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REMOTE SENSING STUDIES OF THE TERRAIN NORTHWEST OF HUMORUM BASIN

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Abstract. We have used near-infrared reflectance spectra and Earth-based radar data to investigate the composition and origin of the various geologic units northwest of Humorum basin as well as the stratigraphy of the Humorum pre-impact target site. The results of our spectral analysis indicate that at least a portion of the inner, mare-bounding ring is composed of pure anorthosite. Other highlands units in the region are dominated by noritic anorthosite. The anorthosites on the inner ring may have been derived from a layer of anorthosite that exists at depth beneath a more pyroxene-rich unit. Both Gassendi G and F craters expose mare material from beneath a highlands-rich surface unit that was emplaced as a result of the Letronne, Gassendi, and other impact events. This ancient basalt unit was emplaced after the formation of Humorum basin but prior to the Orientale impact.

Introduction

Humorum basin is a large multiring impact structure on the southwestern portion of the lunar nearside. The most complete basin ring bounds Mare Humorum and is ~440 km in diameter [Wilhelms, 1987]. A rimlike scarp almost twice as large (~820 km) and resembling the Cordillera ring of the Orientale basin lies outside this mare-bounding (MB) ring. A portion of the highlands terrain northwest of the Humorum basin (Figure 1) exhibits anomalous characteristics in several remote sensing data sets. Gaddis *et al.* [1985] noted the unusual nature of this highland terrain. They pointed out that an area of approximately 45,000 km^2 west of Gassendi crater exhibited relatively low depolarized 3.8-cm radar returns in the radar images presented by Zisk *et al.* [1974]. This anomalous area is centered at 43° W, 15° S. Gaddis *et al.* [1985] discussed the possibility that this area was mantled by relatively high-albedo pyroclastic debris and suggested that additional evidence bearing on the presence of pyroclastic mantling material in this area might come from near-infrared spectral studies. Numerous other unresolved questions exist concerning the nature and origin of the geologic units northwest of Humorum. The purposes of this study include the following: 1) To determine the composition of the various geologic units northwest of Humorum, 2) To investigate the stratigraphy of the Humorum pre-impact target site, 3) To determine the composition and extent of ancient (pre-Orientale) volcanic deposits, and 4) To study the nature and origin of the radar anomaly northwest of Humorum.

Methods

Near-infrared reflectance spectra were obtained utilizing the University of Hawaii 2.24-m telescope and the 60-cm telescope at the Mauna Kea Observatory (MKO). The Planetary Geosciences indium antimonide spectrometer was used. This instrument successively measured intensity in each of 120 or more wavelengths covering a 0.6-2.5 micron region by rotating a filter with a continuously variable band pass. By using the f/35 oscillating secondary mirror on the 2.24-m telescope in its stationary mode, it was possible to collect spectra for relatively small areas (4-8 km) in the Humorum region. More recent observations using the 60-cm telescope obtained spectra for larger areas (10-20 km). Differential atmospheric refraction limited high-resolution observations to periods when the Moon was near zenith.

The lunar standard area at the Apollo 16 landing site was frequently observed during the course of each evening, and these observations were used to monitor extinction throughout each night. Extinction corrections were made using the methods described by McCord and Clark [1979]. These procedures produce spectra representing the reflectance ratio between the observed area and the Apollo 16 site. These relative spectra were converted to absolute reflectance utilizing the reflectance curve of an Apollo 16 soil sample. Analyses of mafic band positions and shapes as well as continuum slopes were made using the techniques described by McCord *et al.* [1981]. The locations and lithologic classification of the spectral data appear in Figure 1, and representative spectra are shown in Figures 2 and 3.

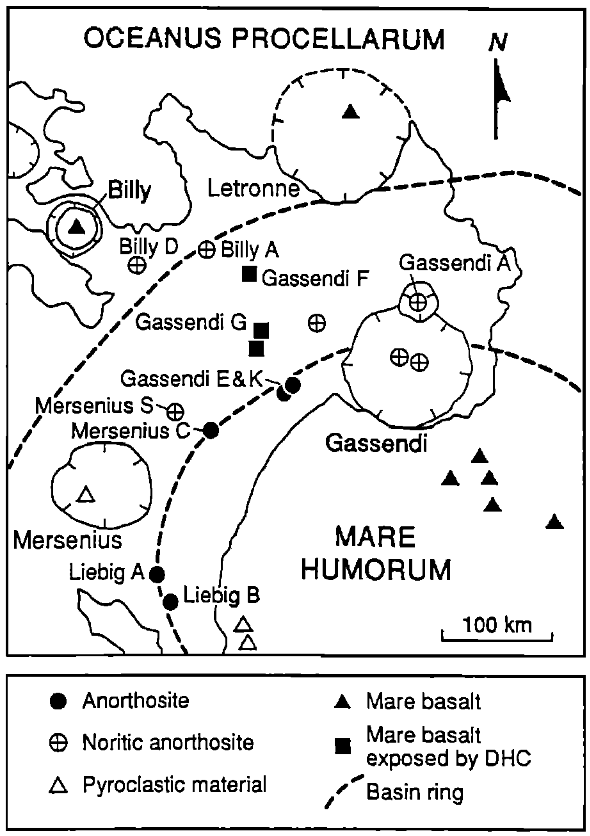

Fig. 1. Sketch map of a portion of the Humorum basin region. The various symbols indicate the lithology of the areas for which near-infrared reflectance spectra have been obtained and interpreted. DHC means "dark halo crater."

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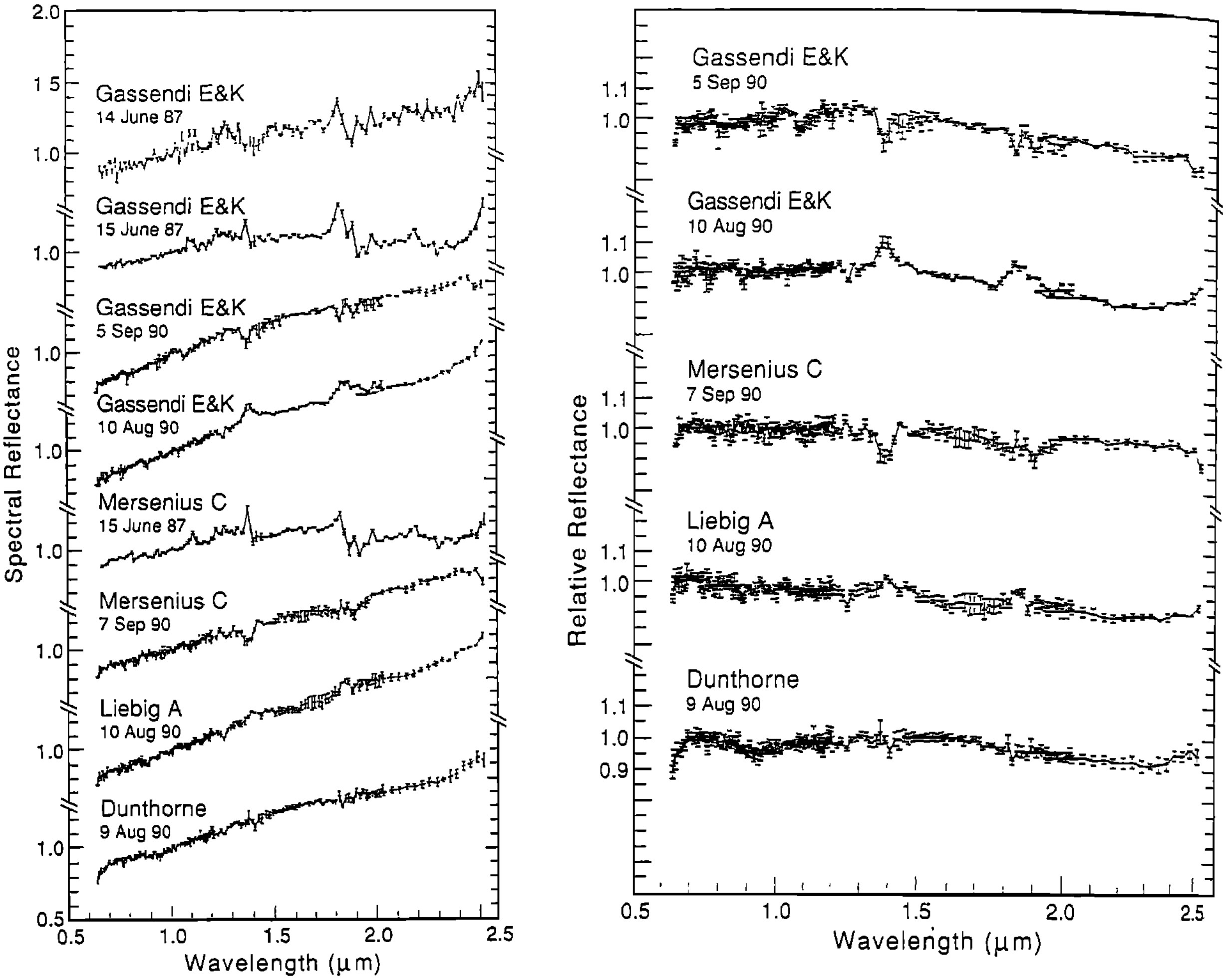


Fig. 2. (a) Reflectance spectra scaled to unity at 1.02 μm for selected features in the Humorum region. All of these spectra, except for Dunthorne, represent pure anorthosite deposits. Differences among spectra obtained for features on different dates are largely due to (1) the different aperture sizes used for the various observations and (2) the lack of thermal corrections in the 2.0-2.5 μm spectral region. (b) Reflectance spectra after continuum removal (straight line estimated for a 1 μm absorption feature).

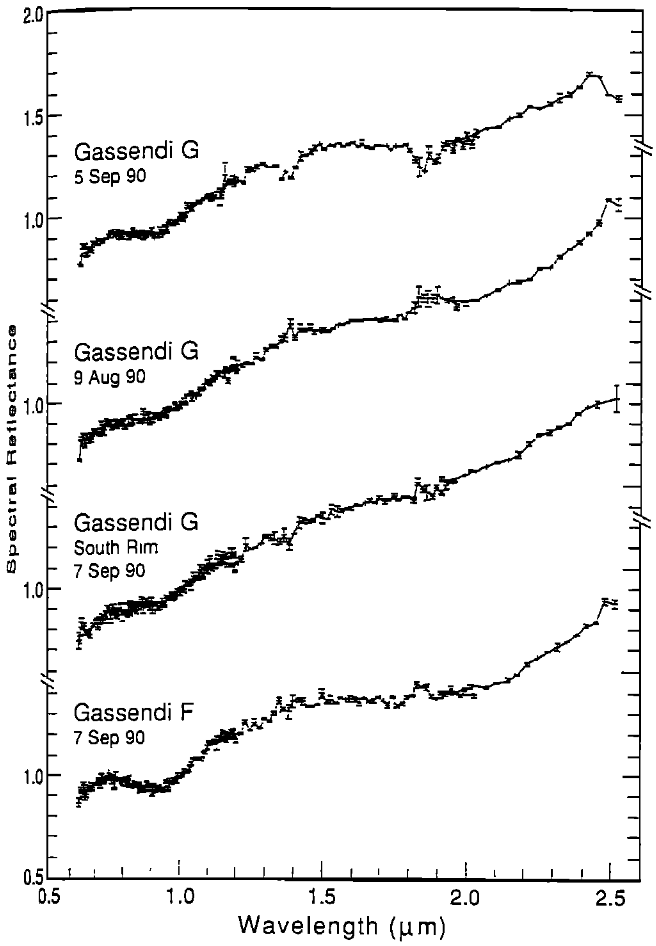
Results and Discussion

At least a portion of the mare-bounding (MB) ring of Humorum is composed of pure anorthosite. Spectra were collected for Mersenius C (diameter=14km), Liebig A (diameter=12km), Liebig B (diameter=9km), and the Gassendi E and K complex (Figure 2). These small impact craters expose fresh material from beneath the surface of massifs in the mare-bounding ring. These spectra exhibit either no "1 μm" absorption features or extremely shallow bands (Figures 2a and 2b). Only very minor amounts of low-calcium pyroxene are present in the areas for which these spectra were obtained; an anorthosite lithology is indicated. Mersenius C and the Gassendi E and K complex were observed during the course of several observing runs, and the diameters of the areas for which spectra were obtained varied from ~3 km to ~20 km. None of these spectra has a significant "1 μm" band. This indicates that anorthosite does not just occur on some small portion of the interiors of these craters; it is the dominant rock type in the ring massifs in this region.

While the mare-bounding ring northwest of Humorum appears to be composed of pure anorthosite, spectra for other sectors of the ring indicate that both anorthosite and more pyroxene-rich material are present [Spudis *et al.*, 1992; Hawke *et al.*, 1991a,b]. Dunthorne is a 16-km crater near the southeastern portion of the MB ring. It and other craters on or near the MB ring expose noritic anorthosite (Figures 2a and 2b). One spectrum was obtained for Billy A, a 7-km impact crater that excavated material from the northwestern portion of the outer Humorum ring (Figure 1). Analysis of this spectrum indicated that noritic anorthosite was present in this segment of the outer ring.

Spectra were also collected for a number of highlands units in the study area northwest of Humorum (Figure 1). Special emphasis was placed on analysis of spectra obtained for fresh surfaces which should expose a relatively high percentage of unweathered rock surfaces. These include the craters Mersenius S, Billy D, Gassendi Zeta, and Gassendi A as well as the central peaks of Gassendi. Analyses of the "1μm" band positions and shapes as well as continuum slopes indicate that these features exhibit many common spectral characteristics. These spectra indicate the presence of relatively fresh highlands rocks dominated by Fe-bearing plagioclase and Ca-poor pyroxene. Noritic anorthosite is the major rock type present in all of the areas for which these spectra were obtained (Figure 1). Our results are consistent with those of a recent CCD-imaging study of Gassendi crater presented by Chevrel and Pinet [1992].

In summary, the northwestern portion of the Humorum MB ring is composed of pure anorthosite. In contrast, the other



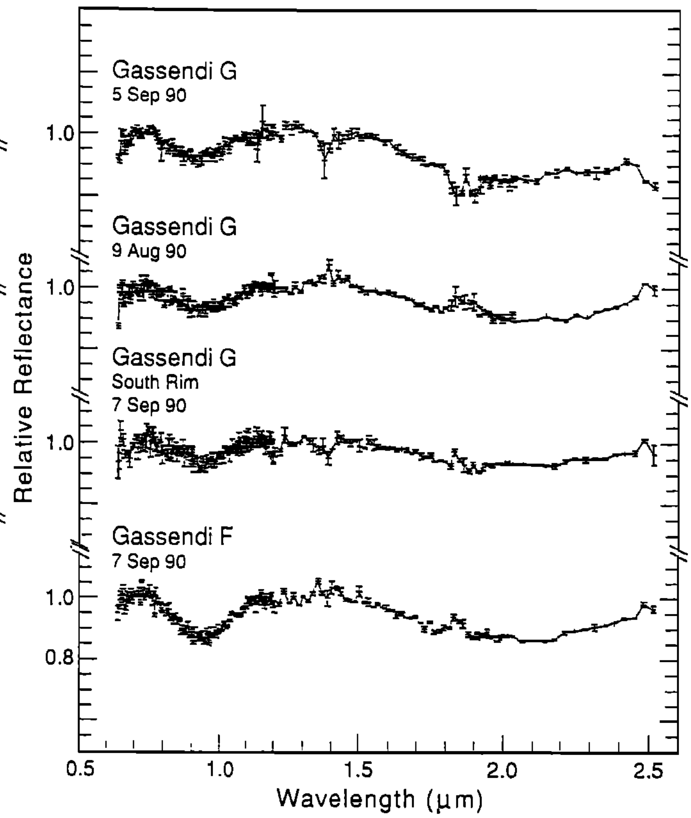


Fig. 3. (a) Reflectance spectra scaled to unity at 1.02 µm for Gassendi G and F craters. (b) Reflectance spectra shown in (a) after continuum removal.

highlands units northwest of Humorum are dominated by somewhat more mafic rock (noritic anorthosite). This includes at least a portion of the outer ring of Humorum. The anorthosites that occur in the inner ring may have been derived from a layer of pure anorthosite that existed at depth beneath a more pyroxene rich unit in the Humorum basin target site. Pure anorthosites have now been identified on the inner rings of Orientale, Nectaris, Grimaldi, and Humorum basins [Spudis *et al.*, 1984, 1989, 1992; Hawke *et al.*, 1991a,b, 1992a,b].

Lucey *et al.* [1991] have recently presented the results of an imaging spectroscopy study of the Humorum basin region. They identified a spectral unit in the highlands northwest of Humorum which appeared to represent a mixture of highlands debris with lesser amounts of mare material. This spectral unit generally correlates with the area that exhibits anomalously low depolarized 3.8-cm radar returns. These low backscatter values could indicate a deficiency in 1-50 cm fragments on or near the surface or the presence of material with a dielectric constant different from that of typical highlands material.

In order to further investigate this anomalous region, we utilized 70-cm radar images provided by T. Thompson. The techniques used to obtain and process these data are described by Thompson [1987]. The anomalous region discussed above exhibits low returns on the 70-cm depolarized radar image. The values for this unit are lower than those of the nearby highland terrain and similar to the values exhibited by some mare deposits. The low 70-cm radar returns could be due to the lack of meter-sized blocks in the near-surface environment or to the presence of a unit with a dielectric constant significantly different from that of the surrounding highlands terrain. In addition, Thompson [1978] noted that the highlands northwest of Humorum exhibit anomalously low values in 7.5-m radar images.

We have obtained a series of near-infrared spectra for different portions of Gassendi G and F, which lie in the area characterized by anomalous radar returns (Figure 3). Both impact craters are 8 km in diameter and exhibit partial dark haloes. These craters excavated material from beneath the surface of the anomalous radar unit. Analysis of our spectral data indicates that both Gassendi G and F exposed mare basalt from beneath a surface enriched in highlands debris. All of the spectra exhibit relatively deep "1 µm" absorption features centered near or longward of 0.95 µm. However, minor differences are seen among the spectra, and these appear to be related to exact locations and sizes of the areas for which the spectra were obtained. The spectrum of Gassendi F indicates the presence of major amounts of mare basalt with only minor amounts of highlands debris. The spectrum obtained for the center of the Gassendi G interior (aperture diameter=5km) indicates the presence of mare basalt that is contaminated by a somewhat higher percentage of highlands material. In contrast, the spectrum of the dark halo immediately south of Gassendi G (aperture diameter=5km) indicates that this area is composed almost totally of mature mare basalt. The spectrum obtained for a relatively large area (diameter=18km) that included both the Gassendi G interior and the dark halo has spectral parameters that are intermediate between the other two spectra. These results confirm and extend the findings reported by Lucey *et al.* [1991].

The spectral data have important implications for the stratigraphy of the Gassendi G and F target sites. A relatively thin highlands-rich surface layer overlies a mare basalt unit which occurs above a deposit of pure highlands material.

Gassendi G fully penetrated the upper two layers, and highlands debris is exposed in the central portion of the crater interior. The stratigraphic evidence suggests that an episode of mare volcanism emplaced basaltic units in this region after the formation of the Humorum basin. Subsequently, large impacts in the vicinity, such as those which formed Gassendi, Mersenius, and Letronne craters, as well as the Orientale impact event, emplaced a veneer of highlands atop the basalt flows. Some ancient mare material could have been mixed with this highlands debris either by local mixing by secondary craters during ejecta emplacement or by vertical mixing due to small crater-forming impacts in the area.

The presence of a mare basalt component in the surface layer could be responsible for the radar anomaly in the region. A significant amount of mare basalt could alter the bulk dielectric constant of the regolith. However, the spatial extent of the radar anomaly argues against this interpretation. The anomalous surface unit extends beyond the limits of the area thought to possess a surface layer containing mare basalt. The radar anomaly commonly extends to near the rim crests of the craters that apparently covered the ancient basalts with highlands debris.

In summary, the anomalous 3.8-cm radar unit can be partly explained by presence of a buried mare deposit that has contributed basaltic material to the regolith. However, the spatial extent of the radar anomaly argues against this explanation. To date, no spectral or morphologic evidence for pyroclastic volcanism has been found in the region which exhibits low 3.8-cm backscatter values.

Conclusions

1. The northwestern segment of the mare-bounding ring of Humorum basin is composed of pure anorthosite.

2. Other highlands units in the region are dominated by noritic anorthosite. This includes the outer ring of Humorum basin.

3. The anorthosites on the inner ring may have been derived from a layer of pure anorthosite that exists at depth beneath a more pyroxene-rich unit.

4. Gassendi G and F craters, which are located between the MB and outer rings, expose mare basalt from beneath a highlands-rich surface unit that was emplaced by the Gassendi, Letronne, Orientale, and other impact events [Lucey *et al.*, 1991].

5. This ancient basalt unit was emplaced after the formation of Humorum basin but before the Orientale impact event.

6. The existence of an ancient mare unit northwest of Humorum can partially account for this area's low 3.8-cm radar return. However, the spatial extent of the radar anomaly suggests that other factors are involved. These include explosive volcanism and an unusual (i.e., Fe- and Ti-rich) highlands composition.

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