LUNAR "COLD SPOTS": A NEW CLASS OF THERMOPHYSICALLY AND MORPHOLOGICALLY DISTINCT CRATERS. J. L. Bandfield[1], E. Song[1], P. O. Hayne[2], R. R. Ghent[3], D. A. Paige[4], [1]Earth and Space Sciences, University of Washington, [2]Geological and Planetary Sciences, California Institute of Technology, [3]Department of Geology, University of Toronto, [4]Earth and Space Sciences, UCLA.

Introduction: The thermophysical properties of the lunar regolith are remarkably uniform due to the ubiquitous processing of the surface layer in the lunar space weathering environment. The most common exception is where rocks are present on relatively young surfaces, which elevate nighttime temperatures [1,2]. There is also a class of anomalously cold surfaces (termed "cold spots" here) that are associated with fresh craters with a unique ejecta morphology.

Observations: *Thermal properties.* Lunar Reconnaissance Orbiter Diviner [3] nighttime temperature data show anomalously cold temperatures for surfaces surrounding some small recent lunar craters (Fig. 1). The area immediately surrounding the craters have increased rock abundances [2], but the cold surfaces have negligible rock abundances similar to most other lunar surfaces. The similarity of brightness temperatures across Diviner's spectral range indicates a uniform surface, rather than a surface composed of materials with highly contrasting thermophysical properties.

Cold spot temperatures remain a relatively constant ~5 K cooler throughout the lunar night compared to typical lunar regolith, indicating that the materials with contrasting thermophysical properties extend to ~5-10 cm depth. In order to reproduce the nighttime temperature curve, the cold spots require a more insulating top layer than is present for typical lunar regolith [4].

The cold spots are not apparent in Diviner daytime temperatures. However, elevated 8-25 μm brightness

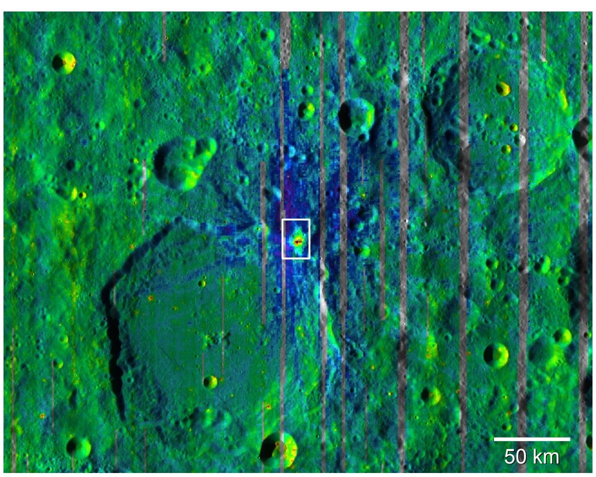

Figure 1. Diviner normalized nighttime regolith temperatures [2] near 151E, 4S (LROC WAC mosaic for shading). Colder surfaces are shown in blue and extend from a 1.5 km diameter crater at the center of the image. White box denotes area covered by Figure 2.

temperature differences indicate that the cold spot regions are slightly rougher (at mm scales) than the surrounding terrain, consistent with a fluffier surface.

A variety of surface patterns are apparent in the cold spots, including features such as rays and exclusion zones [5]. The pattern typically follows that of visible ejecta more proximal to the source crater.

Visible Imagery. LROC Narrow Angle Camera images show relatively bright continuous layers of ejecta within a few crater radii of the rim (Fig. 2). These layers are radially striated, divert around obstacles such as rocks, and have abrupt terminations. Layers are progressively darker with increasing distance from the crater. These features are most prominent in the region interior to the cold spot where blocks near the crater rim elevate nighttime surface temperatures.

At greater distances from the crater and within the region of low nighttime temperatures, ejecta are more

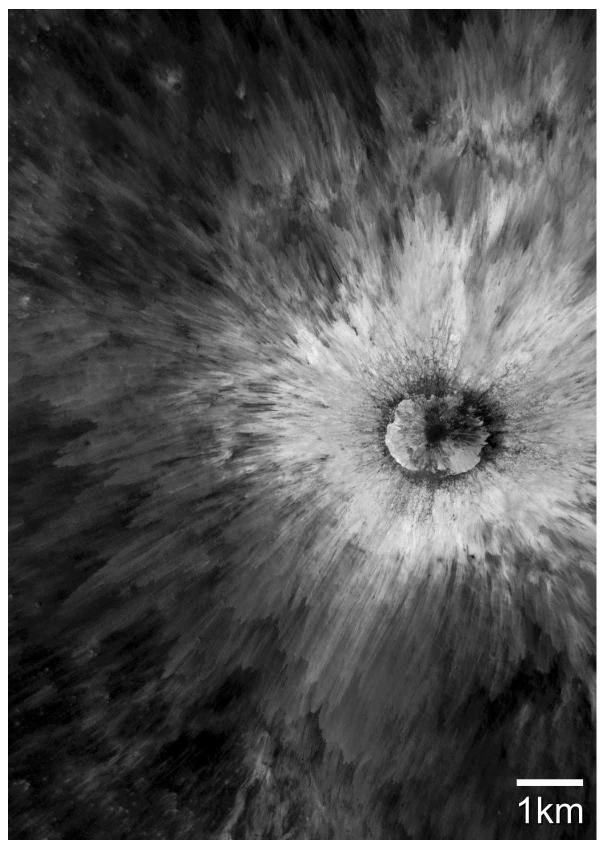

Figure 2. LROC mosaic of cold spot crater with continuous layered ejecta. Striations, abrupt terminations, and diversions around obstacles indicate ground—hugging fluidized flow.

discontinuous and often show wispy, relatively bright features that follow topographic obstacles radially away from the source crater (Fig. 3). However, much of the surface area is indistinguishable from typical surfaces immediately surrounding the cold spots.

Clementine UV/VIS/NIR albedos average 0.0031 (1-2%) higher within 24 prominent equatorial cold spots compared to the surrounding terrain with no apparent color difference. In many cases there is no significant difference. It is possible that the light, wispy features are responsible for the slightly higher albedos. Little new material has been deposited within the cold spots and any reworking of the surface is limited to homogeneous mature materials in the upper 10 's of cm.

Distributions. 435 cold spots have been identified using Diviner nighttime regolith temperature maps. There is no apparent systematic distribution or preferred terrain, though the cold spots are more difficult to identify at higher latitudes (poleward of ~45N/S) because temperature variations due to topographic features interfere with their detection.

Scaling Relationships. Crater ejecta scaling relationships are also inconsistent with deposition of significant ejecta in the cold spots. In the case of one of the larger cold spot areas surrounding a 0.7 km radius crater, basic scaling relationships from [5] indicate 5-10 cm thick continuous ejecta (necessary for the colder temperatures to persist through the lunar night) should only be present within ~10 km of the crater, whereas most of the cold spot area is well outside this radius and extends up to 200 km away from the crater.

The cold spot areas are much larger than surfaces typically modified by small craters. Maximum runout distance for cold spots is typically 50-100 crater radii (Fig. 4) with a positive exponent in the regression, consistent with emplacement via turbulent flow [6,7].

Discussion/Conclusions: Both near-crater ejecta morphology and cold spot scaling relationships indicate emplacement via fluidized, turbulent flow. The extremely large areal coverage of the cold spots, the large thickness of material necessary to change the thermophysical properties, and the lack of albedo/spectral contrast are inconsistent with ejecta deposits. If there is a cold spot pattern that is similar in form to the near crater ejecta deposits, but is not itself composed of ejecta, what process is responsible for these observations? A gas-dominated flow with significant sedimentation of particles within a few crater radii would account for the surface features observed. In particular, flowing gases would extend large distances from the source crater and modify the surface layer without leaving significant deposits.

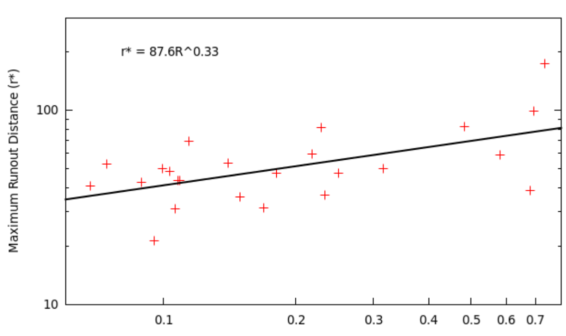

Figure 4. Maximum cold spot runout distance (after that of [6,7]. Cold spots can extend beyond 100 crater radii from the source crater.

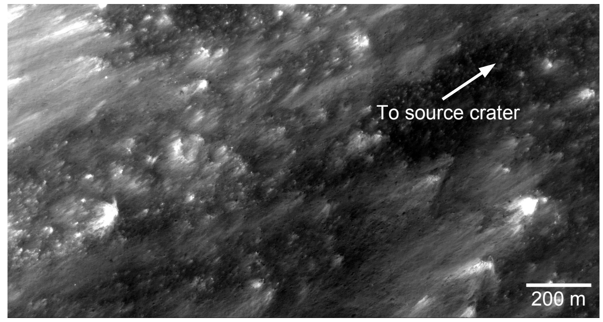

Figure 3. LROC NAC image of a cold spot surface ~13 km from the source crater shown in Figure 2.

Other processes involving only dry particulates (e.g. ballistic sedimentation [8]) can not be responsible because the high particle densities required for grain collision supported flows would deposit significant new material that would brighten the surface similar to the ejecta proximal to the source crater.

These features are only apparent in young fresh craters and it is not clear if there is a limit to the size because of the lack of very recent large lunar craters. Impact angle and terrain type do not appear to be a controlling factor for the presence of cold spots.

The mobilization of regolith by volatiles appears to be a common process associated with lunar impacts. The random distribution and occurrence of the cold spot features indicates that their formation is governed by the composition or velocity of the impactor rather than the target. This appears to be a new class of crater that is likely to be present on other airless bodies with significant gravity, such as Mercury or Vesta.

References: [1] Mendell, W.W. and Low, F.J. (1975) *LPSC*, *6*, 2711. [2] Bandfield, J.L. et al. (2011) *JGR*, 10.1029/2011JE003866. [3] Paige, D.A. et al. (2010) *Space Sci. Rev.*, *150*, 10.1007/s11214-009-9529-2 [4] Keihm, S.J. Et al. (1973) *Earth Planet. Sci. Lett.*, *19*, 337. [5] Melosh, H.J. (1989) *Impact Cratering*, 253 p. [6] Schultz, P.H. (1992) *JGR*, *97*, 11623. [7] Ghent, R.R. et al. (2010) *Icarus*, *209*, 10.1016/j.icarus.2010.05.005/ [8] Oberbeck, V.R. (1975) *Rev. Geophys. Space Phys.*, *13*, 337.