SPECTRAL ANOMALIES IN THE IMBRIUM REGION OF THE MOON. B. R. Hawke[1], D. J. Lawrence[2], J.J. Gillis[3], D.T. Blewett[4], P. G. Lucey[1], C.A. Peterson[1], G.A. Smith[1], P. D. Spudis[5], and G. J. Taylor[1], [1]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]Dept. of Earth and Planetary Sciences, Washington University, St. Louis, MO 63130, [4]NovaSol, 1100 Alakea Street, 23rd floor, Honolulu, HI 96813, [5]JHU-Applied Physics Laboratory, Laurel, MD 20723.

Introduction: Lunar Red Spots make up a major class of spectral anomalies on the nearside of the Moon. Red Spots 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. Several researchers 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 recent years, major controversies have been associated with highlands volcanism, the origin of KREEP, and the nature of Red Spots [e.g., 5,6,7]. Many questions remain unanswered. We have been using 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: The purpose of this report is to present our results for Red Spots in the Imbrium region. 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 were utilized to produce iron, titanium, and maturity images using the spectral algorithms of Lucey *et al.* [8,9]. The 2° x 2° thorium data from the low-altitude portion of the Lunar Prospector mission [10] were utilized. For the Gruithuisen domes region, a 0.5° x 0.5° Th map was produced. Telescopic near-infrared reflectance spectra were analyzed and interpreted for a limited number of spectral anomalies.

Results and Discussion:

*Plato Crater***.** Plato is an Imbrian-aged impact structure located in the highlands just north of Mare Imbrium (51.6° N, 9.3° W). The crater is 101 km in diameter, and its floor has been flooded by mare material. Wood and Head [3] noted that Plato exhibits distinctive red rim deposits. The spectral anomaly corresponds to the proximal ejecta deposits of Plato. The distal ejecta deposits of Plato are not anomalously red.

The crater ejecta west of Plato exhibits Th values of 7.5-9 ppm. Even higher values (9-10 ppm) are exhibited by highlands terrain west of the Plato ejecta deposit. Crater ejecta east of Plato has Th abundances of 6.5-7.5 ppm. Slightly lower Th values (5-7.5 ppm) are exhibited by highlands units east and southeast of Plato. Relatively low Th values are associated with the mare material on the floor of Plato. While the Th values associated with Plato ejecta deposits are lower than those exhibited by such craters as Aristillus, Mairan, and Aristarchus, they are still much higher than those exhibited by typical highlands material. The Th and Sm values [11] associated with the distal ejecta deposits west of Plato are consistent with the presence of major amounts of KREEP-rich material.

The ejecta deposits of Plato crater have FeO values that range from 9.0% to 13%. The higher values (12-13% are generally associated with mixing zones near highlands-mare boundaries. The exterior deposits of Plato have TiO_2 abundances of < 1%. The extremely red proximal ejecta deposits exhibit TiO_2 values of < 0.5%. While the FeO values associated with Plato ejecta are within the range of KREEP basalts, the TiO_2 values are lower than those typical of KREEP.

A large portion (~60,000 km^2) of the highland terrain surrounding Plato is distinguished by a relatively low 3.8-cm depolarized radar return [e.g., 12,13]. Gaddis *et al.* [13] suggested that this low depolarized return at 3.8-cm wavelengths was evidence of a mantling layer of fine-grained pyroclastic debris of intermediate albedo. Gillis and Jolliff [14] proposed that pyroclastic materials covered Th-rich Plato ejecta and were responsible for producing lower Th values in the Plato region.

Imbrium Inner Ring. Mons La Hire and Montes Spitzbergensis form part of a series of isolated mountains and clusters of mountains which lie on the trace of the inner or central peak ring of the Imbrium basin [3]. Wood and Head [3] noted that other elements of the ring are red but not as distinctively red as these features. While most workers consider Mons La Hire to be a portion of the peak ring that formed during the Imbrium impact event, some have suggested that Mons La Hire is a volcanic construct, possibly formed by the extrusion of magma that had risen along a basin-related fault [e.g., 5].

The pixel that contains Mons La Hire has a Th value of 6 ppm. This value is similar to those exhibited by nearby portions of Mare Imbrium. However, it should be noted that Mons La Hire occupies only a 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 highlands features in the region. Both compositional and morphologic data indicate that Mons La Hire is of impact, not volcanic, origin.

Montes Spitzbergensis is a cluster of mountains located NNW of Archimedes crater. The FeO values exhibited by Montes Spitzbergensis range from 7% to 13%. The higher values appear to be related units contaminated by lateral transport from the surrounding mare units. TiO_2 values for this feature range between 1% and 3%. No Th anomaly was identified in the area.

Archimedes Crater. Archimedes (dia.=83 km) is located west of the Apollo 15 site and is just within the intermediate ring of the Imbrium basin. The crater displays distinctive red rim deposits and has a floor that has been flooded by mare material. The ejecta deposits of Archimedes have been embayed by mare basalt flows N, W, and SE of the crater.

The Th values exhibited by Archimedes range from 6.5 to 9.5 ppm. These values are lower than those associated with Aristillus crater (> 12.5 ppm) which lies NE of Archimedes, and those exhibited by the Apennine Bench Fm. (8.5-11.5 ppm) which is located south of the crater [15]. The unflooded portions of Archimedes have FeO values of 11-16% and TiO_2 values that generally range between 0.5% and 2.0%. Very small areas that exhibit TiO_2 values < 0.5% and > 2% were identified. The area with the lowest TiO_2 values correlates with an extremely red area on the southern rim of Archimedes that exhibits a low albedo. The spectral parameters determined for an Earth-based near-IR spectrum that was collected for the low albedo area indicate that it is dominated by pyroclastic debris. Additional evidence for a pyroclastic origin for the dark, red deposit on the southern rim of Archimedes is provided by an optical maturity image of the crater [9]. The dark, red area exhibits unusually low OMAT values which are similar to those associated with pyroclastic deposits elsewhere on the Moon. Finally, the dark deposit exhibits a relatively low 3.8-cm depolarized radar return [16]. Possible source vents for this dark mantling deposit have been identified [14]. We conclude that the dark, red deposits on the rim of Archimedes are composed of pyroclastic debris and that this material is largely responsible for the spectral anomaly associated with Archimedes crater. The presence of this pyroclastic deposit may account, at least in part, for the lower Th values exhibited by Archimedes [14].

Gruithuisen Domes. Gruithuisen Gamma and Delta are very red domical features 15 to 25 km in diameter that occur at the western edge of Mare Imbrium, south of Sinus Iridum [3]. Head and McCord [4] identified a third spectrally distinct dome just NW of Gruithuisen Gamma as well as three red domes west of Mairan crater. These workers concluded that the Gruithuisen and Mairan domes represent morphologically and spectrally distinct nonmare extrusive volcanic features of Imbrian age. Support for this interpretation was recently provided by Chevrel *et al.* [7].

The 0.5° Th map indicates that the Gruithuisen domes have Th values of ~8 ppm. Even higher Th values (10 to 12 ppm) are exhibited by highlands units NW of the domes. Gamma and Delta exhibit FeO values between 6% and 10% and TiO_2 values < 1%. The central 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 which characterize MKFMB.

Near-IR spectra were obtained for Gruithuisen Gamma and Delta. These spectra differ from those collected for typical highlands areas in that they exhibit relatively broad bands centered at or longward of 1µm.

References:

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