

**REMOTE SENSING STUDIES OF THE ORIENTALE BASIN REGION; B. R. Hawke,**

P. G. Lucey, G. J. Taylor, J. F. Bell, C. A. Peterson, D. Blewett, and K. Horton, Planetary Geosciences Division, School of Ocean and Earth Science and Technology, University of Hawaii, Honolulu, HI 96822.  
P. D. Spudis, Lunar and Planetary Institute, Houston, TX 77058

**INTRODUCTION:** In early December, 1990, the Galileo spacecraft encountered the Earth-Moon system and obtained a wealth of new spectral data and imagery for portions of the Moon's western limb and farside that are being used to address a variety of important lunar issues. The focus of the Galileo lunar observations is the Orientale region of the Moon. Orientale is the youngest and best preserved of the giant multiringed impact basins on the Moon. It straddles the western limb; about half of it is visible from Earth. This region is geologically fascinating and unanswered questions abound. We do not know the surface composition of the western limb area with certainty, nor do we know how the composition varies with depth. A detailed study of the region will address both problems because Orientale, like other basins, is a natural drill hole into the lunar crust. Smaller craters and basins are also present in the area, so in principle we can obtain a fairly detailed picture of crustal stratigraphy. Furthermore, we can use compositional data and inferred stratigraphy to test models of the mechanics of basin formation. Finally, we can determine the characteristics of the volcanic products that partially fill the basin and occur in other areas outside it, and also measure the extent of pre-Orientale mare volcanism.

We have been conducting a variety of spectral observations of the Orientale region. Our present efforts continue work reported previously by Spudis et al.<sup>1</sup> We combine both visible and near-infrared spectral observations with multispectral imaging. The purposes of this paper are 1) to present the preliminary results of this effort; 2) to address the fundamental questions outlined above; and 3) to provide a framework in which to interpret the observations made by the Galileo mission.

**METHOD:** Over 100 near-infrared reflectance spectra (0.6-2.5 $\mu$ m) were obtained at the 2.24-m telescope of the Mauna Kea Observatory (MKO) during a series of observing runs conducted during favorable lunar librations. In addition, two observing runs were conducted utilizing the University of Hawaii 60-cm (Air Force) telescope, and fifty spectra were obtained. Digital multispectral images of the Orientale region were obtained at one of the MKO 60-cm telescopes simultaneous with some of the spectral observations. Images were obtained in UV, visible and near-infrared wavelengths (0.375, 0.40, 0.73, 0.86, 0.90, 0.93, 0.96, and 1.00  $\mu$ m, each with 10 nm bandwidth) with a 376x585 element Thompson CCD installed in a commercial astronomical CCD camera produced by Photometrics, Inc. Observations of the Mare Serenitatis standard site were made for photometric calibrations. A rectified color composite of near-IR multispectral imaging intended to show the distribution of anorthosite and noritic material in the Orientale region was produced.

**RESULTS AND DISCUSSION:** We discuss the results in terms of geological location.

*Orientale interior*

With the exception of the Inner Rook massifs, all the highlands units inside the Orientale basin appear to be composed of either noritic anorthosite or anorthositic norite.<sup>1</sup> The Maunder Formation is composed of smooth plains that grade laterally outward into rough-textured material, and is thought to be composed largely of impact melt.<sup>2,3,4,5</sup> Spectra obtained for portions of the Maunder Formation with mature regolith surfaces are almost identical to those taken in the vicinity of the Apollo 16 site. Spectra of fresh surfaces on the Montes Rook Formation, a hummocky unit thought to be primary basin ejecta,<sup>4,5</sup> and of the massifs of the Outer Rook Mountains are similar to one another and indicate the presence of plagioclase and low-Ca pyroxene.<sup>1</sup> Mature surfaces on the Montes Rook Formation are similar in composition to those in the Apollo 16 area.

The Inner Rook Mountains are markedly different from other units within the Orientale basin. Our previous data<sup>1</sup> indicated that two of these mountains are composed of anorthosite. Our new multispectral images confirm this view: the entire eastern Inner Rook Mountains contain only minute amounts of low-Ca pyroxene. Thus, it appears that the Inner Rook ring of the Orientale basin is a mountain range composed of anorthosite. The plagioclase absorption band at 1.25 microns occurs in some spectra, but not in all, suggesting different shock histories for different parts of the Inner Rook ring.

*Orientale exterior*

The Hevelius Formation occurs outside the prominent Cordillera ring and probably contains large amounts of primary ejecta from Orientale. It consists of hummocky to lineated to swirl-textured deposits that extend to almost one basin-diameter (930 km) beyond the Cordillera scarp. We have taken numerous spectra of this deposit,

including several radial traverses across it. The Hevelius Formation is surprisingly uniform in composition and strikingly similar to Apollo 16. It consists largely of noritic anorthosite, like much of the interior deposits in Orientale. The Hevelius Formation grades outward into smooth highlands plains deposits, some of which also appear to be similar in composition to the Apollo 16 highlands.

#### *Crüger region*

Spectral observations of the Crüger region have been reported and discussed by Hawke et al.<sup>6</sup> Crüger is a 46-km diameter, mare-filled impact crater. Spectra of its west rim and of Darwin C (a 16-km crater southwest of Crüger) indicate that the highlands are composed of noritic anorthosites here also. However, the spectrum for the 8-km diameter crater Crüger G exhibits a pyroxene absorption feature minimum beyond 0.95  $\mu\text{m}$ , which indicates a gabbroic anorthosite composition. Gabbroic anorthosite was also exposed by Byrgius A, a 19-km diameter impact crater south of Crüger.<sup>7</sup> The area east of Crüger exhibits unusual characteristics in the multispectral imagery. Some areas mapped as highlands exhibit a mare basalt signature. This suggests that portions of this region could have been the sites of pre-Orientale mare volcanism.

#### *Grimaldi Region*

Grimaldi is a small (430 km) two-ringed impact basin. Our spectral data indicate that there might be anorthosites on its inner ring, analogous to those in the Inner Rook ring of Orientale. We have obtained one spectrum of an anorthosite from a portion of the inner ring. Other spectra for the inner ring exhibit a very shallow pyroxene absorption feature, which indicates the presence of very minor amounts of orthopyroxene. These areas may also prove to be composed of anorthosites. Other highlands deposits emplaced in the Grimaldi region as a result of the Orientale impact event appear to be composed of noritic anorthosite.

#### *Schiller-Schickard Region*

Although this region is over 1000 km from the Cordillera ring, it has been heavily affected by the Orientale impact event. This area contains numerous unusual features. These include the crater Wargentini, the Schiller-Zuccius impact basin, the large crater Schickard (D=227 km), whose floor contains mare deposits as well as a light plains unit, and a high density of dark-haloed impact craters.<sup>8</sup> Bell and Hawke<sup>9,10</sup> presented spectral data which demonstrated that dark-haloed impact craters excavated ancient mare basalts from beneath light plains deposits in the Schiller-Schickard region. They concluded that early (>3.8 Ga) mare deposits existed in the Schiller-Schickard region prior to the Orientale impact and that these basaltic units were covered with a thin layer of highland debris as a consequence of the formation of Orientale basin. Spectra for the light plains deposits in this region exhibit relatively strong "1  $\mu\text{m}$ " bands. Either Orientale primary ejecta in the region contains more pyroxene than similar material in other areas or pyroxene-rich local material (mare basalt?) was incorporated in the light plains deposits by Orientale secondary craters.

#### *Humorum Region*

Humorum is an old multiringed basin east-southeast of Orientale. Our data indicate that anorthosites are exposed on the main ring of this basin. Spectra obtained for small craters in the highlands northwest of the basin indicate the presence of a mare basalt component, which suggests that the region experienced mare-type volcanism prior to the formation of the Orientale basin.

**SUMMARY OF OBSERVATIONS:** 1) Anorthosites occur in the Inner Rook Mountains of Orientale, the inner ring of Grimaldi, and the main ring of Humorum. Imaging spectroscopy shows that the entire eastern Inner Rook Mountains are composed of anorthosites. 2) Orientale ejecta are strikingly like the surface materials in the region where Apollo 16 landed. This similarity indicates similar mineralogy, noritic anorthosite. Thus, Orientale ejecta is more mafic (10-20% low-Ca pyroxene) than the Inner Rook Mountains (no more than a few percent pyroxene). This situation is also true for the Nectaris, Humorum, and Grimaldi basins. 3) Isolated areas in the Orientale region show the presence of gabbroic rocks, but in general Orientale ejecta are noritic anorthosites, which contain much more low-Ca pyroxene than high-Ca pyroxene. 4) Ancient (pre-Orientale) mare volcanism apparently occurred in several areas of the western limb.

**REFERENCES:** 1) P. Spudis, et al. (1984) *PLPSC*, 15, C197; 2) J. Head (1974) *The Moon*, 11, 327; 3) H. Moore et al. (1974) *PLSC*, 5, 71; 4) J. McCauley (1977) *Phys. Earth Planet. Inter.*, 15, 220; 5) D. Scott et al. (1977) *USGS Map 1-1034* 6) B. Hawke et al. (1989) *PLPSC*, 19, 127; 7) C. Pieters (1986) *Rev. Geophys.*, 24, 557; 8) P. Schultz and P. Spudis (1979) *PLPSC*, 10, 2899; 9) B. Hawke and J. Bell (1981) *PLPSC*, 12, 665; 10) J. Bell and B. Hawke (1984) *JGR*, 89, 1899.