SMALL-SCALE PITS IN IMPACT MELTS. R. V. Wagner, M. S. Robinson, and J. W. Ashley. Lunar Reconnaissance Orbiter Camera, School of Earth and Space Exploration, Arizona State University, Tempe, AZ 85287-3603 (rvwagner@asu.edu).

Introduction: Three 100-m scale mare pits were discovered in SELENE images and the pits were proposed to have formed as lava tube skylights [1]. Further observations by the Lunar Reconnaissance Orbiter Narrow Angle Camera (NAC) revealed that at least two of these pits are openings into subsurface voids of unknown lateral extent [2]. These discoveries led to an initiative to search the entire lunar surface for additional pits large enough to be detected in 50 cm pixel scale NAC images. To date, 156 pits with diameters greater than 5 m have been discovered in impact melt deposits of 20 craters, with a median pit diameter of 15 m and a maximum pit diameter of 100 m. An additional 15 m diameter pit was discovered in Mare Smythii (in mare materials).

Automatic Pit Detection: Because of the large number of NAC images acquired each day and their size (typically 5000 samples by 52,224 lines), it is not feasible to carefully search each image manually, so we developed an algorithm which searches an image in thirty seconds. The current method is a simple shadow-detection algorithm. It locates blocks of pixels that are below a digital number (DN) cutoff value indicating that the block of pixels is "in shadow", and saves a sub-image (200 by 200 pixels) of the surrounding region. A human can then decide if the shadow is actually associated with a pit by rapidly scanning the sub-images. This method has a true-to-false positive ratio of around 1:5000 at incidence angles less than 40° (measured from the surface normal), mostly from cases where a non-optimal cutoff value was selected for shadowed pixels. Above 40° incidence the false positive rate is much higher, due to many craters casting shadows. Thus, the current search is limited to parts of the Moon imaged with incidence angles less than 40°. To date, 10.66% of the Moon has been imaged within this constraint.

A few tests have been made with a more complicated algorithm, which checks each shadow for a pattern of bright and dark areas indicative of a vertical-walled pit, rather than a rock casting a shadow, or a crater with a raised rim. In the future, this system may extend the searchable incidence angle range up to ~60°, but false positives remain too frequent in test runs.

Global Distribution: The majority of impact melt pits were found in Copernican age craters, but two craters with pits are Eratosthenian (Harriot W and Klute W), and five are of unknown age (Adams B, Stefan L, Picard, Lalande, Virtanen) [3]. Within the area searched, the majority of the craters with pits were formed in highlands terrain.

Pits have been found in melt ponds with diameters ranging from 2 km to 50 km, with the parent crater diameters ranging from 10-90 km. Most of these craters have only 1-4 pits identified so far, but a few have many more, with the most occurring in the Copernicus (20 pits) and King crater (50 pits) melt deposits. Three large Copernican craters (Tycho, Necho, and Giordano Bruno) have been manually searched without finding any pits not associated with fractures.

Distribution within craters: Where multiple pits were found in a single pond, the pits often occur in one or more small regions (~2-5 km square) within the melt deposit. Pits occur in both rough and smooth (meter to ten scale) melt deposits. Most pits are associated with fractures. The fractures may signal subsurface movement while portions of the deposit are still molten. Occasionally, several pits occur within tens of meters of each other, indicating a possible subsurface connection. See Figure 1 for a representative overview of pit locations. Note that these observations are based on a limited sample area. In most cases, only a single NAC pair has been manually searched for pits at each crater where pits have been found automatically, and only King crater's melt pond has been completely searched manually.

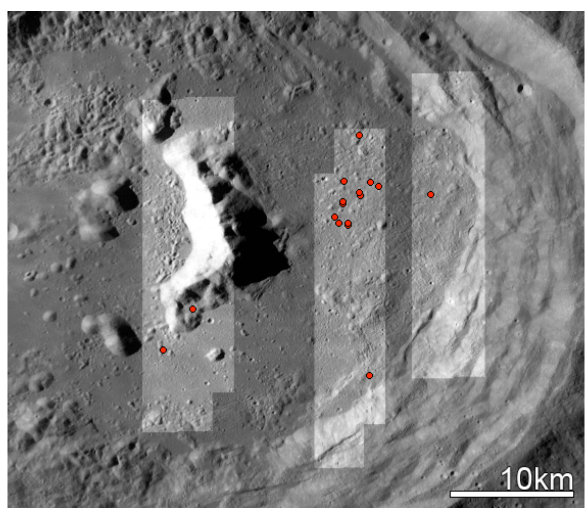

Figure 1: Distribution of pits and searched NAC images in Stevinus crater. Red dots indicate pit locations. Lighter regions indicate images that have been checked for pits. Base image is from WAC global mosaic.

Pit Morphology: Impact melt pits were categorized based on shape and nearby geological features. The categories below are illustrated in Figure 2.

Simple Pits (Figures 2A, 2B): Characterized by near-vertical walls, and a flat to slightly concave floor. The pit plan is often irregular, and typically has a gently inward-sloping funnel shape around the opening. However, most of the pit depth is below the funnel portion of the rim. This class of pits is not associated with any visible fractures or other linear features visible on the surface. Simple pit depth to diameter ratios are usually greater than 1:4.

Concave-bottomed Pits (Figure 2C): Wide, shallow, circular to elliptical features with concave floors. They appear superficially similar to impact craters, but with no raised rim and no visible ejecta. They exhibit a flat or inward-sloping rim terminating in an inward-facing cliff, with numerous interior blocks, and few to no exterior blocks. Probably a similar formation mechanism to simple pits, but with a much wider collapsed area without being any deeper (lesser depth/diameter ratio). Debris from the collapsed roof and walls likely leads to the concave shape of the floor.

Fracture-Associated Pits (Figure 2D): Pits that occur along fractures in the impact melt deposit. This type of pit occurs in nearly every impact melt deposit that contains fractures. Their morphologies range across a spectrum: from localized fracture widening of a few meters, to rounded collapses dozens of meters wide. The latter usually occur at intersections of multiple fractures. Where it is possible to determine the depth of the fractures, fracture-associated pits are no more than a few meters deeper than the parent fracture(s). This type of pit has not been included in the count of pits found due to their high abundance.

Depression-associated pits (Figure 2E): Occasionally pits occur in sinuous concave depressions, similar to skylights in lava tubes. Depression-associated pits rarely have visible floors (due to shadowing), so the depths of host melt tubes, if they exist, generally cannot be estimated. Future imaging at lower incidence angles may reveal true depths. This form of pit is most prevalent in Copernicus crater, but also exists in Crookes and Jackson craters.

Dome-associated pits (Figure 2F): In King crater, some pits have formed on the tops of 100 m scale shallow-sloped rounded domes, which are scattered around the melt pond. Domes with pits have not been identified in other impact deposits.

Significance: The existence of impact melt pits indicates that a complex plumbing system may form in some impact melt deposits, which is unexpected, since impact melt is formed in an instantaneous event, and rapidly pools to its final location. However, due to target rebound (and related subsurface fracturing), pooled melt may drain into cavities or spill over divides, creating subsurface melt channels and voids.

Impact melt pits are also important from an exploration standpoint. If pits connect to sublunarean cavities, they could be a cost-effective way to shield a human outpost from radiation, micrometeorites, and temperature cycling. Pits might also provide access to material that has not been modified by micro-impacts or space weathering [2].

References: [1] Haruyama J. et al. (2010) *LPSC XLI,* Abstract #1285. [2] M.S. Robinson et al (submitted) *Planet. Space Sci.* [3] D.E. Wilhelms (1987) USGS Prof. Paper 1348, plates 10A-11B.

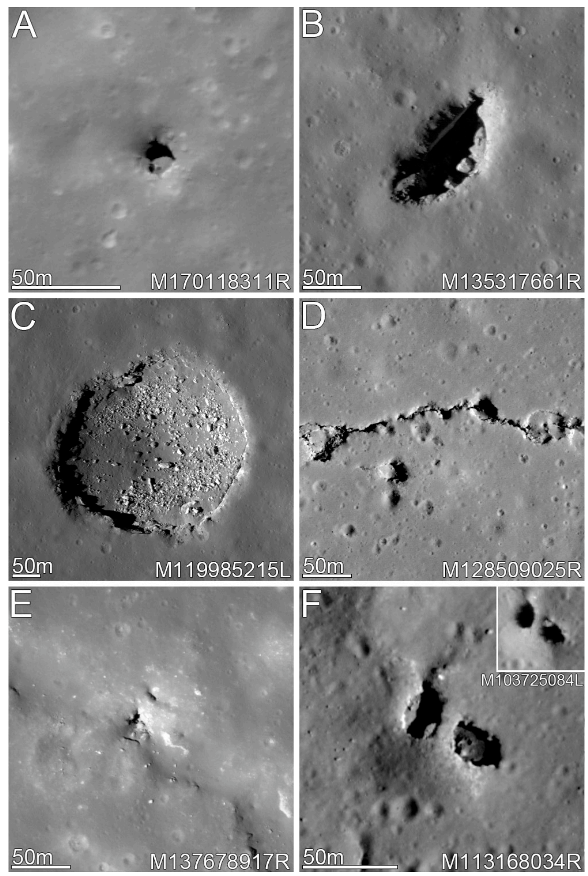

Figure 2: Examples of common pit morphologies. (**A**) Simple pit in Palitzsch B. (**B**) The largest simple pit found so far, in Copernicus crater. (**C**) A concave-bottomed pit in Copernicus crater. (**D**) Fracture-associated pits in the exterior King crater melt sheet. (**E**) A depression-associated pit in Copernicus crater. (**F**) An arch over a pit which formed in the side of a small dome in the King crater melt sheet. Inset shows light shining under the arch from the opposite direction from the main image.