REMOTE SENSING STUDIES OF SELECTED SPECTRAL ANOMALIES ON THE MOON. B. Ray Hawke[1], D.T. Blewett[1,4], P.G. Lucey[1], G.A. Smith[1], G.J. Taylor[1], D.J. Lawrence[2], and P.D. Spudis[3]. [1]Planetary Geosciences, Hawaii Institute of Geophysics and Planetology, University of Hawaii, 2525 Correa Rd., Honolulu, HI 96822, [2]Los Alamos National Laboratory, MS D466, Los Alamos, NM 87545, [3]Lunar and Planetary Institute, Houston, TX 77058, [4]Innovative Technical Solutions, Inc., 2800 Woodlawn Dr., #192, Honolulu, HI 96822.

Introduction

Lunar Red Spots make up an important class of spectral anomalies on the nearside of the Moon. These features are generally located in the highlands and have spectra that are characterized by very strong ultraviolet absorptions. Whitaker [1] used UV-IR color difference photographs to identify numerous Red Spots on the lunar nearside and suggested that these anomalously red areas may have compositions that are substantially different from those of typical highlands. The identified red areas included the Gruithuisen domes, Hansteen Alpha, the southern portion of Montes Riphaeus, Darney Chi and Tau, the Helmet, and an area surrounding the anomalous craters Lassell C, G, and K.

Several workers have presented evidence that at least some Red Spots were produced by highlands volcanism and suggested a connection with KREEP basalts (Medium-K Fra Mauro basalt {MKFMB}) or even more evolved highlands compositions (e.g., High-K Fra Mauro basalt {HKFMB}, dacite, rhyolite) [2,3,4,5]. Malin [2] suggested that the Red Spots are the surface manifestations of pre-mare KREEP basalts. Wood and Head [3] suggested that some red material may have been involved in post-Imbrium extrusive volcanic activity prior to the emplacement of the major maria. In addition, Head and McCord [4] presented evidence that the Gruithuisen and Mairan domes represent morphologically and spectrally distinct nonmare extrusive volcanic features of Imbrian age.

In recent years, major controversies have been associated with highlands volcanism, the origin of KREEP, and the nature of Red Spots. Many questions remain unanswered. We have used remote sensing data to determine the composition of selected Red Spots and to investigate the relationship between Red Spots and KREEP basalts and other evolved highland compositions.

Method

A variety of Earth-based and spacecraft remote sensing data were used to investigate the chemistry and mineralogy of lunar Red Spots. Chief among these were Clementine UVVIS images and Lunar Prospector orbital geochemistry data. Calibrated Clementine UVVIS data at 1 km/pixel spatial resolution were utilized to produce iron, titanium and maturity images using the spectral algorithms of Lucey et al. [6,7]. The $2° \times 2°$ thorium data from the low-altitude portion of the Lunar Prospector mission [8] were reprojected and merged with shaded relief maps of the Red Spot regions. Telescopic near-infrared reflectance spectra were analyzed and interpreted for a limited number of spectral anomalies.

Results and Discussion

Hansteen Alpha: This arrowhead-shaped highlands feature is located in southern Oceanus Procellarum just north of the crater Billy. Wood and Head [3] noted that this rough textured triangular mound (~25 km on a side) appeared distinctive in its surface texture, color, and albedo from nearby highlands and is embayed by adjacent mare units. The values for both mare and highlands units immediately adjacent to Hansteen α range from 5 to 6 ppm. The pixel which contains Hansteen α exhibits a Th value of ~ 7 ppm. It should be noted that the Red Spot covers only a portion of that pixel. The central portion of Hansteen α has an FeO content of 6 to 8% and a TiO_2 abundance of < 1%. These values are below those exhibited by typical MKFMB but are consistent with some of the more evolved highlands lithologies.

Helmet: Wood and Head [3] described this helmet-shaped region which is about 40 km in diameter and lies just northeast of Mare Humorum. They noted that this Red Spot is surrounded by younger mare material and consists of two terrain types: 1) a smooth plains unit which makes up about 60% of the Helmet area and 2) a hummocky to hilly unit which includes Herigonius Pi and Eta. Bruno et al. [9] detected significant spectral differences among the various morphological units within the Herigonius Red Spot and noted that while some of these differences are due to the effects of maturation processes, others appear to reflect differences in mineral abundances and compositions.

Portions of the Helmet occur in four pixels in the Th map. These pixels exhibit the same range of Th values (4 to 6 ppm) as pixels in the surrounding region. The Helmet has FeO values of 10% to 14%. The higher values are immediately adjacent to the mare/highlands boundary and are due to contamination by mare material. FeO values of 11% to 12% appear to be typical of noncontaminated portions of the Helmet. TiO_2 values range from 0.5% to 2.0%. These

values are consistent with the presence of major amounts of MKFMB in the Helmet area.

Darney Chi and Tau: These adjacent spectral anomalies are located in Mare Cognitum. Darney Chi is a plains unit while Darney Tau is composed of a series of hills. These features have a Th value of ~ 6 ppm. This value is well within the range exhibited by the surrounding region. Both have FeO values that range between 10% and 14%. Darney Chi has TiO_2 abundances of 0.5% to 2.0%. In contrast, Darney Tau exhibits TiO_2 values of 1.5% to 2.0%. It should be noted that the small size of these features has resulted in significant contamination by the surrounding mare material.

Southern Montes Riphaeus: The Riphaeus Mts. form a 170 km arc along the northwestern edge of Mare Cognitum and appear to be on the rim of an ancient impact structure [3]. Wood and Head [3] noted that the southern 50 km of this mountain arc are distinctively red. The Th values for this area (6 to 7 ppm) are generally similar to those exhibited by adjacent units. However, higher Th values (7 to 9 ppm) are associated with the northern Riphaeus Mts. Those portions of the Red Spot that are least contaminated with mare basalt, have FeO values of 8% to 12% and TiO_2 values less than 1.5%.

Lassell K, G, C: The Lassell Red Spot is located NW of Lassell crater in northern Mare Nubium. It is associated with several craters (Lassell C, G and K) in an upland patch surrounded and embayed by mare basalts [1, 3]. An analysis of eight near-IR spectra obtained for the Lassell region indicated the presence of both noritic and gabbroic lithologies [10].

The Lassell Red Spot exhibits a Th value (~ 10 ppm) slightly higher than those of its surroundings (7 to 8 ppm). An area with relatively high Th values (9 to 10 ppm) occurs north of the Lassell region. The core portion of the Lassell anomaly exhibits FeO values of 6% to 8% and TiO_2 abundances less than 0.5%. These values are lower than those typical of MKFMB but are consistent with the FeO and TiO_2 abundances of some of the more evolved lithologies.

Mons La Hire: This feature is one of a series of isolated mountains and clusters of mountains which lie on the trace of the inner ring of the Imbrium basin [3]. While most workers consider La Hire to be a portion of the peak ring that formed during the Imbrium impact event, some have suggested that La Hire is a volcanic construct, possibly formed by the extrusion of magma that had risen along a basin-related fault [5].

The Th value for the pixel that contains Mons La Hire is 6 ppm. This value is similar to those exhibited by nearby portions of Mare Imbrium. It should be noted that Mons La Hire occupies only a small portion of one pixel. The peak has FeO values that range between 10% and 14% and TiO_2 values of 1.5% - 2.0%. These values are similar to those exhibited by other Imbrium-related highland features in the region. Both compositional and morphologic data indicate that Mons La Hire is of impact, not volcanic, origin.

Gruithuisen Domes: Wood and Head [3] noted that Gruithuisen Gamma and Delta were distinctive red domical features 15 to 25 km in diameter that occur at the western edge of Mare Imbrium, south of Sinus Iridum. Head and McCord [4] identified a third spectrally distinct dome just northwest of Gruithuisen Gamma as well as three red domes just west of Mairan crater. They concluded that the Gruithuisen and Mairan domes represent morphologically and spectrally distinct nonmare extrusive volcanic features of Imbrian age.

The Gruithuisen domes exhibit Th values between 7 and 9 ppm. Even higher values (10 to 12 ppm) are associated with Mairan crater which is located northwest of the Gruithuisen domes. Gruithuisen Gamma and Delta exhibit FeO values between 6% and 10% and TiO_2 values less than 1%. The core portions of these domes have FeO abundances of 6% to 8% and very low (< 0.5%) TiO_2 values. These values are lower than those typical of MKFMB.

Aristarchus Crater: Aristarchus is a 40 km diameter impact structure located on the southeast edge of the Aristarchus Plateau. A spectral anomaly is associated with a portion of Aristarchus crater [3, 11]. A major Th enhancement (~13 ppm) is centered on the crater.

References

[1] Whitaker E. A. (1972) *Moon, 4,* 348.

[2] Malin M. C. (1974) *Earth Planet Sci. Lett., 21*, 331.

[3] Wood C. A. and Head J. W. (1975) *Origins of Mare Basalts* (LSI), 189.

[4] Head J. W. and McCord T. B. (1978) *Science, 199,* 1433.

[5] Raitala J. *et al.* (1999) *LPS XXX,* #1457

[6] Lucey P. *et al.* (2000) *JGR, 105,* no. E8, 20, 297.

[7] Lucey P. *et al.* (2000) *JGR, 105,* no. E8, 20, 377.

[8] Lawrence D. J. *et al.* (2000) *JGR, 105,* no. E8, 20, 307.

[9] Bruno B. C. *et al.* (1991) *PLPSC 21,* 405.

[10] Muller A. *et al.* (1986) *LPS XVII,* 577.

[11] Zisk S. *et al.* (1977) *Moon, 17,* 59.