MODELS OF IMPACT EJECTAEMPLACEMENT BASED ON ORBITAL INFRARED OBSERVATIONS. P. H. Schultz, Lunar Science Institute, Houston, TX 77058; and W. Mendell, Johnson Space Center, Houston, TX 77058.

The Apollo 17 Infrared Scanning Radiometer (ISR) has provided a high-resolution record of the thermal—and therefore, the physical—character of the western maria. Previous analyses of these data (1) have concentrated on the gradual removal of thermal contrasts by long-term surface degradation. The present analysis examines what the thermal infrared may indicate about the cratering process.

Several large, fresh craters (Aristarchus, Kepler, Öbers A) were included in the ISR ground tracks. The crater interior, ejecta facies, and bright rays of Aristarchus were particularly well covered. Detailed comparison of the thermal levels and surface features reveal several significant correlations:

1. Ejecta facies within 1/2 crater radius from the crater rim (inner Zone I, see 2) exhibits large variations corresponding to block-littered surfaces and certain smooth-surfaced flow units believed to represent solidified impact melts.

2. Ejecta facies 1/2 to 2 crater radii from the rim (Zone II and inner Zone III) exhibits a thermally bland character with temperatures equal to and lower than the surrounding maria.

3. Beyond 3 crater radii outer Zone III ejecta facies, corresponding to secondary crater complexes and bright rays, typically lack thermal enhancements (ΔT < 5°K) and several rays exhibit thermal lows relative to their surroundings. Single, bright-haloed craters, however, exhibit pronounced thermal contrasts (ΔT = 30°K-40°K).

Figure 1 illustrates the temperature profile along two directions from the center of Aristarchus. The same type of temperature profile is exhibited by much smaller craters (diameter = 7 km): beyond 1/2 crater radius from the crater rim the temperature is equal to or lower than the surrounding maria.

These observations are in contradiction with extrapolations from much smaller craters (diameter = 1 km) where the inner ejecta are comprised of large blocks. The absence of pronounced thermal highs associated with bright rays indicates a paucity of blocks larger than 30 cm (see 3), and the occasional correlation with thermal lows suggests blanketing by small-size secondary/tertiary ejecta (relative to the average mare) and/or physical alteration of the surface. Moreover, the relatively bland thermal character of most secondary craters large enough to penetrate well into bedrock is in distinct contrast with the thermally enhanced wall/rim regions of primary craters of equivalent size. Lunar Orbiter photography (2) has shown that sizes of ejected blocks exposed at the surface around secondaries are generally less than 5 m; the ISR data suggest sizes generally less than 30 cm.

There are probably three contributing causes to the absence of blocky ejecta within both the continuous ejecta facies of large craters and the ejecta deposits of secondary/ray systems.

1. Large-size ejecta blocks are probably shock-weakened and friable. As these ejecta strike the surface, they break apart, thereby contributing to small-size ejecta in the continuous ejecta facies and perhaps an anomalous size-distribution around secondary craters and ray systems.
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2. Ejecta near the rim and within secondary complexes probably undergo extensive interactions (2,4,5) in which both secondary debris and locally excavated material may be effectively comminuted.

3. The ejecta size distribution associated with an impact crater \((D > 3\, \text{km})\) may be considerably different from the size distribution around smaller craters.

   The last contributing cause can be understood from two physical processes that probably characterize large impact events. In order to preserve the observed ejecta thickness distribution around craters (6,7), large impacts will involve large volumes of material ejected at large velocities. If ejection velocities are proportional— to first order— to the local peak shock pressure and if the local peak pressure is proportional to the degree of fracturing, then larger impacts must eject proportionally larger amounts of small size material (Fig. 2). This trend is also affected by the target flow-size distribution, which controls the minimum particle size, and the duration of the peak pressure, which affects the maximum particle size (8).

   The second contribution to a different size-distribution from large impact events involves the time the material spends within the crater. A 1 km-diameter crater on the Moon forms on the order of \(10^1\) seconds, whereas a 10 km crater will form on the order of minutes (9). As the impact crater grows, material moves radially outward and then is sheared upward along the crater wall (9,10). The larger the crater, the longer this shearing can act to comminute the already shocked debris before ejection. This process can be illustrated in a semiquantitative way by estimating how long it would take material to be ejected from a crater one-half way down the crater wall at the final ejection velocity (Fig. 3). The resulting long residence times from large impacts should be extremely effective in changing the size-frequency distribution of ejecta.

   Low velocity (subsonic) impacts by either a cloud of heavily comminuted debris or extremely weakly bonded projectiles may be significantly different from impacts by single or multiple impacts by 2 to 3 nearly simultaneous impacts as usually envisioned (11). Not only could the tertiary ejecta-size distribution be altered, but also the amount of local/primary mixing may be different from low-velocity, solid-body impacts. Specifically, late-arriving secondary ejecta may interact with locally excavated debris and may be deposited at the surface rather than buried beneath the surface. Such a process is indicated by the preserved spectral signature of primary ejecta deposits around Proclus and other lunar craters (12,13). Planned experiments for the NASA-Ames Vertical Ballistic Gun Range should provide empirical data for this hypothesis.

   In summary, the thermal infrared signature of large lunar craters suggests that large amounts of fine-grained material are associated with ejecta deposits of the continuous ejecta facies, secondary craters, and crater rays. This unusual result can be understood by three hypotheses that feature fundamental differences between small and large impact events. These observations also provide important clues for understanding certain martian impact craters having ejecta ramparts where permafrost conditions are unlikely, e.g., on the flanks of shield volcanoes (14). Following (14,15) small size ejecta from craters larger than 1-5 km on Mars have been aerodynamically braked and deposited near the rim. The thermal infrared signature of lunar crater ejecta suggests that the proportion of small-size ejecta (both secondary and tertiary) may increase for craters in this size range.
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Figure 1. Night-time temperature profile along two directions across the mare (NW, SW) from the center of Aristarchus as recorded by the Apollo 17 ISR. Variability in surface temperatures beyond 4R represent secondary craters, small primary craters, and ridges. Thermal signatures from secondaries represent a fraction of secondary crater population and are well below thermal enhancement of primary craters.

Figure 2. Comparison of crater volume fraction ejected with velocities greater than 200 m/s from craters 0.5 to 40 km in diameter; corresponding ranges are indicated in crater radii. Velocity-decay relation assumes R^1 scaling with crater size; range in ejected volumes assume different forms of crater growth.

Figure 3. Comparison of estimated time ejecta spent in the crater cavity prior to ejection for different positions in crater (fractions, X/R) of crater radius. Hemispherical crater growth is assumed up to X/R = 0.5; constant crater depth is assumed between X/R = 0.5 and 1.0.