REMOTE SENSING STUDIES OF ANCIENT MARE BASALT DEPOSITS. B. R. Hawke[1], T. G. Giguere[1], D.T. Blewett[1], P. G. Lucey[1], C. A. Peterson[1], G. J. Taylor[1], and P. D. Spudis[2], [1]Hawaii Institute of Geophysics and Planetology, University of Hawaii, Honolulu, HI 96822, [2]Lunar and Planetary Institute, Houston, TX 77058

Introduction: Cryptomaria are ancient (>3.8Ga) mare basalt deposits that are hidden or obscured by superposed higher albedo material [1,2,3]. As such, they represent a record of the earliest mare volcanism and may be a significant volumetric contribution to the lunar crust. Interdisciplinary studies have resulted in major advances in our understanding of ancient lunar volcanism. The purposes of this report are to examine the way that multiple data sets were used to investigate ancient lunar volcanism and to present the most recent results of our studies of cryptomare using Galileo and Clementine multispectral imagery as well as Lunar Prospector data.

Previous Sample, Remote Sensing, and Geologic Investigations: In the immediate post-Apollo era, the traditional view was that the onset of mare volcanism occurred at about 3.9 Ga [4]. Ryder and Taylor [5] first presented arguments that mare-type volcanism was initiated far earlier than 3.9 Ga and cited evidence provided by rare mare-type basaltic lithic and mineral fragments in highlands breccias. Hawke and Head [6] concluded that high-alumina mare basalts were emplaced in the Fra Mauro region prior to the Imbrium impact event. A wide variety of lunar sample data was analyzed by Ryder and Spudis [7] and they concluded that ancient mare volcanism started well before the terminal lunar bombardment. Subsequently, Taylor et al. [8] presented data for basaltic clasts in the Apollo 14 breccia 14305 which demonstrated that non-KREEPy, mare-type volcanism commenced at least as early as 4.2 Ga ago in the Fra Mauro region and possibly across much of the lunar surface.

Mare basalt deposits emplaced well before the end of the terminal bombardment would have been thoroughly reworked and mixed with highlands material [5,7,9]. While little morphologic evidence of these very early basalts would remain, their presence in highlands deposits could be expected to exert an influence on the remotely sensed surface compositions of the regions in which they were emplaced. Later mare basalts, extruded near the end of the terminal bombardment were less thoroughly disrupted and may have been only thinly buried by layers of highlands debris. Hartmann and Wood [10] pointed out that many highlands plains exhibit a lower albedo than the heavily cratered portions of the uplands. They hypothesized that ancient lavas flooded those areas before the end of the ancient intense bombardment and that subsequent cratering events were sufficient to cover these regions with a relatively thin veneer of highlands-rich debris. If so, mare material may have been excavated from beneath lighter surface units by dark-haloed impact craters.

Schultz and Spudis [11,12] have published the results of a major study concerning the identification, origin, and distribution of dark-haloed impact craters that had exposed mare basalts from beneath higher albedo surface units. They suggested that basaltic volcanism may have pre-dated the last major impact basins and that at least some lunar light plains may be early volcanic deposits which were subsequently buried by varying thicknesses of impact ejecta.

Analyses of the orbital geochemistry data have shown that some lunar regions have unusual abundances of certain elements relative to surrounding or adjacent areas, or have a surface chemistry unlike that which would be anticipated from the examination of local geologic relationships. Investigation of the formation of the geochemical anomalies can provide important clues to understanding volcanic processes operative during the early phases of lunar evolution. Hawke and Spudis [9] and Hawke et al. [13] demonstrated the lunar geochemical anomalies on the eastern limb and farside of the Moon (e.g., Balmer basin, NE of Mare Smythii, Langemak region, N of Taruntius) are commonly associated with light plains units which exhibit dark-haloed impact craters. Later, improved Apollo x-ray data were utilized to investigate cryptomare composition and distribution in the Undarum-Spumans and Smythii basin regions [2,14,15].

Hawke and Bell [16,17] presented results of spectral studies of dark-haloed impact craters in various portions of the lunar nearside. Both multispectral images and near-infrared reflectance spectra obtained with Earth-based telescopes were utilized. Since the spectral properties of lunar soils and rocks had been extensively investigated in the laboratory, it was possible to use Earth-based spectra to determine the composition of small areas on the surface of the Moon [18,19]. Analysis of near-infrared spectra clearly demonstrated that dark-haloed impact craters on the Moon have excavated mare basalt from beneath highlands-rich surface material. Hawke and Bell [16,17] suggested that a large but discontinuous mare similar to Mare Australe existed in the Schiller-Schickard region before the Orientale impact event and was covered with a layer of highlands debris as a consequence of the formation of Orientale basin.

Mustard et al. [20] and Head et al. [3] used spectral mixture analysis of Galileo SSI data to investigate the interaction between Orientale primary ejecta and pre-basin mare in the Schiller-Schickard cryptomare region. It was determined that major amounts of local mare material was incorporated into the Orientale ejecta deposit by secondary cratering in the Schiller-Schickard region. Blewett and co-workers [21] used Earth-based near-infrared spectra and multispectral imagery to provide additional support for the local mixing hypothesis. Antonenko and co-workers [2] are currently using Clementine images and other remote sensing data to investigate the Schiller-Schickard cryptomare. Both Earth-based and spacecraft spectral data have recently been utilized to study cryptomaria northwest of Mare Humorum and near Mare Crisium [e.g., 22,23]

Current Results: We are currently using Clementine UVVIS and Galileo SSI images as well as Lunar Prospector data to conduct detailed investigations of selected lunar cryptomaria. The techniques described by Lucey et al. [24,25] and Blewett et al. [25] were applied to calibrated Galileo SSI images in order to produce FeO and TiO_2 abundance maps for the lunar nearside. These maps have a spatial resolution of 1-2 km and were the primary data sets used in this study. Global Clementine FeO and TiO_2 maps with a variety of resolutions (1-35 km) were also used to investigate selected cryptomaria [24,25,26].

Northeast nearside (NEN) region. Dark-haloed impact craters occur on the extensive light plains deposits on the northeastern portion of the lunar nearside. Hence, ancient mare volcanism may have occurred in at least some parts of the NEN region. Gartner D is a small (dia.=8 km) with a partial dark halo which excavates material from beneath the surface of a light plains unit in the interior of Gartner crater. Two near-IR spectra obtained for Gartner D exhibit characteristics which clearly indicate that mare basalt was exposed by this impact event [27]. The Galileo iron map shows enhanced FeO values associated with Gartner D and other nearby impact craters.

A light plains unit was mapped in the area south of Hercules and Atlas craters by Grolier [28]. The spectrum for a dark-haloed crater south of Hercules indicates that mare basalt was excavated from beneath the highlands-rich ejecta blanket emplaced by the Hercules impact event [27]. Other impact craters in the vicinity excavated FeO-rich mare material from beneath the surface of the light plains unit. It appears that this light plains unit was produced by the contamination of a mare deposit with highlands-rich ejecta from Hercules and Atlas craters [29].

South Pole-Aitken (SPA) Basin. SPA is an immense impact structure that dominates the geology of much of the lunar farside. A mafic geochemical anomaly is associated with the interior of this giant basin [30]. The origin of this mafic anomaly is uncertain and it has been suggested that cryptomaria may play at least some role in producing the elevated FeO and TiO_2 values displayed by SPA interior deposits. We have identified two cryptomare deposits in the northern portion of the basin floor. The first is exposed by a 25 km diameter dark-halo impact crater located at ~39°S, 157°E. A circular zone of high TiO_2 and FeO values is centered on the crater and correlates with the dark halo [30]. It appears that major amounts of mare basalt were excavated from beneath a highlands-rich surface unit. The second cryptomare is associated with Davisson crater (80 km diameter, 38°S, 175°W). The floor of this crater was mapped as Imbrian-aged smooth light plains unit [31]. However, much of this floor material has FeO and TiO_2 values similar to those of nearby mare basalt deposits, indicating another probable cryptomare. We expect to locate additional cryptomaria on the SPA interior in the near future.

Cruger region. Numerous small impact craters have excavated a FeO-rich surface unit in the region east of Cruger crater (46 km diameter, 17°S, 67°W). The cryptomare in this region appears to be very thin and discontinuous.

Balmer region. In general, the Balmer cryptomare exhibits elevated FeO and TiO_2 values relative to the surrounding highlands. In addition, Lunar Prospector GRS data indicate that a small Th enhancement is associated with the interior of Balmer basin [32]. Some small, circular areas exhibit FeO values of 14-16% and correlate directly with dark-haloed impact craters. Many of these dark-haloed craters also exhibit elevated TiO_2 values [29]. It has been proposed that this region was the site of ancient mare volcanism and that the basaltic units were later covered by a thin higher albedo surface layer enriched in highlands debris contributed by surrounding large impact craters [13,14]. The existence of dark-haloed impact craters that exhibit elevated FeO and TiO2 values supports this proposal.

Southern central highlands. Most of the southern portion of the lunar central highlands exhibit FeO values that range between 5 and 9 wt.%. However, a small area with anomalously high FeO values has been identified near Maurolycus crater. The highest FeO values (13-15 wt.%) are centered on the dark-rayed crater Buch B (dia.=6 km) which is located on the rim and wall of Buch C. Lesser FeO enhancements are associated with the dark-rayed crater Maurolycus A (dia.=15 km) and Barocius M (dia.=17 km) which may also excavate dark material. However, it should be noted that none of these craters is located on a light plains deposit. We suggest that mafic intrusions were excavated from depth by the dark-rayed craters [29].

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