTM of Pavonis Mons pit. A sloping rim leads to a subsurface void. (hirise.lpl.arizona.edu)

From these observations, lava tube skylights have vertical walls, roughly circular shapes and potentially be clustered together in a linear to sinuous path. Sinkhole style pits will be associated with water, and have circular to ellipsoid shapes with vertical walls. Dilational fault controlled pit chains show circular shapes, sloped walls, and are clustered linearly.

Lunar site observations. Marius Hills Pit shows vertical walls, circular shape, no raised rim, no ejecta, and is located within a sinuous rille. From these observations it is most likely that this is a lava tube skylight. King Crater Arch shows slightly sloping walls an oblong near ellipsoid shape, a central arch, and is located in a region of impact melt. These features do not indicate lava tube, pit chain, or sinkhole style origin and the formation's location in impact melt terrain indicate it is not compatible with Earth analogs.

Martian site observations. The rimless pits of the Tharsis region show both vertical walls and sloped walls, likely representing different pit formation ages. The pts are circular and repeated roughly linearly and trending NE. From these observations this site best matches the characteristics observed in the dilational faulting induced pit chain formation observations made in Iceland. Pavonis Mons Pit shows sloped walls leading into a vertical drop off with a circular shape. It is not obviously associated with any rille or fault.

Constraining pit origins using solely satellite observations is subject to much ambiguity. However, by using a few key observations outlined here, the possible origins of a pit structure can be further constrained by comparison to similar structures on Earth. Final results to be presented at the conference

References: [1] Loeffler S. M. and Thaisen K. G. (2014) Geological Society of America Abstracts with Programs. Vol. 46, No. 6, p.142 [2] Haruyama et al. (2012) Moon (pp. 139-163) [3] Christensen, P. R., et al. Journal of Geophysical Research: Planets (1991–2012) 105.E4 (2000): 9623-9642.[4] Robinson, M. S., et al. (2012) Planetary and Space Science 69.1:18-27. [5] Cushing T. N. et al. (2008) Lunar and Planetary Science XXXIX [6] Ferrill, David A., et al. GSA Today 14.10 (2004): 4-12.