N94-16405

THERMOGEOLOGIC MAPPING OF THE MOON FROM LUNAR ORBIT;

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The Infrared Scanning Radiometer (ISR) onboard the Apollo 17 Command-Service Module (CSM) mapped thermal emission of the lunar surface from orbit. Measured temperature values span the diurnal range of lunar temperatures (85 K to 400 K) and have an accuracy of approximately ±2 K [1]. Surface spatial resolution at nadir is 2.2 km. This Apollo data is being revisited using data presentation software for the Macintosh computer, which was not available 20 years ago, even on mainframes. The new thermal images exhibit subtleties in the delineation of geophysical surface units that were unappreciated in the original survey of the data. Looking first at nighttime thermal emission from the ground tracks over Oceanus Procellarum to Mare Orientale, we have confirmed and expanded on earlier observations of regolith differences between mare and highlands and of a scheme for relative age-dating of larger impact craters of the Copernican age. We see an impact crater near Lenz, just north of Orientale, which exhibits an extraordinarily fresh ejecta blanket. Photography of this area is extremely poor, but we can see the feature in the Galileo data. We plan to derive geophysical surface properties of the overflown region using thermal models of regolith structures.

Thermogeologic mapping of the Moon began with ground-based infrared scans of the eclipsed Moon. Although the lunar disk cooled while in the Earth's shadow, certain features were observed to remain warm relative to the background. These features, called "thermal anomalies", were found subsequently to contain populations of surface rocks, usually excavated by relatively young craters.

Most rocks seen on the lunar surface today have been excavated from beneath mature regolith developed on the lunar highlands and the filled mare basins over the last 2 -3 billion years. Other surface rocks lie on crater rims or mountain tops where they have been exposed by impact-driven mass-wasting processes. All surface rocks are eventually comminuted to soil by the ubiquitous meteorite flux, but the time required to fracture and destroy a rock is a nonlinear function of its size [2]. The most prominent features on thermal maps of the nighttime lunar surface therefore document the most recent lunar depositional and erosional history. In addition, more subtle features in the images relate to regolith maturity, directionality of emissivity, solar albedo, and surface roughness.

Maria-Highland Differences

The data analyzed here are predominantly from within the Procellarum and northern Orientale regions. Most of the thermal anomalies found in this region are associated with features such as primary impact craters and rilles. In general, the highlands are characterized by a low thermal contrasts, while the maria contain a much larger concentration of thermal anomalies on the order of one resolution element in size. Thermal enhancements for resolution-sized features in typical highlands units are approximately 4 K, whereas enhancements in typical maria units are 8 K. Apparently, surface rocks associated with impacts in the highlands are not as numerous, or the rock populations have been comminuted to smaller sizes as a result of exposure to meteorite erosion. The observations suggest that kilometer-sized craters exhibit more excavated bedrock in Procellarum because the regolith there is thinner than in the highlands to the west.

The maria contain abundant medium to large (15-90 km) thermally enhanced impact craters, while such craters with thermal enhancements greater than 10 K are rare in the highlands. Two exceptions are the craters Olbers A and a small unnamed crater located at 259E, 2.56N, approximately 5 km to the southeast of Lenz Crater. The remainder of large anomalies within the highlands come from small craters, ≤ 6 km diameter, having high central temperatures and a slightly thermally enhanced ejecta deposit. Many highland craters classified as Copernican in age, such as Conon, appear relatively featureless and have temperature enhancements much lower than other Copernican craters.

Although a large crater such as Olbers A would be expected to exhume large blocks from beneath the highlands regolith, the smaller craters should not. However, most craters larger than Olbers A do not have significant thermal enhancements. Even if these large craters were unable to expose bedrock or exhume large blocks, impact melt would be expected to form within the crater floor, giving the crater a large thermal enhancement. In order to explain this contradiction, it is proposed that mass wasting processes, such as slumping, avalanching, and the downslope migration of surface materials may operate at much higher rates in the highlands. A highly incoherent regolith would facilitate the movement of materials from the rim crest to crater floor and would essentially cover exposed rock with a layer of fine-grained materials.

Mass Wasting Along Scarps

Several cool anomalies are found. The most noticeable are linear features that lie at the boundary between the Apennines and Mare Imbrium. These cool anomalies correspond to a unit mapped by Hackman [3] as *slope material* which is found at the base of steep slopes. Hackman, however, describes this unit as exposed bedrock and partially sorted talus materials. Since low temperatures are consistent with loose, fine-grained surface materials, this unit may be fine-grained debris. It is possible that these debris deposits are continually accumulated as a metastable regolith forms on a steep slope and sporadically avalanches as minor instabilities arise. Similar deposits are also found along the Carpathians and along the edge of Lacus Veris.

Crater Halos

Within the maria, many of the thermally enhanced craters and their ejecta blankets (if present) are surrounded by an annular region which lacks thermal features and is often cool relative to the surroundings. In general these "halos" span up to one crater radius away from the enhanced ejecta or two crater radii from the crater rim crest. Halos around craters in the highlands such as Olbers A are featureless, but are not noticeably cooler than the surroundings. Typically, crater halos located in the mare have a temperature approximately 2 K lower than the surrounding region,. There appear to be a continuum of states ranging from craters having enhanced ejecta deposits and well defined halos, to craters containing only a well defined halo extending from the rim, to craters containing halos that are barely distinguishable with respect to the surroundings. Mendell [1] has proposed that crater halos could be a result of the blanketing of subresolution (~100 meters) craters with the ejecta from a larger crater. The concentric placement of the halos around the blocky craters suggests that it is a part of the original ejecta blanket which has had its surface rocks comminuted into soil. This scenario could work if the ejecta from a large crater has a gradation of large blocks near the rim crest to smaller blocks at the edge of the ejecta deposit. Since small blocks erode at a faster rate than larger ones, the halo should appear to expand towards the rim crest as the ejecta deposit erodes through time. As smaller craters form within the halo, the region should loose its cool appearance because of the excavation of blocks beneath the thin, fine-grained cover.

Conclusions

The Apollo 17 ISR obtained high resolution thermal maps of the lunar surface that show document the degradation of geologically young lunar features. Evidence of mass wasting processes is found at the base of the Apennine scarp and other high relief slopes. Slumping, avalanching, and the downslope migration of surface materials are also believed to be responsible for the decrease in temperatures of crater floors. Micrometeorite weathering is believed to play a major role in the production of soils on relatively flat surfaces. Models of the lunar surface thermal regime and of the fragmentation of rocks should allow estimation of ages for many Copernican Age features.

References:

[1] Mendell W. W. (1975) *Proc. Lunar. Sci. Conf. 6th*, p. 2711-2719. [2] Horz, F., et al. (1975) *The Moon*, **13**, 235 - 258.. [3] Hackman R. J. (1966) 'Geology of the Moon: Montes Apenninus Region,' *I-463 (LAC-41)*. U.S Geological Survey Geological Atlas of the Moon.