LUNAR GEOLOGIC MAPPING: PRELIMINARY RESULTS FOR THE COPERNICUS QUAD.

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Introduction: We describe prelimary 1:2.5 M scale geologic map results of the Copernicus quad as part of a new pilot program for systematic, global lunar geologic mapping (***Figure 1***). This program continues the systematic lunar geologic mapping efforts that ended almost 30 years ago during the Apollo era.

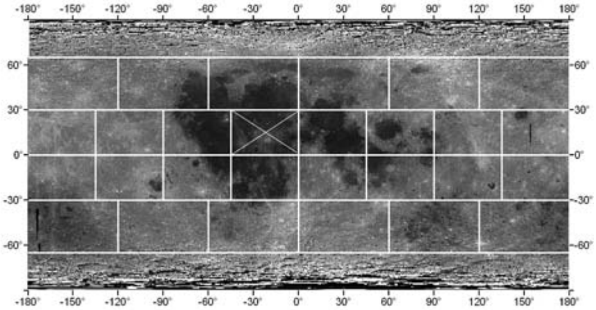

Figure 1. *Mapping scheme for lunar geologic maps at 1:2.5 M scale. The Copernicus Quad is marked with an X. Image base is Clementine 750-nm albedo.*

Background: In the late 1960's, 44 geologic maps at 1:1 M scale were made based on the Lunar Orbiter photographs (1 to 500 m resolution; [1]), including a geologic map of the Copernicus Quadrangle [2]. These maps were followed by a series of 1:5 M global geologic maps [3-8]. The stratigraphic basis for lunar geologic mapping was established by Shoemaker and Hackman [9]. These authors applied well-established stratigraphic principles to the materials observed in and near Copernicus crater (~90 km dia.). The 'Copernicus quandrangle' thus became the type area from which major lunar stratigraphic units could be traced over broad regions of the Moon.

Lunar geosciences have been significantly advanced since the original geologic maps were compiled [e.g., 10]. Wilhelms has presented a revised lunar stratigraphy (***Table 1***) that has become the standard for lunar geologic maps. This stratigraphy forms the basis of our revised mapping of the Copernicus quad.

Methods: We digitally process datasets and lay geologic linework using ESRI's ArcGIS software package supplemented by Adobe Photoshop and Illustrator and the USGS ISIS software [11-13]. The primary bases for the Copernicus quad are the controlled Clementine global mosaic of "albedo" at 750-nm [14] and Lunar Orbiter IV (LO-IV) image mosaics. These robust bases are supplemented by multispectral Clementine UVVIS and NIR data, as well as Clementine UVVIS and NIR spectral and color-ratio data. Additional image bases include co-registered Lunar Orbiter frames [15] and Clementine global topography and shaded relief data [16], as well as digital versions of previous geologic maps. Derived compositional maps include optical maturity (OMAT), and FeO and TiO_2 content [17-23] as well as LP measured elemental abundance maps [21, 24-28].

Table 1. Lunar Time-Stratigraphic Units

PERIOD	EVENTS	AGE (BY)
Copernican	Fresh rayed craters, minor maria	1.2 to present
Eratosthenian	Slightly degraded craters, significant maria	3.2 to 1.2
Late Imbrian	Most maria	3.75 to 3.2
Early Imbrian	Imbrium and Orientale basins, Cayley plains, degraded craters	3.85 to 3.75
Nectarian	Nectaris and other basins, degraded craters, some light plains	3.92 to 3.85
Pre-Nectarian	Degraded basins and craters, volcanic and intrusive igneous rocks, megaregolith and crust	Before 3.92

Manipulation of these digital data has dominated the early phases of this work. The regional extent, relatively high spatial resolution, and surface morphologic and textural information make the coregistered Clementine (8, 16, and 32-bit multi-band and mixed band datasets) and LO-IV image mosaics the best data for quadrangle-wide geologic and stratigraphic assessments. These data are supplemented by LO-V medium- and very-high resolution (1 to 30 m) digital photos of the Copernicus crater central peak, floor, walls and rim, and proximal ejecta facies [29]. Coregistration of supplemental data using ISIS and ArcGIS place the data within 2 km of controlled, match images (this value may be improved by further warping of separate layers). Digital versions of previous geologic maps are helpful in outlining broadly occurring geologic units while illustrating the utility of Clementine color data in revealing geologic relationships unobservable in previously used image bases (***Figure 2***).

Geologic Mapping: The 1:2.5M scale Copernicus quadrangle encompasses a lunar geologic and stratigraphic 'crossroads', as it contains units of southern Mare Imbrium, eastern Oceanus Procellarum, basin margin and related highland materials, and Copernicus

(93 km dia.) and Eratosthenes (58 km dia.) craters, the type craters for two major lunar stratigraphic time periods. Geologic units in the Copernicus quad include Lower Imbrian, basin-related materials (Alpes and Frau 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. Reconnaissance geologic mapping has begun with characterization of morphologic and superposition relations among these surficial units. Emphasis is being placed on identification and characterization of units formed during major geologic periods (e.g., albedo at 750-nm, UVVIS and NIR color and color-ratio values, soil maturity, Fe and Ti content). Initial work has emphasized the delineation of geologic contacts and facies in the vicinity of Copernicus and Eratosthenes craters based on their regional stratigraphic prominence. Geologic contacts mapped in the vicinity of these units are being extended into southern Imbrium basin and surrounding regions. Geologic mapping continues within the plains, highlands, inter-crater regions, and is galvanized by the identification of major structural features.

***Figure 2**. Copernicus crater (93.0 km, 9.7N, 20.1W). Co-registered LO IV (Frames 126H2 & 121H2) and Clementine color ratio data (R=750/415; G=750/950; B=415/750).*

Results: Our investigation and characterization of geologic units in the Copernicus quad focuses on several major lunar science topics: (1) characterization and possible redefinition of the Copernican/Eratosthenian (C/E) boundary through analysis of soil maturity (i.e., OMAT) data for crater ray presence/absence, brightness, continuity, and distribution [30]; (2) geomorphologic and textural examination and subdivision of units in the Copernicus crater floor, wall, rim, and ejecta blanket based on color diversity among and within units. These observations likely reflect compositional diversity in target material rather than large differences in soil maturity, and indicates that Clementine color data is a key tool in mapping previously unrecognized geologic units such as multiple impact melt facies, central peak units, and/or possible excavated deposits of ancient (pre-Nectarian or Nectarian) basin-related materials; (3) examination of the nature and distribution of volcanic deposits, particularly in Sinus Aestuum (SA), and the relationship of these materials to deposits outside of the quadrangle (e.g., at Rima Bode to the east). Detailed compositional mapping of deposits from dark-halo craters in SA may help to identify older volcanic craters (possible vents) and mare units with which the surficial units at Rima Bode were originally associated.

Summary: Although centered at the Copernicus quadrangle, this project marks the initiation of a reinvigorated lunar geologic mapping program that takes full advantage of robust, new datasests and analytical methods to further advance the our understanding of lunar geology. The anticipated results of this study 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 quad, submitted for publication as a USGS I-map, and (4) a draft lunar geologic mappers' handbook with recommendations on the integration of spectral color, chemistry, mineralogy, elevation, morphology, etc. in the identifycation and interpretation of lunar geologic map units. These products will be established foremost as resources for prospective lunar geologic maps at scientifically interesting areas.

References: [1] Bowker and Hughes, 1971, NASA SP-206. [2] Schmitt et al., 1967, USGS I-515 (LAC-58). [3] Wilhelms and McCauley, 1971, USGS I-703. [4] Lucchitta, 1978, USGS I-1062. [5] Wilhelms et al., 1979, USGS I-1162. [6] Wilhelms and El-baz, 1977, USGS I-946. [7] Scott et al., 1977, USGS I-1034. [8] Stuart-Alexander, 1978, USGS I-1047. [9] Shoemaker and Hackman, 1962, Symp. 14 IAU, 289. [10] Wilhelms, 1987 USGS Prof. Paper 1348, 302 pp. [11] Hare and Tanaka, 2001a, LPS XXXII, #1725. [12] Hare and Tanaka, 2001b, Planetary Mappers Meeting, Albuquerque, NM. [13] Hare et al., 2003 ISPRS 2003, LPI. [14] Eliason et al., 1999, LPS XXX, #1933. [15] Becker et al., this volume. [16] Rosiek et al., 2002, LPS XXXIII, #1792. [17] Lucey et al., 1995, Science 268, 1150. [18] Lucey et al., 1998, JGR 103, 3679. [19] Lucey et al., 2000a, JGR 105, 20,297. [20] Lucey et al., 2000b, JGR 105, 20,377. [21] Lawrence et al., 2002, JGR 107, 2001JE001530, 13-1. [22] Elphic et al., 2000, JGR 105, 20,333. [23] Gillis et al., 2003, JGR 108, 3-1. [24] Lawrence et al., 1998, Science 281, 1484. [25] Lawrence et al., 2000, JGR 105, 20,307. [26] Prettyman et al., 2002a, LPS XXX, #2012. [27] Prettyman et al., 2002b, Moon Beyond 2002, Taos, N.M., #3069. [28] Feldman et al., 2002, JGR 107, E3, 10.1029/2001JE001506. [29] Becker, T. et al., this volume. [30] Hawke et al., this volume.