THE LUNAR GEOLOGIC MAPPING PROGRAM AND STATUS OF COPERNICUS QUADRANGLE MAPPING.

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Introduction: A pilot lunar geologic mapping program is underway [1-3], with funding from the NASA Planetary Geology and Geophysics Program. Supported by newly available digital data, we are mapping a quadrangle at 1:2.5M scale that centers on Copernicus crater [4-6]. The goal is to demonstrate integrated use of these data for geologic unit mapping on the Moon. For more information and periodic updates, please see: http:://astrogeology.usgs.gov/Projects/PlanetaryMapping/Lunar/

Mapping Scheme and Scale: Use of digital map bases means that identification of map scale and layout scheme for global mapping is adaptable and less restrictive than in the past. However, a uniform scale is needed for systematic mapping, and that scale must take into account differences in available image resolution and quality for various regions. For example, Lunar Orbiter (LO) frames are ~60 m/pixel for the near side and up to 400 m/pixel for the far side. If one assumes an 'average' pixel resolution of 200 m/pixel for the upcoming LO global mosaic, then a common mappers' 'rule of thumb' suggests ~10 pixels/mm as optimal resolution for mapping with digital data. At the 1:2.5 M scale of this lunar mapping program, the mapping resolution translates to 12.5 pixels/mm, or slightly better than optimal.

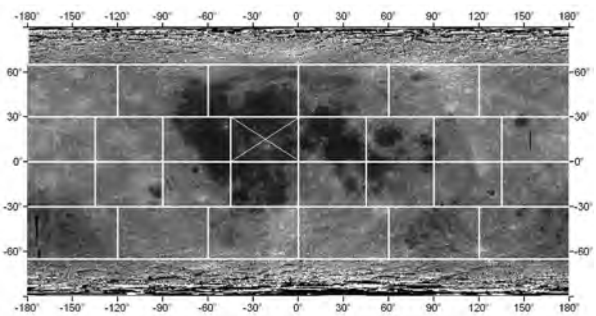

Figure 1. *Mapping scheme for lunar geologic maps at 1:2.5 M scale. The Copernicus quadrangle is marked with an X. Image base is Clementine 750-nm albedo.*

The 1:2.5M scale was considered 'ideal' for lunar geologic mapping [7], and it divides the Moon into 30 quadrangles (**Figure 1**). Polar regions are mapped in polar stereographic, latitudes between 30˚ and 60˚ in lambert conformal conic, and equatorial quads in mercator projections. At this scale mappers can survey major geologic units, refine unit boundaries and types, apply new unit names and contact types where necessary, and map major structures. Quadrangle maps at this scale also print at the relatively convenient size of ~21.5"x15" without text.

Geologic Setting: The Copernicus quadrangle contains impact craters and ejecta material from Copernicus (94 km dia.) and Eratosthenes (58 km dia.) craters, both type localities of impact crater-related units that formed the basis for the original lunar stratigraphic mapping by Shoemaker [4] and others [5, 6]. The quadrangle contains Lower Imbrian basin-related materials (Alpes and Fra Mauro Fms.), Upper Imbrian mare basalts and pyroclastic deposits (Mare Insularum, Sinus Aestuum, and marginal Mare Imbrium), Eratosthenian mare basalts (central Mare Imbrium) and crater materials, and Copernican impact and related deposits. With the stratigraphy of Wilhelms [8] as a starting point, we are using color and maturity information from Clementine to identify highland, volcanic, and crater-related units. One emphasis of this work is a local and regional characterization and refinement of the boundary between time-stratigraphic units of the Copernican and Eratosthenian Periods using optical maturity data [9]. Preliminary mapping shows a substantially more diverse—both compositionally and temporally—and complex series of geologic units than were previously mapped in the Copernicus quadrangle.

Data and Methods: We processed, orthorectified, and co-registered data using image processing (ISIS) and GIS (ArcMAP) platforms. All geologic digitization was completed in an ESRI "geodatabase" format. Basemaps include a LO-IV regional photomosaic (60 m/px; [10-12]), Clementine UVVIS (100 m/px, [13]) and NIR data (500 m/px, [14]), Clementine topographic data (1 km/px, [15]), Earth-based 3.8 cm radar (3.1 km/px; [16]), as well as Clementine-derived optical maturity (OMAT; [17, 18]) data. We also use high (9 m/px) and very-high (1.3 m/px) resolution LO-IV frames of the Copernicus crater floor, wall, and central peak [12].

Preliminary Mapping Results:

Highland units. Most highland units are associated with the formation of Imbrium basin and re-dictribution of Nectarian materials. Clementine color data (esp. 950/750 nm) show potential pre-Imbrium (Nectarian) geologic units among pre-Imbrium highland deposits in the Montes Apenninus as well as lower sequences of Sinus Aestuum and Medii.

Mare units. Clementine color and OMAT data show that some mare basalts previously mapped as continuous units have significant variations in color, ferrous iron and titanium contents, and/or local optical maturity [18, 19]. Preliminary mapping of stratigraphic and geologic unit boundaries of maria and pyroclastics reveals a larger number of and more compositional diversity among these deposits than had been previously recognized.

Crater units. Clementine data show substantial variation in optical maturity and in reflectance and morphology among crater-related deposits from Copernicus and

Eratosthenes craters, particularly at the 2780-nm (NIR) wavelength. For example, the northwest crater wall and ejecta of Copernicus have significantly elevated 750-nm values, suggesting local excavation and redistribution of a relatively bright, iron-poor material, possibly derived from Imbrium basin massifs. Eratosthenes crater, which partly overlies Imbrium basin massif materials, shows a somewhat subdued color variation, suggesting that the northernmost ejecta may contain excavated pre-Imbrium (Nectarian) basement rocks. Ejecta from smaller craters that impacted mare basalts, particularly near mare/highland boundaries, also show distinct color and local optical maturity properties. These relationships suggest that we are mapping a greater diversity of crustal materials in association with impact craters than previously mapped.

Using stratigraphic tools and terminology developed and implemented for terrestrial planets [20-22], we have produced a preliminary geologic map that minimizes subjective bias in unit delineation and characterization (**Figure 2**). These approaches incorporate recent advances in the use of optical maturity values to characterize stratigraphic boundaries and sequences [9, 18, 23], and are resulting in a refinement of the nature and timing of the Copernican/Eratosthenian boundary.

Pyroclastic materials. A fourth unit is comprised of significant deposits of pyroclastic materials [24]. Clementine color data suggest that these materials are high in iron and titanium content and they may be more spatially extensive than previously mapped. The lack of preserved impact craters and curious stratigraphic relationships with highland and mare units make this an interesting region to study with spectral datasets.

Summary: Our Copernicus quadrangle project marks the initiation of a new lunar geologic mapping program that takes full advantage of robust, new data and analytical methods to further advance our understanding of lunar geology. Expected results of this project include (1) a systematic lunar mapping scheme, (2) a tested method for formatting and releasing digital lunar map bases, (3) a geologic map of the Copernicus quadrangle for publication as a USGS SIM-map, and (4) a lunar geologic mappers' handbook with recommendations on the integration of spectral color, chemistry, mineralogy, elevation, morphology, etc. in the identification and interpretation of lunar geologic map units. These products will be placed online at the aforementioned Web site as resources for prospective lunar geologic maps at scientifically interesting areas on the Moon.

References: [1] Gaddis et al., 2005, LPSC XXXVI, #2021. [2] Gaddis et al., 2005, Abst. Plan. Mappers Mtg., USGS OFR 2005-1271. [3] Gaddis et al., 2005, GSA Ann. Mtg., Abs. 514-4. [4] Shoemaker and Hackman, 1962, Symp. 14 IAU, 289. [5] Schmitt et al., 1967, USGS I-515. [6] Wilhelms and McCauley, 1971, USGS I-703. [7] Wilhelms, 1972, USGS Interagency Report: Astrogeology 55, 36 pp. [8] Wilhelms, 1987, USGS Prof. Paper 1348, 302 pp. [9] Hawke et al., 2005, Abst. Plan. Mappers Mtg., USGS OFR 2005-1271, and this volume. [10] Gaddis et al., 2003, LPS #1459. [11] Becker et al., 2005, LPSC XXXVI, #1836. [12] Weller et al., this volume. [13] Eliason et al. 1999, PDS_CL_4001 to _4078. [14] Gaddis et al., 2005, NIR PDS archive, in prep. [15] Rosiek et al., 2002, LPSC XXXIII, #1792. [16] Zisk et al., 1974, Moon, 10, 17. [17] Lucey et al., 2000, JGR 105, 20377. [18] Wilcox et al., 2005, JGR-P 110, E11001. [19] Hiesinger et al. 2003, JGR 108(E7). [20] North American Stratigraphic Code 1983, AAPG Bull. 67, 841-875. [21] Skinner and Tanaka 2003, LPSC 34th, abs. 2100. [22] Wagoner et al. 1988, SEPM Spec. Pub. No. 42. [23] Grier et al. 2001. JGR 106, 32847-32862. [24] Gaddis et al., 1985, Icarus 61, pp. 461-488.

Figure 2. *Preliminary geologic map of the Copernicus Quadrangle. Image base is a Lunar Orbiter photomosaic at 60 m/pixel.*