
The Luna 24 mission to the southeast portion of Mare Crisium returned a sample of lunar regolith material obtained by drilling onto the upper 2 m of the mare surface1. Regolith stratigraphy is locally determined by the amount of primary ejecta arriving at a site from surrounding craters (a function of crater size and range) and the style in which this material is ballistically emplaced. It is difficult to estimate regolith stratigraphy at a specific point on the Moon due to azimuthal variations in the distribution of primary ejecta9, particularly within the zone of discontinuous ejecta deposition. Although the role of secondary cratering in producing distinctive textures within the ejecta deposits surrounding large, fresh lunar craters is widely recognized, secondary cratering also occurs during the ballistic deposition of primary ejecta excavated by craters less than 10 km in diameter2. Isolated secondary crater clusters, and chains produced by primary ejecta from small craters (observed rim crest diameter, D, <10 km) may have a major influence upon local regolith stratigraphy. In particular, the crater Fahrenheit (D = 6.4 km) situated at a range of 18.4 km from the Luna 24 site has been considered to be a potentially important source of material at the site by previous investigators1,3. Although Fahrenheit appears to be morphometrically unmodified (depth/diameter = 0.23), the morphology of its exterior deposits is extensively degraded: rays cannot be distinguished, the continuous ejecta deposit lacks crisp texturing, and the rim is pitted with subsequent craters. The purpose of this study was to estimate the amount of primary Fahrenheit ejecta that may have arrived at the Luna 24 site and to examine the manner in which it may have been emplaced.

The amount of primary Fahrenheit ejecta anticipated at a range of 18.4 km (i.e., the Luna 24 site) can be estimated by employing ejecta distribution models in conjunction with the observed morphometry of the Fahrenheit crater3,4. Rim height measured above the original ground surface varies from a maximum value of ~335 m on the northeast side of Fahrenheit to ~225 m on the southeast side of the crater in the direction of the Luna 24 site (LTO 62B1). The crater rim consists of a deposit predominantly composed of primary Fahrenheit ejecta underlain by a structurally uplifted section of the original ground surface. Assuming that 70% of the observed rim height is primary ejecta5 and that the average thickness of primary ejecta deposited at range r varies in proportion to (r/Ro)^-3, where Ro is the observed rim crest radius of a crater6, then an average thickness of 0.9 m of primary Fahrenheit ejecta should have reached the Luna 24 site1,3. However, the Luna site lies at a range of ~6 crater radii from Fahrenheit which is within the zone of discontinuous ejecta deposition2. Therefore, the actual amount of Fahrenheit ejecta that was transported to the site cannot be estimated without additional photogeological evidence of the density of Fahrenheit secondary craters and rays near the Luna 24 site. A fresh crater of comparable size should provide information on deposits at this range. Lichtenberg B is a Copernican-aged crater in northern Oceanus Procellarum (31.25°N, 61.50°W) with a rim crest diameter of 5.1 km. The rim deposits of Lichtenberg B are characterized by a smooth surface morphology. At ranges of 1.4 Ro a hummocky texture develops which gives way to
EMPLACEMENT OF FAHRENHEIT EJECTA

Settle, M. et al.

arcuate dune-like structures at ranges of 2.2 R₀ (similar to morphology of Mosting C described by [2]). The ground between dunes is characterized by fine-scale radial to subradial lineations, indicating substantial interaction between the ejecta and preexisting terrain. Nonlinear interdune ground is rarely observed. Dunes begin to grade into arcuate secondary crater chains at about 3.7 R₀; these chains extend to about 5 R₀, where they begin to break up into individual crater clusters and more linear chains. At a distance of 6R₀, the Lichtenberg B ejecta deposit is characterized by numerous but isolated secondary chains and clusters (Fig. 1). Linear terrain similar to that found between dunes is found downrange from these secondary craters, and unaffected preexisting terrain is regularly encountered between clusters and chains.

The mode of deposition of primary Fahrenheit ejecta near the Luna 24 site can be inferred by examining secondary cratering effects at comparable ranges from the much fresher crater Lichtenberg B. Assuming an ejection angle of 15⁰ (measured from local horizontal), primary Fahrenheit ejecta landed at the Luna 24 site at a velocity of ~230 m/sec. At these relatively low impact velocities Fahrenheit ejecta would have primarily broken up and excavated local material; shock metamorphic effects produced by such impacts would have been minor. Comparable impact velocities for Lichtenberg B ejecta occur at a range 18 km from the crater center (normalized range r/R₀ ≈ 7). At this range Lichtenberg B ejecta has produced a variety of secondary crater clusters and chains consisting of individual secondary craters that vary from 70-150 m in diameter.

Oberbeck et al.² have used various scaling relationships to determine the ratio of secondary ejecta/primary ejecta produced by secondary craters. Their results indicate that primary ejecta transported over distances of 100 km or more by large lunar impacts is capable of excavating several times its own mass. Secondary cratering effects produced by much smaller craters (D <10 km), however, have not been extensively investigated. The model of Oberbeck et al. indicates that masses of primary ejecta from Lichtenberg B should have locally excavated 0.3-0.5 times their own mass in the process of forming the secondary chains and clusters observed at a range of 7 R₀. By analogy, these model results imply that ballistic deposition of Fahrenheit ejecta at the Luna 24 site was primarily depositional in nature, in the sense that more primary ejecta was actually emplaced at the site than was locally excavated by its impact. Furthermore, if the size range of Fahrenheit secondary craters in the vicinity of the Luna 24 site were comparable to that observed at ranges of 7 R₀ from Lichtenberg B, then Fahrenheit secondaries should have excavated material from depths of 50 m or less at the Luna site.

The ejecta deposits surrounding secondary craters formed at a range of 7R₀ from Lichtenberg B are highly asymmetric, and it is possible that a significant fraction of the primary ejecta fragments forming an individual secondary crater were deposited downrange of the crater. In addition, secondary craters produced by relatively low-velocity impacts may have much smaller depth/diameter ratios than those surrounding larger craters, in which case the model of Oberbeck et al. would not be applicable. These considerations suggest that secondary crater scaling relations developed for large craters should be ap-
plied with caution to much smaller secondary crater features.

Assuming that primary Fahrenheit ejecta was distributed across the surface of Mare Crisium in accordance with the -3 radial decay relation discussed above, then approximately 1/6 of the total volume of primary Fahrenheit ejecta (~13.3 km$^3$) should lie beyond a range of 6 $R_o$. Impact crater ejecta is excavated in such a manner that the shallowest material travels the greatest distances. If the amount of primary Fahrenheit ejecta transported to ranges greater than 6 $R_o$ were originally situated in the uppermost portion of the crater cavity excavated during the Fahrenheit event, then primary Fahrenheit ejecta impacting in the vicinity of the Luna 24 site should have been initially derived from depths of 500 m or less. Therefore the process of ballistic deposition of Fahrenheit ejecta at the Luna site should have consisted of (Fahrenheit) mare material derived from depths of 500 m or less locally excavating and mixing with (Luna 24) mare material derived from depths of 50 m or less.

Two distinct mare units can be identified in this region: one is a low-titanium unit of low albedo apparently overlain by a unit of intermediate titanium content possessing a relatively higher albedo. Fahrenheit is situated upon the latter, moderate albedo unit and the Luna 24 site appears to be within the low albedo unit. The mottled appearance of the SE portion of the basin suggests that the more recent flows of moderate albedo are relatively thin here (on the order of 10-100 m). Thus it is possible that primary Fahrenheit ejecta ballistically deposited at the Luna 24 site consists of material derived from the stratigraphically lower, low-Ti unit which impacted and mixed with material of similar composition at the Luna 24 site. This scenario is consistent with the predominance of a single rock type (gabbro) found within the Luna 24 core sample. However, the subdued morphological character of small craters in the vicinity of the Luna sites makes it impossible to identify positively Fahrenheit secondary craters and the actual influence of Fahrenheit ejecta upon the Luna 24 site cannot be determined unambiguously. It is also possible that the 2 m deep Luna 24 sample is dominated by ejecta deposits produced by much smaller (several hundred meters) nearby Eratosthenian-aged craters.

References:
- C. Florensky et al. (1977) Proc. Lunar Sci. Conf. 8, 325;
- B. Ivanov and L. Comisarova (1977), Lunar Science VIII, 499;

Figure 1