**HIGHLAND SMOOTH PLAINS, AN EXCEPTIONAL GROUPING.** M. S. Robinson[1], P.C. Thomas[2], B. W. Denevi[3], T. Tran[1], E. B. Cisneros[1], J. Plescia[3], C. H. van der Bogert.[4], H. Hiesinger[4], [1]School of Earth and Space Exploration, Arizona State University, Tempe AZ, [2]Cornell University, Ithaca NY, [3]Johns Hopkins University Applied Physics Laboratory, Laurel MD, [4]Institut für Planetologie, Westfälische Wilhelms-Universität, Münster, Germany.

**Introduction**: Smooth deposits are widespread on the Moon and are attributed to three main modes of formation: basaltic flood volcanism, (fluidized) basin impact ejecta, and impact melt [**1**]. The first type are thought to cover about 30% of the Moon, and the third type are localized within and near (<1 crater diameter from the rim) relatively recent (Copernican, <1Gy) impact craters. Basin ejecta are globally distributed and form relatively smooth surfaces in topographic lows and are of ancient age.

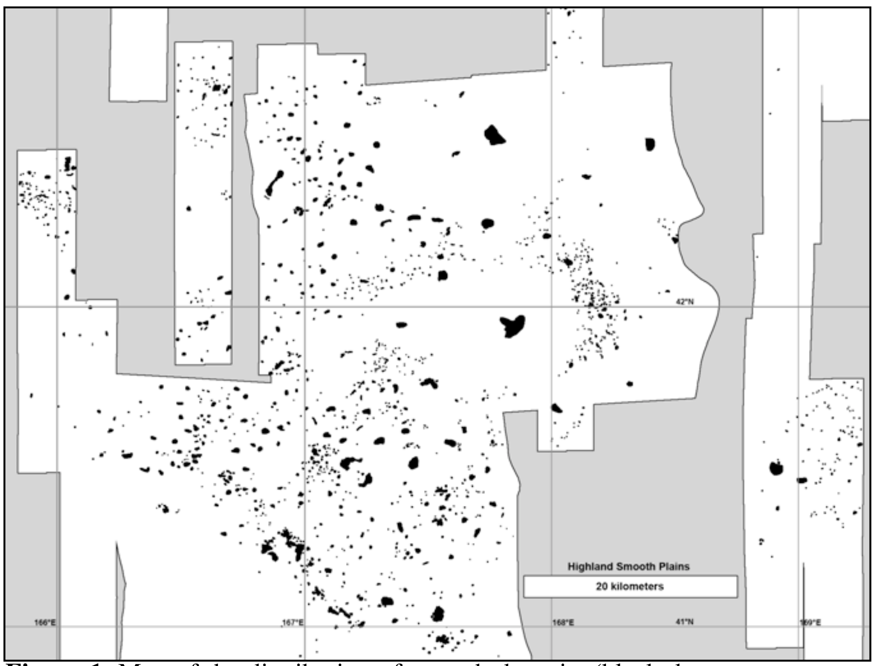


**Figure 1**. Map of the distribution of smooth deposits (black denotes areas covered). Large occurrences of the material typically occur in topographic depressions – impact craters. White shows current NAC coverage, gray WAC coverage only.

**Morphology and Distribution:** Lunar Reconnaissance Orbiter Camera (LROC) Narrow Angle Camera (NAC) meter scale images [**2**] reveal a large region (>3000 km$^2$, at 41°N, 167°E) containing hundreds of young (**Fig. 1**), discrete smooth deposits. These deposits are manifested as ponded materials, with associated viscid flows, and thin veneers on surrounding slopes that suggest widespread emplacement of a fluid material. The NAC images reveal meter- and decameter-scale textures that indicate the viscid material was emplaced with velocities high enough that allowed uphill movement of still molten material. Textures include flows with festoons of boulders along fronts, flows with bulbous margins, fractures (cooling cracks?) in ponds, and a rough texture on steep slopes.

The ponded nature of the deposits is well demonstrated with 2-m scale digital elevation models (DEM) (**Fig. 2**) derived from NAC stereo images [**3**]. The standard deviation of elevations for a given pond is typically <0.5 m consistent with a fluid seeking an equipotential surface.

How did the ponds form? 1) Effusive volcanism seems unlikely. Such a scenario requires multiple small eruptions with as many vents, no albedo contrast or color contrast with the substrate, and can't easily reconcile with apparent uphill flow. 2) The viscid forms and discrete ponds are unlike any other known pyroclastic deposit previously identified on the Moon. 3) Due to the young age of the deposits they cannot be formed as Cayley plains-like basin ejecta. 4) Impact melt is a possible origin which the material being ballistically transported and deposited across a large area, in some cases coating the surface and in others flowing in depression to form ponds.

**Age**: Observations of impact crater densities show the pond ages to be Copernican (<1Gy), and likely younger than 100 Ma (**Fig. 3**). However, the morphology of many of the crater forms raises questions as to whether they all represent a post-emplacement primary crater population. Many craters are shallow and subdued and may represent syn-impact of debris into a still partly molten deposit. It is interesting to note that the crater frequencies for these deposits are nearly identical to those for melt deposits associated with Tycho crater [**6**].

**Source**: If the material is impact melt, then where is the source crater? Smooth deposits and crusts have a minimum volume >1 km$^3$ requiring a source transient crater >10 km in diameter. The young age of the ponds limits the source to be a late Copernican crater. No nearby crater (<50 km distant) meets such criteria. Ejecting melt far from a crater most likely requires an oblique impactor, further limiting possible source craters. Several source crater candidates have been identified: Buys-Ballot crater 700 km distant, it is highly elliptical, ~60 km diameter, but its proposed age is not Copernican; Stearns crater (36 km diam) is only 100 km distant, of Copernican age but does not appear to be formed from an oblique impactor; Larmor Q is an oblique, very fresh crater, 22 km diameter located ~500 km to the SE and contains extensive impact melt deposits on its floor; Jackson crater (71 km diam) – >500 km distant and Tycho crater (85 km diam) is thought to have formed from an oblique impactor, is late-Copernican in age but is on the other side of the Moon — in fact it is almost exactly anti-podal to the ponds. Crater size-frequency distributions for Tycho impact melts [**6**] are similar to those of the ponds, though we have not completed an analysis of the crater size-frequency distributions for other possible source craters.

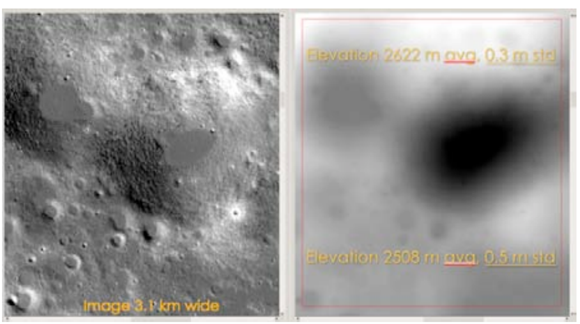


**Figure 2.** LROC NAC stereo image (left) and corresponding derived DEM (right) of small portion of pond region (each 3.1 km wide).

The current map of ponds shows NW/SE elongation. Flow indicators commonly imply a NW/SE source, most commonly from the NW. The geometry requires melt thrown in from many tens of kilometers or possibly 100’s to 1000’s of kilometers!

These features suggest unknown mechanisms or more likely that impact melt can be deposited in significant volumes far (tens of diameters or more) from a source crater, distances not before appreciated. The current candidate source craters all require melt ejected many tens of kilometers to 100s to 1000s of kilometers. These features suggest unknown mechanisms or ballistic emplacement of impact melts over distances not before appreciated.

**References**: [**1**] D. Wilhelms (1987) U.S. Geol. Survey Prof. Paper 1348. [**2**] Robinson, M. S. et al. (2010) *Space Sci. Rev., 150*, 81-124. [**3**] Tran T. et al. this volume. [**4**] Neukum, G. et al. (2001) *Space Sci. Rev., 96*, 55-86. [**5**] Neukum, G. and Ivanov, B. (1994) Hazards due to Comets and Asteroids, 359-416. [**6**] Hiesinger H. *et al.,* (2010) *LPSC XLI,* abs. #2287. [**7**] Michael, Neukum (2007) LPSC XXXVIII. #*1825.*

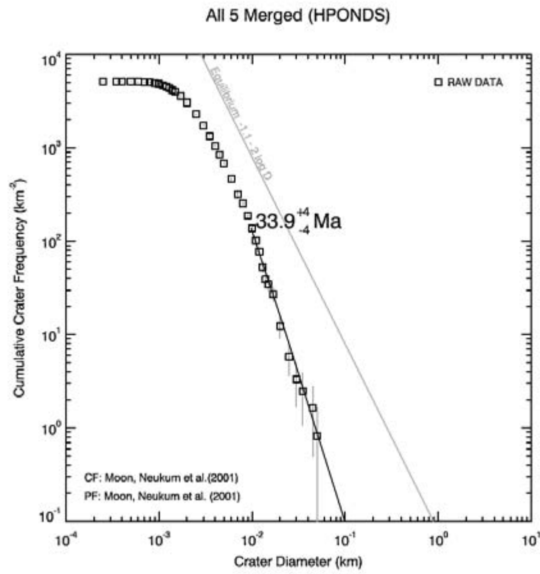


**Figure 3**. Combined crater counts for five areas of smooth material. An absolute model age of 33.9 ± 4 Ma is indicated based on the chronology of [**4,5**]. The CSFDs were plotted and fitted using CraterStats [**7**].

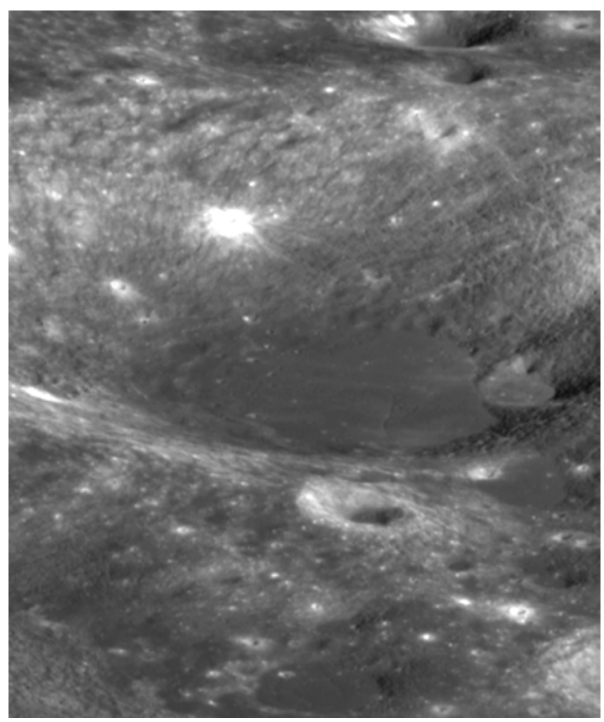

**Figure 4.** LROC NAC oblique view of small portion of highland pond region (central smooth pond is ~500 m wide).