POSSIBLE LAVA TUBE SKYLIGHTS NEAR THE NORTH POLE OF THE MOON. Pascal Lee[1,2,3], [1]Mars Institute, [2]SETI Institute, [3]NASA Ames Res. Center, Moffett Field, CA 94035, USA, pascal.lee@marsinstitute.net

Summary: Possible lava tube skylights are identified in Philolaus Crater near the North Pole of the Moon, making them potential access points to subsurface lunar polar volatiles.

Introduction: Lava Tube Skylights on the Moon. To date, over 200 pits have been identified on the Moon in mare basalt, impact melt deposits, and highland terrain, and interpreted as volcanic lava tube skylights or post-flow features [1]. Skylights are intriguing as they represent access points to subsurface voids and potentially vast networks of subsurface cavities enjoying substantial isolation and insulation from lunar surface environmental conditions. While it has been hypothesized that lunar lava tubes might serve as cold traps for volatiles, all skylights reported to date are located outside of the polar regions of the Moon where substantial amounts of near-surface volatiles are actually detected. We carried out a search for possible lava tube skylights in the North and South polar regions of the Moon using Lunar Reconnaissance Orbiter (LRO) Narrow Angle Camera (NAC) images, and report here on the identification of candidate skylights in Philolaus Crater in the North polar region of the Moon.

Philolaus Crater: Philolaus Crater (Diam ~ 70 km) is located at 72.1°N, 32.5°W, on the North polar near side of the Moon **(Fig. 1).** The crater is 540 km away from the lunar North Pole. Philolaus is of Copernican age (< ~1.1 Ga old). The impact melt deposits on the crater's northeastern floor are among the youngest lava flows known on the Moon.

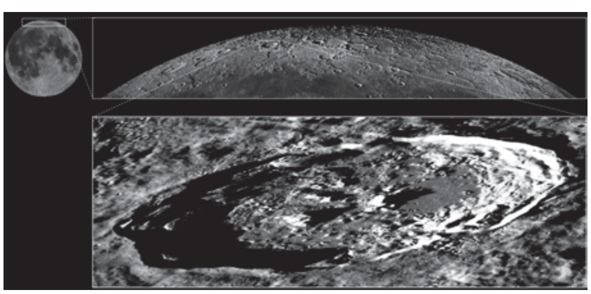

Figure 1: Philolaus Crater as seen from the Earth. Philolaus Crater (D~70 km) is located at 72.1°N, 32.5°W, on the North polar near side of the Moon (NASA LRO).

Candidate Skylights in Philolaus Crater: The impact melt deposits on the floor of Philolaus Crater are dissected by a network of crisscrossing winding depressions or sinuous rilles. The depressions are typically less than 100 m in width. Some may be traced for several kilometers. Because of their sinuosity, and the discontinuities they present along some sections, these rilles are likely collapsed lava tubes interrupted interrupted by occasional intact (uncollapsed or only partially collapsed) sections. Some of these intact sections present short chains of discrete, round, rimless pits no wider than the local rille width, suggesting that the pits are possible lava tube skylights. **Figure 2 E and F** shows three such pits, numbered 1 through 3, that are among several candidate lava tube skylights present on the floor of Philolaus Crater. The pits appear near a Y junction split in the local sinuous rille network. Pits #1 and #2 are ~ 15 m across, while Pit #3 is roughly 30 m in diameter. **Figure 3** is one of the highest resolution LRO NAC image available of these three pits (R. V. Wagner, *pers. comm.*).

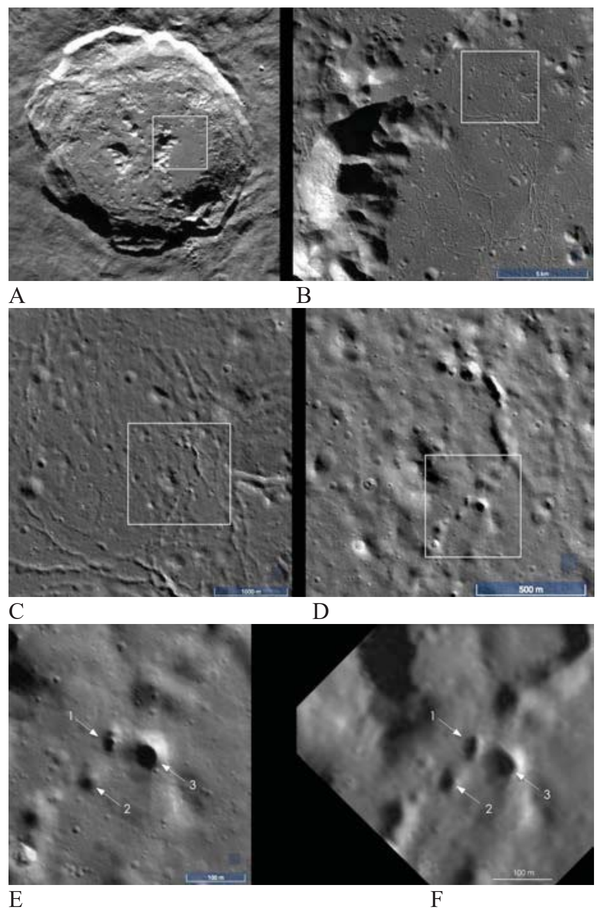

Figure 2. Candidate Lava Tube Skylights in Philolaus Crater. Sequence of nested Lunar Reconnaissance Orbiter (LRO) images showing the locations of the candidate lava tube skylights identified in Philolaus Crater. **A:** Philolaus Crater (N is to the upper right); **B:** Smooth plains on the crater's northeastern floor; **C**: Network of sinuous rilles on the crater floor; **D:** Discontinuous sinuous rilles with pitted segments; **E and F**: Closeups of area boxed in D showing 3 candidate lava tube skylights numbered 1-3. (NASA LRO LROC).

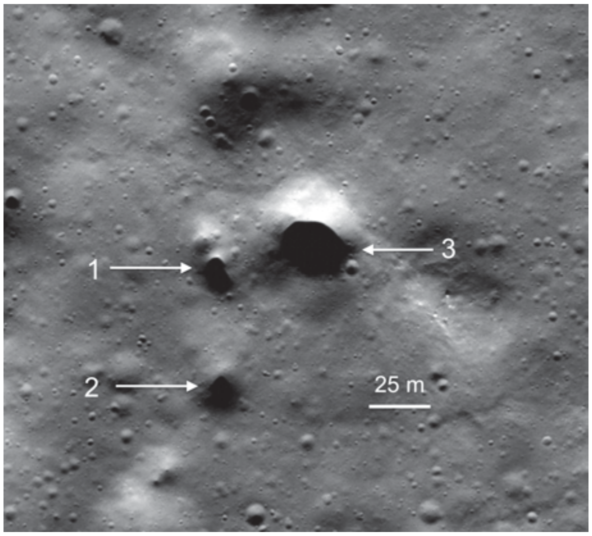

Figure 3: Candidate lava tube skylights in Philolaus Crater. Lighting conditions indicate that the pits are rimless. At Pit #1, a bright semi-circular feature at the immediate edge of the shadowed zone might be part of a skylight wall. (NASA LRO NAC).

Physics of lava tube environments at Philolaus Crater: Given Philolaus Crater's high latitude (72.5°N) and typical lunar skylight dimensions and geometries, the floors immediately below candidate skylights 1 through 3 are expected remain permanently shadowed. Thus, in contrast to lower latitutde skylights on the Moon, sunlight never penetrates the new candidate skylights to illuminate (and warm) their floors. Temperatures in these near-polar lava tubes might therefore remain extremely low, similar to equilibrium temperatures reached in the permanently shadowed terrain at the lunar poles (T ~ 25 K). Such low temperatures would allow water ice, if present in the first place, to be stable over geological timescales.

In terrestial lava tubes set in cold regions, such as the Lofthellir lava tube in Iceland, water ice often finds sufficient shelter to occur in massive form. Although some of the sources of the water and the thermodynamic conditions in these terrestrial lava tubes are not applicable to the Moon, the analogy merely emphasizes the fact that the interior of lava tubes may enjoy substantial shelter and cooling compared to their outside environment.

Due to Philolaus Crater's high latitude, external ground temperatures are modest. Maps of measured temperatures on the Moon from the LRO Diviner instrument indicate that daytime temperatures on the floor of Philolaus Crater are in the 200-240 K range.

Significance: The present finding is of significance because a) Philolaus Crater is relatively young; its impact melt deposits and lava tubes would therefore be similarly young too; b) the network of lava tubes in these deposits is extensive; *and* c) these subsurface cavities have a near polar location and might be cold enough to cold-trap water ice over geologic timescales.

Mission to Philolaus Crater: An important next step is to confirm, with higher spatial resolution imaging, whether the pits in Philolaus are truly lava tube skylights. If confirmed, then surface missions (robotic and/or human) to explore Philolaus and its lava tubes could follow [3]. Exploring Philolaus would represent the first *in-situ* investigation of a large impact structure formed during the Copernican Era, allowing it to be dated precisely and older lunar crustal remnants excavated by the impact to be examined. Investigating Philolaus' impact melts would allow assessing modern lunar crustal geochemistry and volatile content. Exploration of Philolaus' relatively young and little-modified lava tubes might give access to well-preserved volcanic volatiles and cold-trapped subsurface H_2O ice. Exploring Philolaus' skylights and lava tubes would also help prepare for the exploration of analogous features on Mars.

Relatively smooth landing areas are available on the floor of Philolaus near the candidate lava tube skylights sites. Earth is directly visible from most locations of Philolaus' impact melt deposits above the potential lava tube network. Mobility is required to effectively explore and sample the crater floor. For robotic systems, accessing subsurface cavities through lava tube entrances and skylights would likely require non-wheeled systems such as walkers, hoppers, or rollers [*e.g.,* 2].

Human exploration missions could be of high value following robotic reconnaissance. If Philolaus Crater's network of lava tubes proves to be a substantial repository of accessible subsurface ice, then the site might be ideal for establishing a long-term base.

Figure 4: Human exploration of a lunar lava tube skylight. (P. Lee, composite image).

References: [1] Wagner, R. V. & M. S. Robinson (2014). *Icarus 237*, 52-60. [2] Thangavelautham, J. et al. (2017). *2nd Int'l Wkshp on Instrumentation for Planet. Missions*. [3] Lee, P. 2018. *Lunar Sci. for Landed Missions Wkshp*, Jan 2018, NASA SSERVI.

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