

THE PILOT LUNAR GEOLOGIC MAPPING PROJECT: SUMMARY RESULTS AND RECOMMENDATIONS FROM THE COPERNICUS QUADRANGLE. J. A. Skinner, Jr., L. R. Gaddis, and J. J. Hagerty, Astrogeology Science Center, U.S. Geological Survey, 2255 N. Gemini Drive, Flagstaff, AZ 86001 (jskinner@usgs.gov).

Introduction: The first systematic lunar geologic maps were completed at 1:1M scale for the lunar near side during the 1960s using telescopic and Lunar Orbiter (LO) photographs [1-3]. The program under which these maps were completed established precedents for map base, scale, projection, and boundaries in order to avoid widely discrepant products. A variety of geologic maps were subsequently produced for various purposes, including 1:5M scale global maps [4-9] and large scale maps of high ‘scientific interest’ (including the Apollo landing sites) [10]. Since that time, lunar science has benefitted from an abundance of surface information, including high resolution images and diverse compositional data sets, which have yielded a host of topical planetary investigations.

The existing suite of lunar geologic maps and topical studies provide exceptional context in which to unravel the geologic history of the Moon. However, there has been no systematic approach to lunar geologic mapping since the flight of post-Apollo scientific orbiters. Geologic maps provide a spatial and temporal framework wherein observations can be reliably benchmarked and compared. As such, a lack of a systematic mapping program means that modern (post-Apollo) data sets, their scientific ramifications, and the lunar scientists who investigate these data, are all marginalized in regard to geologic mapping. Marginalization weakens the overall understanding of the geologic evolution of the Moon and unnecessarily partitions lunar research.

To bridge these deficiencies, we began a pilot geologic mapping project in 2005 as a means to assess the interest, relevance, and technical methods required for a renewed lunar geologic mapping program [11]. Herein, we provide a summary of the pilot geologic mapping project, which focused on the geologic materials and stratigraphic relationships within the Copernicus quadrangle (0-30°N, 0-45°W).

Geologic Setting: The Copernicus region is dominated by high-albedo units of the young (~0.8 Ga) Copernicus crater. These units are superimposed on older basin rim and ejecta units of Imbrium basin (highlands of Montes Carpatius), as well as old or intermediate-aged highlands, mare, pyroclastic, and impact crater (e.g., Eratosthenes, diam. 58 km) units. Mapped geologic units within the quadrangle include the Lower Imbrian materials of Imbrium basin (Alpes and Fra Mauro Fms.), Upper Imbrian mare basalts, cones, dark-halo craters, and pyroclastic deposits (Mare Insularum, Sinus Aestuum, and SE Mare Im-

brium), Eratosthenian mare basalts (central Mare Imbrium) and crater materials, and young Copernican impact and related deposits. Previous geologic maps (at various scales), and numerous topical studies, have detailed the origin, distribution, and composition of geologic units within this region [e.g., 12-14].

Data and Methods: We processed, orthorectified, and coregistered data using image processing and geographic information system software. Geologic mapping layers included a LO-IV photomosaic (60 m/px; [e.g., 12]), Clementine 5-band ultraviolet and visible range mosaics (100 m/px, [13]), 6-band near infra-red data (500 m/px, [14]), derived maps of iron [15] and titanium, Clementine-derived topographic data [16], Earth-based 3.8 cm radar (3.1 km/px; [17]), and optical maturity (OMAT) [18]) data. We also used 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]. We did not define a particular data set as the dedicated geologic base map so that we could independently evaluate each in regard to unit delineation.

All digitization was completed in a geodatabase format to simplify data compilation, vector attribution, topological cleaning, interlayer analyses, and data sharing. Vector linework was digitally streamed between 1:500K (20% of the publication map scale) and 1:1.25M (50% of publication map scale) in order to assess sufficiency in detailing geologic contacts and features for both hard-copy and digital map publications. Linework was streamed directly into a GIS database in Mercator projection using a digital mapping tablet. The placement of vertices varied from 500 to 1250 meters (1 vertex per 1 mm at digitizing map scale). Attributes were assigned using attribute domains stored within the geodatabase, which was iteratively refined and updated over the course of the project. Geologic map symbols were derived from FGDC Digital Cartographic Standards for Geologic Map Symbolization and adapted where necessary to convey the geologic information unique to the quadrangle.

Results: The iterative and exploratory approach that we employed for the pilot mapping project provided scientific and technical observations that significantly expanded the results afforded by previous lunar mapping efforts. These include:

- Spectral data permit us to advance beyond “morphostratigraphic” mapping, allowing units to be divided by morphology and spectral characteristics.
- Stratigraphic relationship takes precedence over compositional or morphologic characteristic. For ex-

ample, we use "Ccr_a--Copernican-age, crater unit, rim sub-unit, member a" versus "Ccrh--Copernican-age, crater unit, rim sub-unit, hummocky member."

- Broad heterogeneity in optical maturity, reflectance, and morphology of Copernicus wall, floor, and ejecta units suggests that materials have diverse composition and, in some locations, were not intimately mixed during crater formation.
- Local 'KREEP-rich' rock unit is not present in Copernicus due to a lack of thorium enrichment.
- The northernmost ejecta of Imbrium basin may contain materials from excavated pre-Imbrium (Nectarian) basement rocks, based on rocks exhumed by Eratosthenes crater, which partly overlies highlands units of Imbrium basin rim deposits.
- Clementine-derived OMAT data allow for the stratigraphic re-evaluation of some small-diameter impact craters (including Aristillus, Autolycus, Tarantius, O'Day, Eudoxus, and Pytheas). However, the derivative nature of OMAT data does not allow them to supersede cross-cutting relationships and crater counts, where available, for stratigraphic subdivision.
- Ruled and dashed patterns are helpful in indicating unit subdivision based on color variations within a single geologic unit.
- Minor secondary scatters and chains are identified by a crater ray pattern, though overlapping rays of Copernicus, Kepler, and Aristarchus craters are not differentiated within the mapped ray patterns. We do not discriminate secondary rays, craters, or materials when they superpose primary rim materials of the parent impact.

Recommendations: The results of the pilot lunar geologic mapping project serve to outline the critical pathway for formalized and systematic lunar mapping. These results guide our recommendations on the strategic approach of a renewed lunar geologic mapping program.

- Renewed geologic mapping should follow a 1:2.5M scale mapping scheme that subdivides the lunar surface into 30 discrete quadrangles using three different and latitude-specific projections. The scheme sufficiently balances the areal coverage and scale of modern (post-Apollo) data sets with those previously used as base maps and we determined that it was appropriate for hard-copy and digital publication.
- Lunar mappers should employ a strategic approach that recognizes the uniqueness of the lunar surface relative to other planetary bodies and should consciously divide primary (base map) and supplemental (descriptive) data sets. The volume, type, resolution, and areal diversity of available data requires

preference and down-selection for timely completion.

- Compositional information is fundamental to a renewed geologic mapping program and critical to the delineation, description, and interpretation of geologic units. As a result, there is a need for multiple base maps for a particular mapping project. However, these should be carefully selected and justified in order to avoid narrowing the objective scope of the geologic map.
- Emphasis should be placed on the explicit delineation of multiple impact crater facies, contrary to recent geologic maps of other planetary bodies. The pervasive nature of surface impact as a predominant contributor to the evolution of the lunar crust is critical to placing compositional observations into appropriate context.
- Geologic maps should closely adhere to the guidelines provided in the recent Planetary Geologic Mapping Handbook [19], so that there is visual and contextual continuity between USGS published geologic map products.

Conclusions: Lunar geologic mapping is undergoing a renaissance similar to that experienced by Mars geologic mapping following the flight of Mars Global Surveyor. Lunar geologic map products are expected to hone closely to cartographic standards, which evolve over time as a result of increased types and scales of planetary observation. Moreover, the emergence of geospatial mapping and analytical environments has provided a need for the expedited evolution of lunar mapping strategies. The pilot lunar geologic mapping project has successfully raised awareness in regard to the need for a renewed geologic mapping program funded through NASA PGG. We note that geologic maps are expected (and suggested) at higher scales (smaller areas) based on recent and ongoing acquisition of high resolution LROC data.

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