"SPIDERS" ON THE MOON: SITES OF REGOLITH DRAINAGE INTO SUBSURFACE VOIDS.

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Introduction: Typically, the surface of the Moon is covered by a meters-thick layer of regolith. The surface morphology at the scale of meters is smooth and subdued, being dominantly controlled by regolith gardening, which acts as topographic diffusion [1,2] smoothing the surface. Sharp, "crisp" meter-scale morphologic features are observed only where regolith is absent or very thin, or where it was recently disturbed. Such "crisp" morphologies occur predominantly in geologically young impact craters of different size and in their continuous ejecta. Features with absent, very thin or recently disrupted regolith outside young craters are rare. The largest class of such features (in terms of area) is the set of rocky slopes and solidified melt ponds in the area approximately antipodal to crater Tycho [3, 4], interpreted as a result of focusing of Tycho ejecta and thus are also of impact origin.

"Crisp" morphologies are also observed in Irregular Mare Patches (IMPs), small (tens of m to several km) rare features of uncertain origin [e.g., 5 - 7] (Fig. 1). IMPs are depressions consisting of two units [6]: a lower bright immature hummocky floor unit and an upper smooth darker convex-upward mound-like unit; in some largest IMPs the upper unit also form island-like domes amid the lower floor unit. 70 IMPs and their clusters were catalogued in [6], and [7] added 21 more. In [6] IMPs were interpreted to be very young lava flows with sharp depressions, similar to terrestrial inflated lavas. Challenges to this interpretation include: (1) the gradational nature of the contact between presumably young upper unit and surrounding old mare surface, and (2) the morphology of small craters superposed on the upper unit, suggesting an old, thick regolith. In [7] the IMPs were interpreted as old volcanic features made of highly vesicular lavas; in this scenario ongoing sifting of the regolith into the shallow subsurface voids is responsible for the observed "crispness" and immaturity of the lower unit. In [8] the IMPs were suggested to form through removal of regolith from the lower unit by sudden geologically recent release of pressurized subsurface gas.

Here we report on a rare new type of small "crisp" young feature, informally referred to as "spiders".

Observations: *Morphology:* "Spiders" are small asterisk-shaped depressions (Fig. 1). Their typical diameter is ~70 m, varying only from ~50 m - 80 m, comparable to the accuracy of size determination. An LROC NAC DTM is available for one "spider" set; however, spider topography is not resolved. The absence of shadows in low-sun (~70° incidence angle) images and visual comparison with larger depressions resolved in topographic data indicate that the depth of "spiders" is on an order of 10 m. "Spider legs" are re-entrants that are open toward the feature center, widening as they dip down toward the center. Some re-entrants merge and thus form an incipient dendritic pattern. The re-entrants are meters wide and on order of a meter deep. The most pronounced "spider" has a small (5 m in diameter) sharp rimless depression in its center, apparently a steep-walled pit. High-sun images (Fig. 1) show sharp, high-contrast, asterisk-shaped high-albedo features; bright, apparently immature "spider legs" coincide with the re-entrants seen in the low-sun images.

Location and geological settings: We identified four sets of "spiders" in the western part of Mare Tranquillitatis: (A) 8.80°N 22.00°E (Fig. 1), (B) 8.85°N 21.75°E, (C) 8.43°N 21.91°E, and (D) 7.90°N 22.00°E. Each set consists of 3 – 5 "spiders"; all four sets are located in the same region, the distance between sets is 7 – 14 km. The region is a typical Late-Imbrian-age mare; its absolute model age of emplacement is ~3.7 Ga [9]. All "spider" sets are located in gentle rimless depressions 20 – 40 m deep, ~0.5 km wide, ~1 – 2 km long, and elongated in an ~E-W direction. Origin of the depressions cannot be unambiguously determined, but they appear to be ancient pits of volcanic origin, rather than clusters of degraded impact craters.

Relation to IMP: This part of Mare Tranquillitatis is rich in small IMPs [6-7] and there are numerous small IMPs in immediate proximity to the "spiders". The first two "spider" sets are within an ~E-W-trending linear chain of small IMPs. Some IMPs in the "spider" region have re-entrants incising their slopes; those re-entrants are identical in size and appearance to the "spiders' legs". This suggests a connection between "spider" and IMP formation mechanisms. We did not find any other occurrences of "spiders" in the immediate vicinity of known IMPs.

Age constraints: The immature high-albedo soil associated with the "spiders" suggests a young age. Topographic diffusion [1,2] due to regolith gardening would obliterate "spider legs" geologically rapidly. We modeled diffusive degradation of "spider" topography and found that the "legs" become topographically indistinguishable in less than a million years, assuming scale-dependent topographic diffusivity according to [10].

Possible formation mechanism: "Spider"-like features (so-called araneiforms) are known on Mars [11]; their morphology is variable, and some of them resemble lunar “spiders”. Martian araneiforms form by soil displacement by gas flow, channelized beneath an impermeable slab of seasonal CO_2 ice. While tempting to consider a similar formation mechanism in connection with the gas blow hypothesis of IMP formation [8], it is unclear what could play the role of an impermeable lid on the Moon.

We suggest that “spiders” formed by regolith and draining into shallow subsurface voids in a manner similar to the “old volcanic” scenarios of IMP formation [7]. Shallow sufficiently voluminous voids are known to exist in the lunar maria [12], and are interpreted to have subsequently collapsed to create IMPs (see Figs. 14, 16, in [13]. The E-W trending orientation of these examples is consistent with dike emplacement events [14].

We interpret the processes as follows: Sudden collapse of a part of a void roof would cause rapid regolith flow and drainage into the void, and the formation of a funnel-shaped depression in the regolith. In addition, regolith cohesion and its dynamic fluidization by funnel-forming granular flow could initiate flow instabilities, channelizing granular flow, and formation of growing near-radial chutes. When the slopes of the growing funnel and chutes become sufficiently gentle, flow ceases, leaving the observed “spider” landform/albedo feature. In accordance with this mechanism, the final “spider” size is defined by the regolith mechanical properties and thickness only, explaining why all “spiders” in this unit appear to have the same size.

Granular flow fluidization under lower lunar gravity would be more effective, and it is reasonable to suggest that chutes with a higher length/width ratio could form on the Moon in comparison to short chutes forming when steep banks of slightly cohesive soli collapse on the Earth. Thus, formation of “spiders” by draining of regolith through a newly formed opening is plausible. We are currently researching regolith flow dynamics and void geometries to further assess this mechanism for formation of “spiders”, this new class of lunar feature.

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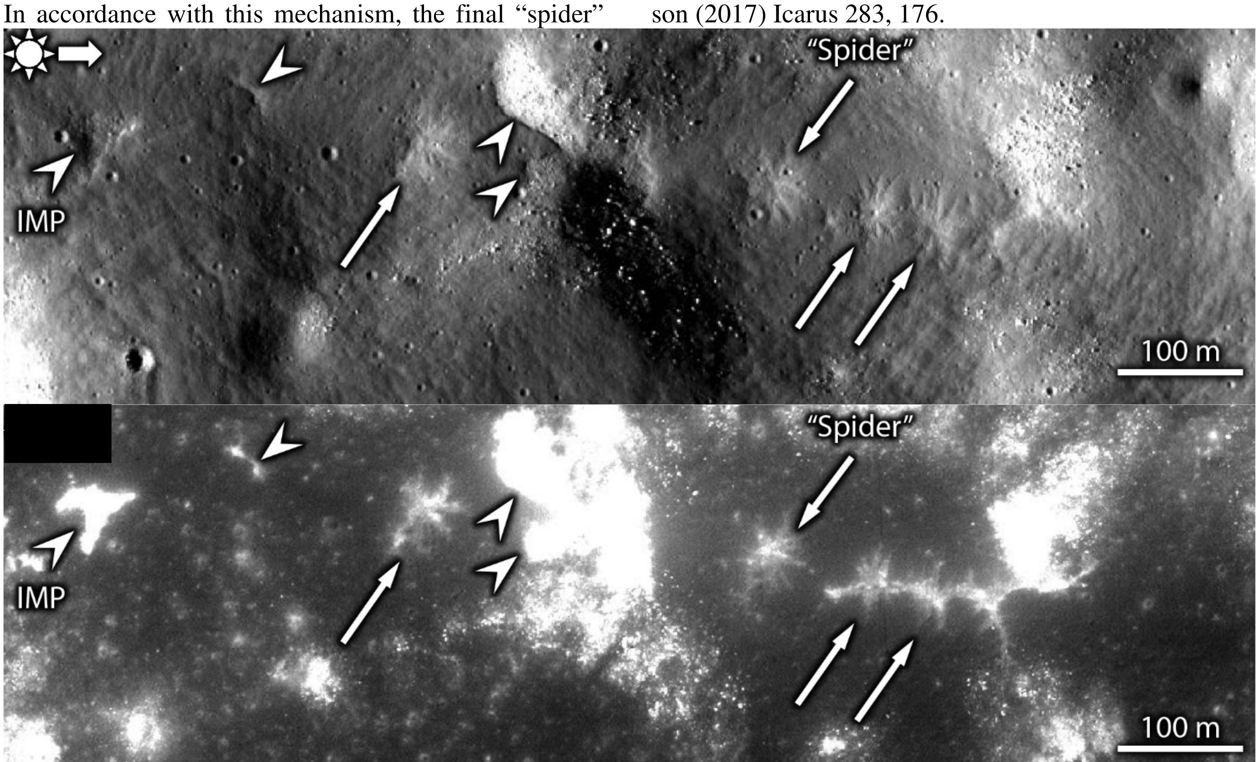

Fig.1. “Spiders” (long arrows) and IMPs (short arrows) in Mare Tranquillitatis at 8.80°N 22.00°E. LROC NAC images: top, low-sun image illustrating topography; bottom, high-sun image illustrating albedo.