rim and crater interiors could not be determined for comparisons with terrestrial craters.

Overall crater frequency is higher by a factor of about 5, and the modal crater size is a few meters larger for the interior terrace lunar unit than for terrestrial collapse craters. Differences between the lunar and terrestrial environment may account for some discrepancies. Lunar lavas appear to be more fluid than terrestrial flows (*9*), which may result in a higher crater frequency. Field observations indicate that fluid basalt flows tend to form more collapse craters than do viscous flows.

Anomalous crater frequencies of small craters on some lunar surfaces have been attributed to clusters of secondary impacts (*10*). The interior terraces, however, are in relatively shielded areas (valleys between slump blocks), and the crater statistics represent several different terraces within the wall region. It is unlikely that the interior terraces would have been selectively bombarded by ejecta blocks to form secondaries to the exclusion of the other adjacent units.

Similarities in surface morphology, cumulative frequency slope, and maximum number of craters that are 10 to 20 m in diameter all suggest that craters in the inner wall terraces of Copernicus have had an origin similar to terrestrial basalt collapse craters. We conclude, therefore, that the anomalously high crater frequency can be accounted for by the addition of endogenous craters in the interior terrace unit, and we suggest that the interior terraces are lava flows that were extruded through fractures between slump blocks representing postimpact adjustments following the formation of Copernicus.

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Lunar Metallic Particle ("Mini-Moon"): An Interpretation

Abstract. *A troilite-rich nickel-iron particle ("mini-moon") recovered from the moon may be a mound detached from a sphere of silicate glass. Erosion and pitting of the particle may have been caused by passage through a cloud of hot gas and particulate matter formed by meteorite impact on the lunar surface. This explanation is in contrast to the theory that the particle was meteoritically derived molten material that was furrowed during solidification after lunar impact, subsequently pitted by high-velocity particles, and then abraded and polished by drifting dust while on the lunar surface.*

The 30 January 1970 issue of *Science* has a spectacular photograph of a deeply furrowed and cratered, troilite-rich, nickel-iron metallic particle ("mini-moon") on its cover and an interpretation of its origin and history by Mason *et al.* (*1, 2*). They proposed that the lensoid-shaped, dendritically structured metallic particle was once a molten droplet of nickel-iron and iron sulfide that fell onto the lunar soil. They state that the droplet cooled more rapidly on the lower surface, with the result that a rough matte-like texture developed, and that subsequently the cooled droplet was cratered by high-velocity particles, and then abraded and partially polished on the upper surface by drifting dust while exposed on the lunar surface.

Carter and MacGregor (*3*, figures 21, 22, 28, 30, and 31), McKay *et al.* (*4*, figure 5), and Frondel *et al.* (*5*, figure 5) have shown troilite-rich, nickel-iron mounds attached to silicate-glass spherules. Subsequent loss of mounds from the surface of the silicate-glass spherules, either by differential cooling or by high-velocity impact with small particles, left textured, hemispherical, dimple-shaped imprints in the spherules (*3*, figures 28, 31, 33, 34, and 35). Conceivably, the particle studied by Mason *et al.* was deposited initially as a mound on a large, molten, silicate-glass spherule and then subsequently detached.

The lensoid shape of the particle is difficult to explain if it solidified under conditions of zero gravity in free fall. The lensoid shape, however, would be expected because of the interaction of surface tension, if the particle formed as a mound of troilite-rich nickel-iron on the surface of a silicate-glass spherule. The difference in texture between the two sides of the mound, which Mason *et al.* ascribe to polishing by drifting dust, may simply have resulted when one surface (that with the matte finish) cooled in contact with the host glass, whereas the polished surface cooled as a free area. Detached lensoid-shaped mounds with opposite sides of unequal smoothness are shown by Frondel *et al.* (*5*, figure 12).

Mason *et al.* interpreted the deep furrows as cooling structures. In all similar lunar nickel-iron and iron sulfide mounds that we have examined with the scanning electron microscope, cooling has produced either a finely rippled surface without furrows or a simple pattern of one or two narrow furrows (*3*, figure 24; *4*, figure 8). We have not seen numerous deep furrows in any of these cooled metallic particles.

We propose, as one possibility, that the furrows are an erosional or ablative feature formed by the passage of the solidified particle through a cloud of hot gas and particulate matter formed by the initial meteorite impact. After most of the erosion had taken place, the pits were formed in flight by high-velocity encounters with lunar particles associated with the impact-produced cloud (*3, 4, 6*), rather than by high-velocity impacts after the particle came to rest on the lunar surface. This theory is compatible with the presence of a coating of glass of lunar composition on the interior of the pits (*2, 6, 7*). This ablation-and-pit-formation hypothesis requires a local lunar atmosphere of gas and small particles. Evidence for a local lunar atmosphere includes the following observations: (i) the presence of numerous, small nickel-rich iron mounds arranged in geometrical patterns on silicate-glass spheres [these mounds imply condensation from a vapor (*3*, figures 21, 22, 39, and 40; *6*, figure 10)]; (ii) the presence of silicate-glass rays that wrap around a silicate-glass sphere [these rays imply gas-flow deflection of the splashed glass

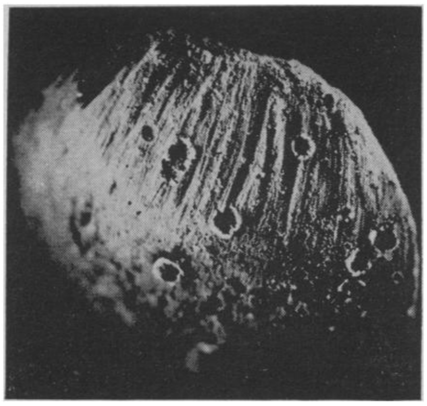

Fig. 1. Lunar particle 4 mm in diameter composed of nickel-iron and iron sulfide.

(*3*, figure 17)]; and (iii) the presence of numerous craters less than 1 μm in diameter (*3*, figure 14) (these craters imply the presence of very small particles).

Another theory that may account for the furrows is that they are scrape marks caused by the particle impacting the lunar soil. Such an event may form imprints of the soil and leave embedded soil particles on the lower surface of the particle. These features are not apparent in the photograph and description by Mason *et al.* (*1*, figure 2; the *Science* cover is shown here as Fig. 1) but may be present in the photograph on the *Science* cover. Similar features are seen on the surfaces of impact-produced silicate-glass spherules (*3*, figures 29 and 36). Carter and MacGregor have interpreted these features to be the result of a collision of the still-plastic silicate-glass spherule with the lunar soil. If the scrape marks on the metallic particle resulted from impact with the lunar soil, the impact-produced pits must have formed after the collision with the lunar soil. The data of Carter and MacGregor (*3*) and of McKay *et al.* (*4*) suggest that there is a sequential relationship in the impact-produced features on the silicate-glass spherules and further suggest that relatively high-velocity impacts occur in the impact-produced cloud, or, alternatively, that the temperature of the target spherules may be near the melting point. After the furrowing event, the metallic particle was thrown back into the local lunar atmosphere (as a result of meteoroid impact) and pitted. Recycling of near-surface fragments into the local lunar atmosphere is a normal consequence of repeated impacts on the lunar surface.

From the findings of Carter and MacGregor (*3*) and McKay *et al.* (*4*), a general sequence of events in the formation of the metallic particle may be summarized as follows: The silicate-glass spherule, with the solidified mound attached, passed through the impact-produced cloud of hot gas and particulate matter at a high relative velocity, which caused ablating, furrowing, and eroding of the upper and forward-facing portions of the mound. The pattern of the gas flow was determined primarily by the large silicate-glass spherule, but was influenced locally by the mound. As the gas passed to the lee side of the mound, it formed faint, branching, V-shaped patterns on the upper surface of the mound and at the end of the deep furrows, then ceased eroding the mound. Similar furrows and V-shaped patterns are found on experimentally ablated surfaces (*8*). After this ablation, the silicate-glass spherule encountered lunar particles with high relative velocities. The mound was pitted on the upper surface, knocked loose by these impacts, less densely pitted on the lower surface, and splashed with liquid silicate before finally impacting upon the lunar soil. Alternatively, the furrows resulted when the metallic particle struck the lunar surface, and the pitting occurred during a subsequent flight of the particle through an impact-produced cloud of vapor, liquid, and particulate matter.

These explanations may account for the lensoid shape, the peculiar location of the furrows, the ablation or erosion on one surface but not on the other, and the greater porportion of pitting on the upper surface than on the lower. Although this proposed process is complicated and involves several steps, we believe that such an explanation is necessary to explain the complex features of this remarkable particle.

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Solifluction: A Model Experiment

Abstract. *Laboratory experiments that subjected soil to repeated freeze-thaw cycles in an inclined container revealed every process of solifluction, especially of frost creep. Multiple slope-angle effects on the amount of particle movement on the soil surface in every cycle are interpreted by several characteristic processes of frost creep. Gelifluction was found to occur in thicker layers of soil, owing to the excess water retained in soil after thawing. For further development of the problem, a similarity law for the model experiment was derived from thermal considerations.*

Despite many pertinent field observations, knowledge of solifluction (downslope mass-wasting processes) in cold climates is still largely qualitative. Some aspects of the work by Washburn in northeast Greenland (*1*) include perhaps the most precise and quantitative fieldwork to date. He proposed to divide the phenomena into two processes: frost creep and gelifluction. However, so many factors are involved in frost creep and gelifluction, and they are so intertwined in nature, that it is very difficult to separate their effects except in laboratory experiments. The purpose of this experiment was to find good methods for measuring the movement of soil particles, either at the surface or at depth, and to obtain quantitative results for the effects of some of the factors.

Natural slopes were simulated in a cabinet, the lower part of which was a tilted box (67 by 42 by 15 cm) filled with soil to a depth of approximately 10 cm. The box was insulated at the sides and had a perforated bottom, from which many wicks extended