**GEOLOGICAL MAPPING OF THE LUNAR IMBRIUM IMPACT BASIN.** J. N. Murl, School of Ocean and Earth Science and Technology, University of Hawaiʻi at Mānoa, 1680 East-West Road, POST 502, Honolulu, HI 96822, jmurl@hawaii.edu; P. D. Spudis, Lunar and Planetary Institute, Houston, TX 77058, spudis@lpi.usra.edu; G. Y. Kramer, Lunar and Planetary Institute, Houston, TX 77058 ; kramer@lpi.usra.edu

**Introduction:** Geologic mapping and analysis are important tools to classify and interpret the complex surface geology of the planets. Subdividing surfaces into observable and meaningful stratigraphic units allows us to learn about relative ages, structures, formations, active and past processes. The collection of units represented on a geologic map provide a foundation for future analysis and understanding on planetary to fine scale that are not realistically possible with only ground work. The high costs of human and robotic missions to extraterrestrial locations necessitate remote geologic mapping and analysis to ensure the extraction of maximum information.

The accuracy of geologic mapping is dependent on the resolution and variety of data available and the ability to combine data with current geologic knowledge. The existing geological map of the near side of the Moon was published in 1971 using terrestrial telescopic photographs, supplemented by Lunar Orbiter IV images [1]. The purpose of this project was to update the geological map and estimate the petrological and geochemical composition of Imbrium basin deposits and locate likely exposures of accessible basin deposits for possible sampling of future human and robotic missions. We mapped an area centered around the deposits of the Imbrium basin, north of Imbrium basin clockwise from 80° north to the western edge of Mare Crisium to Mare Nubium in the South. We used high-resolution imaging and data from the Lunar Reconnaissance Orbiter Camera (LROC), the Lunar Orbiter Laser Altimeter (LOLA), Clementine, and Chandrayaan-1 Moon Mineralogy Mapper ($M^3$).

This updated map refines the units previously established and mapped by Wilhelms and McCauley [1]. For example, the Alpes Formation from the Imbrium basin is more extensive than previously shown. Additionally, we have identified new areas of possible Imbrium basin impact melt and analyzed surface FeO, $TiO_2$, and Th composition of mapped units. Lastly, we have analyzed the vertical composition of units by using the ejecta of superposed craters as natural “drill holes” into the deposits.

**Methods:** The LROC Wide Angle Camera (WAC) and GLD 100 topography image mosaics, at 100 meters per pixel, were orthographically projected from the center of Imbrium basin using USGS Integrated Software for Imagers and Spectrometers (ISIS). These images served as the base-map and topographic layer in ArcGIS 10.1. The LROC Narrow Angle Camera (NAC) images in combination with the WAC base-map and LOLA topography were used to identify geologic units based on surface texture, structure, and stratigraphic position. The LROC data give us vastly superior image resolution as compared to Lunar Obiter IV and terrestrial telescopic photographs. Additionally, Clementine FeO and $TiO_2$ (wt. %) [2] and Lunar Prospector Th (ppm) maps [3] were orthographically projected at 200 meters per pixel and added as layers to the base-map to assist in unit identification of morphologically similar areas by compositional abundance. This updated map used the same unit names and color scheme of [1] to maintain consistency and alignment with current lunar maps. New and previous units were re-mapped based on their morphology and composition, not simply because they were mapped in a location on previous maps.

The units of initial interest are the Imbrium basin ejecta deposits (Alpes and Fra Mauro Formations), Apenninus material, the pre-Imbrian massifs, and the possible basin impact melts. The electronic stencils of these units were placed on the Clementine FeO, $TiO_2$ and Lunar Prospector Th maps and the zonal statistics tool of ArcGIS 10.1 was used to calculate the mean and standard deviation of the pixel values inside the unit stencils. This provided an overall compositional average and deviation for the surface of each mapped unit. Vertical variations in the units’ composition were determined by mapping superposed crater ejecta in a unit stencil and performing the same zonal statistic calculations. The individual crater diameters were graphed as a function of crater ejecta mean composition. Larger craters excavate deeper material [4]. Comparing compositional differences in large vs. small craters gives us a window into the vertical composition of surface unit.

**Results:** In broad terms, the mapped units are similar to those shown on the previous map of the near side of the Moon [1] with the exception of the Alpes Fm. being discovered extensively outside of the Imbrium basin, which can be observed in Figure 1. Specifically, we have found Alpes Fm. from 800 to 1000 km to the north, east, and south of the edge of Imbrium basin. Additionally, we have subdivided some of the Alpes Formation based on influences of other material such as pyroclastic, dark ash (located on the west to southwest rim of Mare Serenitatis) and smooth plains material (located east of Mare Insularum) being deposited on top of Alpes Fm. The areas of possible basin impact melt have been identified near Montes Apenninus at 21.2°N, 1.7°W and on the floor of Murchison at 5°N, 0.6°W and few additional areas (see also companion abstract by Spudis et al., this vol.)

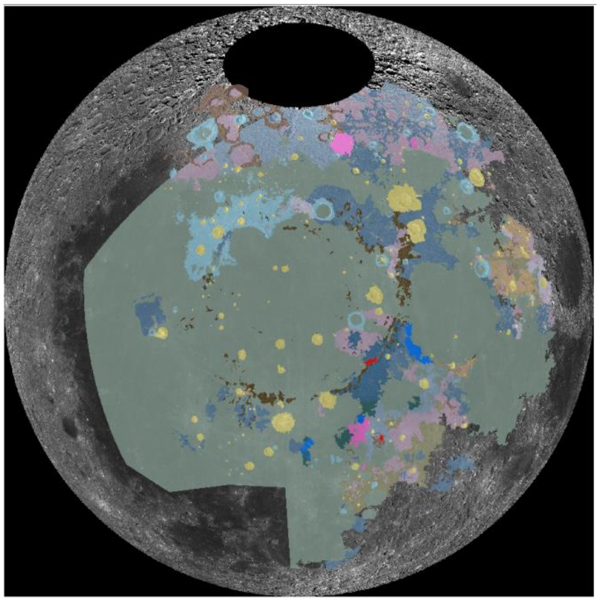

**Figure 1.** Updated map centered on Imbrium basin. Imbrium basin units are shades of blue, basin impact melt is red, massifs in dark brown, plains in pink, mare in green and post-mare craters in yellow.

Clementine and Lunar Prospector surface compositions for different ejecta units are shown in Table 1. The mean values represent the overall average for a geologic unit's FeO (wt. %), $TiO_2$ (wt. %), and Th (ppm). This was then compared to the individual stencil mean compositions.

| Geologic Unit | FeO wt % | $TiO_2$ wt % | Th ppm |
|---|---|---|---|
| Alpes | 10.0 ± 3.4 | 1.2 ± 1.2 | 4.8 ± 2.6 |
| Apenninus | 11.7 ± 1.9 | 1.7 ± 1.0 | 7.5 ± 1.7 |
| Fra Mauro | 8.4 ± 4.0 | 1.2 ± 1.7 | 4.2 ± 2.2 |
| Massifs | 11.2 ± 3.0 | 1.4 ± 1.0 | 6.4 ± 2.8 |
| Impact Melts | 12.0 ± 1.2 | 1.2 ± 0.4 | 6.7 ± 0.1 |

**Table 1.** FeO, $TiO_2$, and Th Concentrations for Imbrium Basin geologic units

The composition of ejecta from craters excavating one of the larger Alpes Fm. as a function of the youngest crater diameters, presumably excavating material from depth. Results suggest no significant variation of chemical composition with depth.

The spectral data from $M^3$, of fresh crater walls on the Alpes Fm., shows the dominant mineral type as orthopyroxene with varying amounts of calcium, suggesting a broadly noritic composition, in agreement with several previous studies (e.g., [5]).

**Conclusions:** Ejecta from the Imbrium basin is different from the similarly sized Orientale basin in both the distribution of units and their composition. The knobby Alpes Fm. of Imbrium is similar to the Montes Rook Fm. of Orientale but the Alpes Formation can be found as far as 1000 km from the basin rim while Montes Rook Fm. extends no more than 200 km from the basin's Cordillera rim. The Montes Rook Fm. has a surface composition much more feldspathic [6] than the Alpes Fm. (Table 1).

The composition reveals that units are generally homogenous within the expansive Alpes Formation. However, the effects of mixing of maria, plains, and highland materials are evident. These smaller mixed units could be broken down into subgroups in the future. The units more distant from the basin rim are more feldspathic than the units closer. This relation suggests that the Imbrium impact excavated predominantly mafic material to the southwest and feldspathsic material to the north and south east. However, additional mapping of the western part of basin deposits is needed.

The vertical composition of basin ejecta deposits was estimated from crater ejecta on four of the largest Alpes Fm., one on Fra Mauro Fm., and one on Apenninus material. Every unit indicates that the vertical composition is (more or less) homogenous. The $M^3$ was only fully analyzed for 1 of the Alpes Fm. and it shows low-Ca pyroxene to be the principal mafic mineral present.

Interestingly, the Taurus-Littrow area around Apollo 17 has also been partly covered by Alpes Fm. [7]. The surface composition suggests mixing of local material with Imbrium basin Alpes Fm. A re-examination of the geology of the Apollo 17 landing site looking for Imbrium ejecta might be a fruitful avenue of research.

**References:** [1] Wilhelms D. E. and McCauley J. F. (1971) *USGS* map I-703. [2] Lucey P.G. et al. (2000) *JGR* **105**, 20297. [3] Lawrence D. et al. (2007) *GRL* **34**, 3, doi: 10.1029/2006GL028530 [4] Spudis P.D. (1993) *Geology of Multi-Ring Impact Basins* Cambridge Univ. Press. [5] Spudis P.D. et al. (1988) *PLPSC* **18**, 155. [6] Spudis P.D. et al. (2014) *JGR* **199**, doi: 10/1002/2013JE004521. [7] Spudis P.D. et al. (2011) *JGR* **116,** doi:10.1029/2011JE003903