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A SPECTRAL SURVEY OF THE SERENITATIS BASIN REGION OF THE MOON. B. R. Hawke[1], C. A. Peterson[1], P. G. Lucey[1], D. T. Blewett[1], J. F. Bell III[2], and P. D. Spudis[3], [1]Planetary Geosciences, SOEST, University of Hawaii, Honolulu HI 96822, USA, [2]NASA Ames Research Center, Moffett Field CA 94035, USA, [3]Lunar and Planetary Institute, 3600 Bay Area Blvd., Houston TX 77058, USA.

Introduction: The returned lunar samples contain much petrological and compositional information for small, select portions of the surface of the Moon. Many of the highland samples returned from the Apollo landing sites are somehow related to lunar multiringed impact basins, either as primary ejecta or reworked local material. These highland samples cannot always be related to a basin directly, and it is extremely difficult to characterize the composition and lithology of basin ejecta based on a small number of returned samples. However, the Apollo orbital geochemistry instruments and Earth-based remote sensing techniques provide compositional data for large portions of the lunar surface, including basin ejecta deposits. These data provide a regional framework within which to interpret the significance of the returned samples as well as information concerning the stratigraphy of the lunar crust [1].

In recent years, we have utilized the Apollo orbital geochemistry datasets and Earth-based spectral reflectance data to investigate the composition of highland units associated with lunar multiring basins. These include Imbrium [2], Orientale [3,4], and Nectaris [1,5] Basins. We have also analyzed a large number of near-IR reflectance spectra and multispectral images in an attempt to answer a variety of questions concerning the Serenitatis Basin. These questions include (1) What is the composition of highland units in the region and how do these compositions vary as a function of position around and distance from Serenitatis? (2) What was the crustal stratigraphy of the Serenitatis preimpact target site? (3) How do the Apollo 17 samples relate to geologic units in the surrounding highlands? (4) What is the nature and origin of light plains deposits in the region? (5) Do cryptomare occur in the Serenitatis region? The purpose of this paper is to present the preliminary results of our analyses of spectral data obtained for the Serenitatis Basin region.

Method: Near-infrared reflectance spectra (0.6–2.5 μm) were obtained at the 2.24-m telescope of the Mauna Kea Observatory during a series of observing runs using the Planetary Geosciences indium antimonide spectrometer. 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 atmospheric extinction throughout each night. Extinction corrections were made using the methods described by McCord and Clark [6], and spectral analyses were made using the techniques described by McCord et al. [7]. The multispectral images used in this study were described by McCord et al. [8] and Bell and Hawke [9].

Results and Discussion: *Taurus-Littrow region.* Spectra were obtained for various portions of the North and South Massifs at the Apollo 17 site. Analysis indicates that they exhibit "1-μm" bands that are centered at 0.92 μm and have band strengths of ~6%. These characteristics indicate a feldspar-bearing mineral assemblage with a mafic component dominated by low-Ca orthopyroxene. The areas for which these spectra were obtained contain abundant anorthositic norite.

Spectra were also collected for various areas of Littrow Crater. The dominant lithology is anorthositic norite. However, spectra for a small, fresh crater on the north rim of Littrow as well as the floor of Littrow have "1-μm" bands centered at slightly longer wavelengths (~0.94 μm) than the spectra obtained for the Apollo 17 massifs. The highland-rich soil in the floor of Littrow may contain minor amounts of dark mantle material of pyroclastic origin.

Both localized (LDMD) and regional dark mantle deposits (RDMD) of pyroclastic origin occur in the Taurus-Littrow region. The Taurus-Littrow RDMD occurs west of the Apollo 17 site, and the thickest portion covers an area of 4000 km^2 [10,11]. We have obtained near-IR spectra for several portions of this RDMD. The spectra exhibit very steep continuum slopes and broad, shallow 1.0-μm absorption bands. Band analysis suggests that olivine is the most abundant mafic mineral. Previous studies have demonstrated that the black spheres from the rim of Shorty Crater are the characteristic ingredients and dominate the spectra of the Taurus-Littrow RDMD [11–14]. These dark pyroclastic spheres, which contain abundant ilmenite and olivine, are the quench-crystallized chemical equivalents of the homogeneous Apollo 17 orange glasses. This RDMD exhibits very weak echoes on 3.8-cm radar images; a lack of surface scatterers (fragments 1–50 cm in size) is believed to be responsible for the low radar returns [11,12]. Previous studies of lunar RDMD have suggested that they would be excellent sites for lunar outposts and that the pyroclastic debris could be a source of several valuable resources [15].

The dark floor deposit in Vitruvius Crater was mapped as an LDMD by Wilhelms and McCauley [16]. The spectrum obtained for this deposit falls in LDMD group 2 as defined by Hawke et al. [10]. These spectra closely resemble those obtained for mature mare.

Plinius-Dawes region. The preliminary results of analyses of CCD imaging and spectroscopy data obtained for the Plinius-Dawes region was recently presented by Bell and Hawke [9]. Dawes (18 km) has a symmetrical band centered at 1.0 μm that is deeper than that of the surrounding mare, indicative of a lesser degree of soil maturity. In addition, Dawes has little or no highland signature in its six-color spectrum. In contrast, Plinius Crater (43 km) spectra exhibit more complex 1-μm bands. Spectra for the southwest wall and southwest floor have bands that appear rather symmetrical and are centered near 1.0 μm. The bands are not as deep as those exhibited by the Dawes spectra or those of surrounding mature mare surfaces. The 1-μm bands of the Plinius central peak and northeast wall spectra are clearly composed of two features: a short-wavelength component centered near 0.92 μm and a longer wavelength component centered near 1.0 μm. The 0.92-μm feature is weaker than the 1.0-μm band in the northeast wall spectrum, suggesting that this is primarily mare material with a minor highland component. However, the 0.92-μm band is much more prominent in the central peak spectrum, suggesting that the peak is primarily noritic highland material with minor mare contamination [9]. Our linear mixing model studies of the six-color CCD images verify and extend the spectral interpretations. The Plinius central peak and several regions of the floor clearly have a substantial highland signature, and small outliers of highland material can be seen in the northwest ejecta. In addition, several regions of the floor and south-southwest rim exhibit a spectral signature more like that of the low-Ti Serenitatis mare than the Tranquillitatis basalts.

Montes Haemus region. The Haemus Mountains form one segment of the mare-bounding ring of the Serenitatis Basin. Menelaus Crater straddles the mare-highlands border, and the interior and exterior deposits are very heterogeneous in composition. The dominant highland material associated with the interior of Menelaus is noritic anorthosite [17]. However, more pyroxene-rich highland debris also occurs in the Menelaus area. No deposits of pure anorthosite have been identified in the Serenitatis Basin region. The most plagioclase-rich material in the region was exposed by Menelaus.

Small craters in the Haemus region generally expose anorthositic norites. This material was derived from relatively shallow depths and is probably dominated by Imbrium Basin ejecta. Previous studies have shown that Imbrium ejecta on the backslope west of the Haemus region is dominated by norite and anorthositic norite [2].

The Sulpicius Gallus RDMD covers ~6000 km² in the western portion of the Haemus region. Spectral studies indicate that this deposit is a mixture of orange glass and black spheres [11].

Terrain north and east of Serenitatis. Band analysis of the limited number of spectra available indicates that mare basalts are exposed in the walls of Burg Crater and that the Burg peak has a mafic assemblage dominated by high-Ca pyroxene. Anorthositic norites are exposed in the peak of Eudoxus Crater as well as the walls and peak of Romer. Dark-haloed impact craters south of Hercules and southeast of Posidonius have excavated mare basalts from beneath highland-rich surface units. At least small areas of cryptomare appear to exist northeast of Serenitatis Basin.

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THE SERENITATIS BASIN AND THE TAURUS-LITTROW HIGHLANDS: GEOLOGICAL CONTEXT AND HISTORY.

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Introduction: The Apollo 17 mission was targeted to land at the southeastern edge of the Serenitatis Basin, one of a number of large impact basins on the Moon. The choice of the landing site was influenced heavily by the desire to obtain detailed information about large impact basins [1] by constructing a composite "geological traverse" radial to a basin [2] (Fig. 1), with the Apollo 16 site (Descartes) representing the most distal regions, the Apollo 14 site (Fra Mauro) the intermediate textured ejecta unit, the Apollo 15 site (Hadley-Apennine) the basin topographic rim, and the Apollo 17 site (Taurus-Littrow) within the basin interior. The remarkable geologic exploration of the Taurus-Littrow Valley by astronauts Harrison Schmitt and Eugene Cernan provided fundamental information about processes associated with impact basin formation and evolution [3]. This information, further analysis of returned samples and other data, and subsequent exploration of the Moon have raised additional questions that can potentially be answered from the site data. The Apollo 17 site is thus a keystone to the understanding of the geology of impact basins in general and basin interiors specifically. In this contribution, the geologic setting of the Apollo 17 site is reviewed, the implications for the formation of basins from Apollo 17 results are assessed, and unanswered questions potentially addressable with existing and new data are outlined.

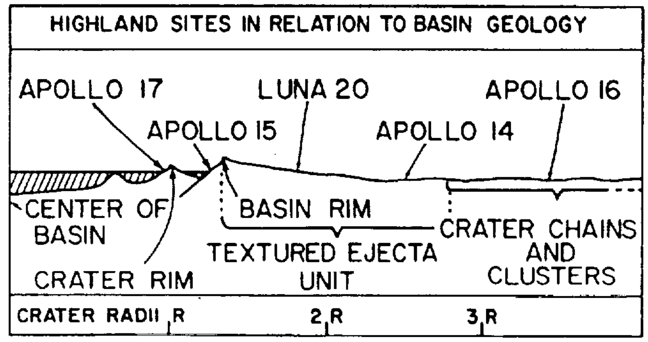

Fig. 1. Composite cross section across lunar impact basin showing relationship of Apollo landing sites to basin geology. From [2].

Geological Setting of the Serenitatis Basin: Mare Serenitatis is paradoxically one of the most clearly defined circular maria, but the basin structure itself is so indistinct, primarily due to modification by the post-Serenitatis Imbrium Basin, that some early basin studies did not even discuss it [4]. In fact, Serenitatis appears to be one of the more recent lunar basins. Stratigraphically, Serenitatis is one of 12 basins that have been assigned a Nectarian age [5]. It lies within the younger group of these basins and is immediately predated by Crisium, Humorum, and Humboldtianum, and immediately postdated by Hertzsprung. In terms of its regional setting, several pre-Nectarian and Imbrian-aged basins have had a major influence on its history.

Pre-Serenitatis basin geology. Serenitatis lies within the ancient pre-Nectarian Procellarum Basin, which may be as large as 3200 km diameter [5,6]. The Serenitatis impact would have occurred astride the first ring, extending westward into the basin interior and eastward to the vicinity of the second ring. The Vitruvius Front [7], a topographic scarp occurring in the area to the east of the basin, may be related to the Procellarum Basin [5]. This structure, a long, irregular, but generally north-trending scarp, occasionally rises over 2 km about the surrounding terrain and is associated with a plateau to the east. It does not appear to be directly associated with the Serenitatis Basin [5–7] and may be a remnant of the second ring (excavation rim?) of the Procellarum Basin [5,6]. If so, the Apollo 17 site would lie just within the excavation cavity and Procellarum deposits there would be dominated by impact melts and deep ejecta emplaced on a substrate thinned considerably by impact excavation.

One of the most obvious basins forming in the vicinity of the target area prior to the Serenitatis event is the 800-km-diameter pre-Nectarian Tranquillitatis Basin. The outer ring of this structure actually intersects the Serenitatis Basin in the vicinity of the Apollo 17 site and thus early site geology may be influenced by geologic structure and deposits similar to those seen along the Cordillera ring of the Orientale Basin, or the Apennine ring of the Imbrium Basin at the Apollo 15 site. Crisium is interpreted to have just predated the Serenitatis event [5]. There is no clear evidence of Crisium secondaries near the eastern Serenitatis basin deposits and some Serenitatis secondary craters are interpreted to lie on Crisium ejecta [5]. In addition to these major basins, a number of impact craters in the sub-basin size range must have occurred subsequent to Procellarum and Tranquillitatis. Continuing documentation of the presence of cryptomaria in pre-Orientale times [8–11] suggests that many ancient basins may have been floored by early mare basalts, or KREEP