LUNAR HIGLANDS VOLCANISM: THE VIEW FROM A NEW MILLENIUM.

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Introduction: Since the Apollo era, the search for highlands volcanism has focused on selected light plains deposits as well as a class of spectral anomalies known as Red Spots. These spectral anomalies have spectra that are characterized by very strong ultraviolet absorptions. UV-IR color difference photographs were used by Whitaker [1] to identify and characterize Red Spots on the lunar nearside. He suggested that these anomalously red areas may have compositions that are substantially different from those of typical highlands. In the immediate post-Apollo era, several workers {2,3,4] 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) or even more evolved highlands compositions (e.g., High-K Fra Mauro basalt, dacite, rhyolite).

Method: Both Earth-based and spacecraft remote sensing data were used to investigate the chemistry and mineralogy of lunar Red Spots and selected light plains deposits. Calibrated Clementine UVVIS images were utilized to produce FeO, TiO_2, and maturity images using the spectral algorithms of Lucey *et al.* [5,6]. The 2° x 2° thorium data from the low-altitude portion of the Lunar Prospector mission [7] were reprojected and merged with shaded relief maps of the Red Spot regions. Telescopic near-IR spectra were analyzed and interpreted for selected Red Spots and light plains units.

Results and Discussion: We have completed a preliminary investigation of the following Red Spots: Darney Chi and Tau, Helmet, Sourthern Montes Riphaeus, Hansteen Alpha, Lassell K, G, and C, Mons La Hire, and the Gruithuisen domes[8,9]. Strong evidence of a highlands volcanic origin has been found only for Hansteen Alpha and the Gruithuisen domes [4,8,9,10].

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 deposits. The 0.5° x 0.5° Th map indicates that Th abundances range from ~4.5 ppm to ~8 ppm in the Arrowhead region. The Arrowhead itself exhibits Th values of ~6 ppm. Slightly higher values (6.0 – 6.5 ppm) are associated with the eastern portion of Hansteen crater and its adjacent ejecta deposits. Based on these preliminary results, it does not appear that the Arrowhead is composed of highly evolved highlands lithologies that are extremely rich in Th. The central portion of Hansteen Alpha has an FeO content of 5% to 8% and a TiO_2 abundance of <1%. Nearby highlands units are much richer in FeO and TiO_2. For example, the ejecta deposits of Billy and Hansteen craters exhibit FeO values that range between 11% and 15%. If the Arrowhead was present prior to the Billy and Hansteen impact events, it should have been covered by FeO-rich ejecta from both craters. Since it was not, the Arrowhead was formed after these Imbrian-aged craters. This Red Spot was emplaced by highlands volcanism. Two near-IR spectra were obtained for Hansteen Alpha. Both have relatively shallow (3.7% - 4.1%) “1 µm” bands centered shortward of 0.95 µm.

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 Marian domes represent morphologically and spectrally distinct nonmare extrusive volcanic features of Imbrian age. Support for this interpretation was recently provided by Chevrel *et al.* [10].

The 0.5° x 0.5° Th map indicates that the Gruithuisen domes have Th values of about 8 ppm. Even higher Th values (10 to 12 ppm) are exhibited by highlands units northwest of the domes. Gamma and Delta exhibit FeO values between 6% and 10% and TiO_2 values <1%. The core portions of these domes have FeO abundances of 6% to 8% and very low (<0.5%) TiO_2 values. Near-IR spectra were collected for Gruithuisen Gamma and Delta. These spectra differ from those collected for typical highland areas in that they exhibit relatively broad bands centered at or longward of 1 µm.

Light Plains Deposits: Some light plains units for which a highlands volcanic origin had been proposed have now been demonstrated to be cryptomaria [e.g., 11, 12]. The best candidate for a light plains deposit that was emplaced by non-mare volcanism is the Apennine Bench Fm. Recent remote sensing studies have demonstrated that the chemistry and mineralogy of the Apennine Bench is consistent with KREEP basalt [e.g., 13].

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