ANCIENT VOLCANISM IN THE SCHILLER-SCHICKARD REGION OF THE MOON. B.R. Hawke[1], T.A. Giguere[2], D.T. Blewett[3], J.J. Gillis-Davis[1], J.J. Hagerty[4], D.J. Lawrence[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, Honolulu, HI 96822, [2]Intergraph Corporation, P.O. Box 75330, Kapolei, HI 96707, [3]NovaSol, 733 Bishop 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 region around the craters Schiller and Schickard, near the extreme southwestern limb of the Moon's Earth-facing hemisphere, contains numerous unusual features which have provoked controversy since the earliest days of lunar study. These include the crater Wargentin, whose floor is topographically higher than the surrounding terrain; the large crater Schickard (diameter 227 km), whose floor contains both mare and light plains deposits; the elongated crater Schiller; and a high density of dark-haloed impact craters. The association of exogenic dark-haloed craters (DHCs) with light plains deposits has been cited as evidence of ancient (pre-Orientale) mare volcanism in the region [e.g., 1,2,3,4,5,6,7,8].

We have used remote sensing data and a variety of spacecraft imagery to investigate the composition and origin of geologic units in the Schiller-Schickard (SS) region. The goals of this study include the following: 1) To identify and map the distribution of DHCs in the region, 2) To search for cryptomare deposits and to investigate the processes responsible for their formation, 3) To determine the compositions and ages of any buried mare units, 4) To investigate the origin of light plains deposits in the region, and 5) To search for geochemical anomalies and determine their origins.

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., 9]. Data from this DIM were mosaicked to produce an image cube centered on the Schiller-Schickard area. 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 [10,11]. Five-point spectra were extracted from the calibrated and registered Clementine UV-VIS image cube. In addition, Earth-based near-IR reflectance spectra obtained for DHCs were utilized in this investigation. [3,4,7].

Three Lunar Prospector (LP) gamma ray spectrometer (GRS) 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.* [12,13]. 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.* [14]. The 2-degree thorium data were described by Lawrence *et al.* [15].

Results and Discussion:

Dark-Haloed Impact Craters. Several workers have identified a limited number of DHCs in the SS region and suggested that the region was the site of ancient mare volcanism [e.g., 1,4,6,7,8,16]. We have used Clementine 750 nm images to identify numerous DHCs in the region, and 28 well-developed DHCs were selected for detailed analysis. Five-point spectra were extracted from the Clementine UV-VIS image cube for DHCs in the SS region. These spectra have moderately strong "1µm" bands centered near 0.95 µm. The portions of the dark haloes for which these spectra were obtained are dominated by mare basalts. FeO and TiO_2 maps produced from UV-VIS images were used to determine the compositions of DHCs in the SS region. The FeO and TiO_2 values range between 11.4 wt% and 15.3 wt% FeO and from 0.4 wt% to 3.0 wt% TiO_2. Clearly, a major expanse of cryptomare exists in the Schiller-Schickard region.

Cryptomare in the Schiller-Schickard Region. Several workers have devised criteria for the identification of cryptomare [e.g., 1,6,17,18]. A classification of evidence for cryptomare identification was presented by Antonenko *et al.* [6]. 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 [5,7]. 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 SS region.

Cryptomare occurs in most portions of the Schiller-Schickard region. The mapped cryptomare deposits extend from north of Lacus Excellentiae to Zucchius crater and from just east of Schiller to Inghirami crater in the west. Much of the interior of the Schiller-Zucchius basin contains cryptomare deposits. The largest expanses of cryptomare are correlated with Imbrian-aged light plains deposits and other highlands units thought to have been emplaced as a result of the Orientale impact event.

It is important to determine the ages of the buried mare basalts in the SS region. Since most of the cryptomare are associated with deposits emplaced by the Orientale basin, these buried basalts are Imbrian or older in age. At least one DHC appears to have excavated mare material from beneath the rim deposits of a pre-Nectarian crater, so at least some of the mare basalts could have been emplaced during pre-Nectarian time. Some of the cryptomaria in the SS region are related to the mare basalts that were emplaced after the Orientale event. These post-Orientale basalts have been obscured by highlands-rich ejecta from Zucchius and other craters.

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 the early partial melts. Hence, we used the composition of DHCs in the SS region to investigate the compositions of the buried basalts. After correction for highlands contamination, it was found that the pre-Orientale cryptomare deposits have TiO_2 abundances that range from 0.4 wt% to 2.6 wt%. Both VLT and low-TiO_2 mare basalts were emplaced in the SS region prior to the Orientale impact. The VLT basalts are concentrated in the southwestern portion of the study area. Post-Orientale cryptomare deposits have TiO_2 values that range from 1.5 wt% to 4.8 wt%. Since all of the DHCs exhibit FeO values <15.3 wt%, at least some high-alumina mare basalts may occur in the region.

A major mafic geochemical anomaly is associated with the Schiller-Schickard region. The LP-GRS FeO values for the SS cryptomare surfaces range between 7 wt% and 11 wt%. These values are in general agreement with those measured from Clementine FeO images (7-13 wt%). No major LP-GRS TiO_2 or Th anomalies were identified in the region. Spectral mixing analyses have suggested that major amounts of mare material were incorporated into the light plains units by local mixing during the emplacement of Orientale basin ejecta in the Schiller-Schickard region [5,7]. The LP-GRS FeO values (7-11 wt%) exhibited by the cryptomare surfaces in the SS region are consistent with a highlands-mare mixture.

Processes Responsible for the Formation of Cryptomare Deposits. The highland-rich, continuous ejecta of Copernicus crater covers underlying mare basalt flows. The existence of these buried mare units has been confirmed by the presence of dark-haloed impact craters whose spectra clearly indicate that basaltic material has been excavated [e.g., 4]. The occurrence of DHCs on the ejecta blankets of Theophilus, Maunder, and other large impact craters demonstrated that mare deposits are buried by their continuous ejecta deposits. Cryptomaria that were formed by the burial of mare units by the thick, continuous ejecta of a single impact crater are termed Copernicus-type cryptomare because the relationship was first conclusively demonstrated at Copernicus crater. In the SS region, a Copernicus-type cryptomare deposit is associated with the ejecta blanket of Hainzel A crater.

Far away from the continuous ejecta deposits of major impact craters, mare basalt flows can still be obscured by the compound effects of discontinuous, distal ejecta deposits of several nearby impact structures. Such a situation was identified by Hawke and Spudis [17] and Hawke *et al.* [18] near Balmer crater on the east limb of the Moon. They noted that the light plains units associated with crpytomare near Balmer are surrounded (within 250 km) by five major impact structures and several smaller craters. The net result of the nearby impacts was the production of a thin surface layer on top of the basalt flows that is enriched with variable amounts of highland material. Such a surface would exhibit a higher albedo than an uncontaminated regolith developed on mare basalt flows. A Balmer-type cryptomare deposit has been identified immediately west of Schiller crater in the SS region. Here, a post-Orientale mare deposit has been contaminated by highland-rich distal ejecta from Zucchius and other nearby craters.

When a cryptomare is located near a large impact basin, the ancient mare unit will be covered by a primary ejecta deposit that is thick and continuous. In proximal basin ejecta-type cryptomare, local mixing by secondary impacts will not be an important process, and the spectral signature of the buried mare unit will be swamped by primary basin ejecta. At greater distances from major impact basins, ejecta deposits will be thinner, and a larger percentage of local material will be incorporated into the resulting basin deposits by secondary cratering processes [19]. The combined effects of thin ejecta deposits and high percentages of incorporated local material allow the chemical and spectral signatures of cryptomare to be preserved [6,18]. Most of the cryptomaria in the Schiller-Schickard region are of the distal basin ejecta type.

References: [1] Schultz P. and Spudis P. (1979) *PLPSC 10*, 2899. [2] Schultz P. and Spudis P. (1983) *Nature, 302*, 233. [3] Hawke B. and Bell J. (1981) *PLPSC 12*, 665. [4] Bell J. and Hawke B. (1984) *JGR, 89*, 6899. [5] Head *et al.* (1993) *JGR, 98* (E9), 17,149. [6] Antonenko I. *et al.* (1995) *E.M.P., 69*, 141. [7] Blewett D. *et al.* (1995) *JGR, 100* (E8), 16,959. [8] Antonenko I. and Yingst R. (2002) *LPS XXXIII*, #1438. [9] Eliason E. *et al.* (1999) *LPS XXX*, #1933. [10] Lucey *et al.* (2000) *JGR, 105* (E8), 20,297. [11] Lucey *et al.* (2000) *JGR, 105* (E8), 20,377. [12] Lawrence D. (2001) *LPS XXXII*, #1830. [13] Lawrence D. (2002) *JGR, 107* (E12). [14] Prettyman T. *et al.* (2002) *LPS XXXIII*, #2012. [15] Lawrence D. *et al.* (2003) *JGR, 109* (E9). [16] Antonenko I. and Head J. (1998) *LPS XXIX*, #1880. [17] Hawke B. and Spudis P. (1980) *PCLHC*, 467. [18] Hawke B. *et al.* (1985) *E.M.P., 32*, 257. [19] Oberbeck V. (1975) *RGSP, 13* (2), 337.