REMOTE SENSING AND GEOLOGIC STUDIES OF THE BALMER REGION OF THE MOON. B. R. Hawke[1], J. J. Gillis[1], T. A. Giguere[2], D. T. Blewett[3], D. J. Lawrence[4], P. G. Lucey[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]Intergraph Corporation, 2828 Pa`a St., Honolulu, HI 96819, [3]NovaSol, 1100 Alakea Street, Honolulu, HI 96813, [4]Los Alamos National Laboratory, MS-D466, Los Alamos, NM 87545, [5]Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20723.

Introduction: The Balmer region is located just east of Mare Fecunditatis on the east limb of the Moon. The region is centered on the Balmer basin which is a pre-Nectarian impact structure that exhibits two rings, approximately 210 and 450 km in diameter [1, 2]. This impact basin played a major role forming the topography of the region. The interior of the basin exhibits extensive light plains deposits of Imbrian and Nectarian age [2, 3]. Wilhelms and El-Baz [3] described these light plains units as part of a Young Volcanic Province that may have been produced by an episode of non-mare volcanism. Support for this hypothesis was provided by Haines et al. [4]. These workers identified a Th enhancement associated with selected light plains deposits in the Balmer region.

Additional studies of the Apollo orbital chemistry data sets identified a variety of geochemical anomalies in the Balmer region [1, 5, 6, 7, 8]. The association of exogenic dark-haloed craters (DHCs) with light plains deposits that exhibit mafic chemical anomalies has been cited as evidence of ancient mare volcanism in the region [e.g., 5, 6, 7, 8, 9, 10].

We have used Clementine multispectral images, Lunar Prospector (LP) gamma ray spectrometer (GRS) data, and a variety of spacecraft imagery to investigate the composition and origin of geologic units in the Balmer basin region. The goals of this study include the following: 1) To search for geochemical anomalies in the region and determine their origins, 2) To identify and map the distribution of DHCs in the region, 3) To search for possible cryptomare and to investigate the processes responsible for their formation, 4) To determine the compositions and ages of any buried mare units, and 5) To investigate the origin of the light plains deposits in the Balmer region.

Methods: The U. S. Geological Survey's Astrogeology Program has published on CD-ROM a Clementine five-color UV-VIS digital image model (DIM) for the Moon [e. g., 11, 12]. Data from this DIM were mosaicked to produce an image cube in simple cylindrical projection centered on the Balmer basin. This calibrated image cube served as the basis for the production of a number of other data products, including optical maturity (OMAT) images and FeO and TiO_2 maps [e. g., 13, 14]. In addition, five-point spectra were extracted from the calibrated and registered Clementine UV-VIS image cube.

Three LP elemental abundance data sets were used. The half degree iron abundance data product contains data from the LP-GRS acquired during the low-altitude portion of the mission. A description of the reduction of this data set is given by Lawrence et al. [15, 16]. The 2 degree titanium abundance values were derived from LP-GRS measurements acquired during the high- and low-altitude portions of the mission. The reduction of the data is described by Prettyman et al. [17]. The 2 degree Thorium data were described by Lawrence et al. [18].

Results and Discussion:

Dark-Haloed Impact Craters. Several workers have identified a limited number of dark-haloed impact craters in the Balmer region and suggested that the basin was the site of ancient mare volcanism [e. g., 5, 6, 9, 10]. We have used Clementine 750 nm images to identify numerous dark-haloed craters (DHCs) in the Balmer region and 25 well-developed DHCs were selected for detailed analysis. Five-point spectra were extracted from the Clementine UV-VIS image cube for DHCs in the Balmer region. These spectra have moderately strong "1 μm" bands centered near 0.95 μm. The portions of the dark halos for which these spectra were obtained are dominated by mare basalts. FeO and TiO_2 maps produced from Clementine UV-VIS images were used to determine the compositions of DHCs in the Balmer region. The FeO and TiO_2 values range between 11.5% and 15.6% FeO and from 0.9% to 2.1% TiO_2. Clearly, a major expanse of cryptomare exists in and around the Balmer basin.

Cryptomare in the Balmer Region. Several workers have devised criteria for the identification of cryptomare [e. g., 5, 6, 8, 9]. A classification of evidence for cryptomare identification was presented by Antonenko et al. [8]. The major criteria are 1) the presence of dark-haloed impact craters, 2) association with mafic geochemical anomalies, and 3) the presence of a significant component of mare basalt in the high albedo surface unit as determined by spectral mixing analysis [19, 20]. We have used the location of DHCs as well as FeO and TiO_2 maps produced from Clementine images to determine the distribution of cryptomare in the Balmer region. Other evidence included the identification of mare basalt outcrops on crater walls and the occurrence of impact craters with partial or faint dark haloes which exhibit enhanced FeO abundances.

The mapped cryptomare in the Balmer region is restricted almost exclusively to the interior of the Balmer basin. The area within the inner basin ring is almost entirely mapped as cryptomare. The largest expanse of cryptomare is correlated with light plains of Imbrian and Nectarian age. Smaller areas of cryptomare occur beneath other highlands units such as large crater ejecta deposits. How thick are the cryptomare deposits in the Balmer region? The DHCs range in diameter from 1 km to 39 km. Most are less than 6 km in diameter. A conservative estimate of the maximum depth of excavation of lunar impact craters is 0.1 of the diameter [e. g., 21, 22]. Hence, most mare basalts were excavated from depths of < 0.6 km. However, some mare material may have been derived from depths as great as 3.9 km.

Because the most ancient mare basalts were formed by magmas generated by the earliest melting of the lunar mantle, chemical data for cryptomaria provide information concerning the composition of these early partial melts. Hence, we used the compositions of DHCs in the Balmer region to investigate the compositions of the buried basalt. The FeO and TiO_2 values obtained for the DHC ejecta deposits range between 11.5% and 15.6% FeO and from 0.9% to 2.1% TiO_2. Apparently, most of the buried mare basalts in the Balmer region are low TiO_2 basalts.

It is important to determine the ages of the buried mare basalts in the Balmer region. Most of the cryptomare on the interior of the Balmer basin are associated with light plains deposits of Imbrian or Nectarian age. Mare material was excavated by Kapteyn B, a Nectarian-aged impact crater. The evidence indicates that some mare basalts were emplaced in the Balmer basin during Nectarian time. Volcanism continued during Imbrian time before ending in the late Imbrian.

A mafic geochemical anomaly was identified in the Balmer region. LP-GRS FeO values for the Balmer basin range from 7% to 11%. These values are in good agreement with those measured using Clementine FeO images (7% - 12%). No anomaly was identified in the LP TiO_2 data for the Balmer region. A slight Th enhancement was noted in the LP Th data. Maximum values of 3 – 4 ppm are exhibited by portions of the region.

Processes Responsible for the Formation of Cryptomare. At Copernicus crater, highlands-rich, continuous ejecta covers underlying mare material, the existence of which has been confirmed by the presence of dark-haloed impact craters whose spectra clearly indicate that basaltic material has been excavated [e. g., 8, 23]. Cryptomaria that were formed by the burial of mare basalts by the thick, continuous deposits of a single, proximal impact crater are termed Copernicus-type because the relationship was first conclusively demonstrated at Copernicus crater. In the Balmer region, Copernicus-type cryptomare deposits are associated with Humboldt, Petavius, Palitysch B, La Perouse, and Langrenus craters.

At greater distances from an impact crater, mare basalt units may still be obscured by the compound effects of discontinuous, distal ejecta deposits of several nearby impact craters. The light plains units within Balmer basin are surrounded by 5 major impact structures. Calculations based on ejecta distribution equations as well as presence of secondary crater chains and clusters indicate that these impacts contributed significant amounts of highlands material to the Balmer plains units. The net result of the nearby impacts was the production of a thin surface layer enriched with variable amounts of highlands debris. Such a surface would exhibit a higher albedo than an uncontaminated regolith developed on mare basalt and would appear to be a light plains unit.

References:

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