A NEW LUNAR GEOLOGIC MAPPING PROGRAM. L. Gaddis[1], K. Tanaka[1], T. Hare[1], J. Skinner[2], B.R. Hawke[3], P. Spudis[4], B. Bussey[4], C. Pieters[5], and D. Lawrence[6], [1]U.S. Geological Survey, Astrogeology Program, 2255 N. Gemini Drive, Flagstaff, AZ (lgaddis@usgs.gov), [2]Environmental Geomatics, Raleigh, NC; [3]PGD/SOEST, Univ. Hawaii, Honolulu, HI; [4]Johns Hopkins Univ., Baltimore, MD; [5]Dept. Geological Sciences, Brown Univ., Providence, RI; [6]Los Alamos National Laboratory, Los Alamos, NM.

Introduction: We describe a new pilot program for systematic, global lunar geologic mapping that flexibly incorporates and integrates data from a variety of remote sensing sources at several spatial scales. To define and test digital mapping tools and methods for this new mapping program, a 1:2.5 M mapping scale will be used to map a single quad encompassing the Copernicus crater region (***Figure 1***).

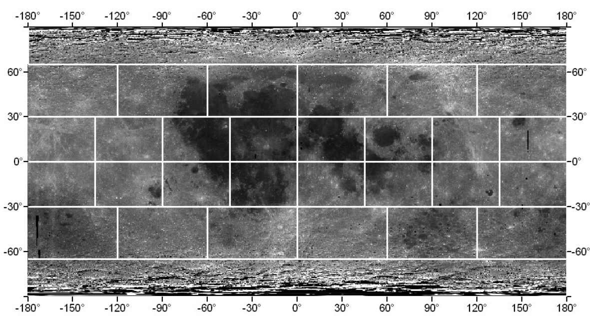

Figure 1. Mapping quad scheme for lunar geologic maps at 1:2.5 M scale. Image base is Clementine 750-nm albedo.

The Moon has not been geologically mapped in a systematic fashion in more than 25 years, and yet major advances in lunar science have occurred in the last 10 years. Current ideas about major lunar science issues such as the spatial and temporal distribution of ancient lunar maria and highland volcanism, ages and compositions of major basin impact melt sheets, and the dating of the lunar cataclysm have developed and evolved substantially since the last period of lunar geologic mapping. These advances have largely been achieved because of recent acquisitions of global compositional and geophysical data, and these data will be integrated into a new view of the geology of the Moon.

Background: Lunar geologic mapping came of age in the late 1960's, when the five Lunar Orbiter (LO) missions in 1966 and 1967 provided an excellent photographic image base at ~99% coverage with resolutions of less than 500 meters down to 1 meter [1-3]. Forty-four geologic maps at 1:1 M scale were made, followed by a 1:5 M near side geologic map [4]. Global geologic mapping coverage of the Moon was completed at 1:5 M with maps of the north, south, east, west, and central far sides [5-9].

Shoemaker and Hackman [10] established a firm foundation for the lunar geologic mapping of the 1960's and 1970's. These authors applied the well-established methods of stratigraphy (the study of the spatial distribution, chronologic relations, and formative processes of layered rocks) to the materials observed in and near Copernicus crater (~90 km dia.). The Copernicus region was selected for mapping because it (1) had been observed from Earth and from orbit (so state-of-the-art data could be used), (2) showed the effects of major surface processes on the Moon (impact cratering and basin formation, volcanism, and tectonic modification), and it (3) provided young and old units for determination of a local stratigraphic sequence. Copernicus thus became the type area from which major lunar stratigraphic units could be traced or extended over broad regions of the Moon.

Digital Geologic Mapping: A digital mapping approach will be taken in this project. Use of digital data readily supports image manipulation and enhancement, as well as derivation of products such as spectral band-depth maps, slope maps from topography data, image texture maps, density-sliced albedo and color, etc. Digital mapping methods using common drafting and analysis tools such as the Geographic Information System (GIS) by ESRI ArcView, GRASS, Adobe Photoshop and Illustrator, and Deneba Canvas will be tested, and recommendations will be provided to other mappers [11-13].

Dynamic Digital Image Bases: The fundamental image base for lunar mapping is the controlled Clementine global mosaic of "albedo" at 750-nm [14]. This base is supplemented by multispectral Clementine UVVIS and NIR data, as well as Clementine UVVIS color-ratio data (R=750/415; G=750/950; B=415/750) and similar NIR data. Additional complementary image bases likely will include digital Lunar Orbiter data [15] and Clementine global topography and shaded relief data [16]. Derived compositional maps may also be included, such as optical maturity and FeO and TiO_2 content [17-23] and LP measured elemental abundance maps [21, 24-28]. These digital map bases will be updated and augmented with new products as they become available.

Mapping Approach*:* We will examine the identification of both rock-stratigraphic units as used previously in lunar geologic mapping [29, 30] and unconformity-based units (UBUs), as advocated by [31] for Mars. Although the former approach has the weight of history and may be completely adequate for a renewed lunar geologic mapping program, the latter approach emphasizes description of unconformable unit boundaries rather than just unit characteristics and has the major advantage of emphasizing relative-age information associated with geologic unit contacts, resulting in units that describe geologic events and epochs of regional significance that may include assemblages of diverse lithologies. This approach carefully delineates secondary features and textures that may result from much later activity. This need is evident when considering the turmoil over stratigraphic schemes and the interpretation of regional and global histories for Venus where mapping approaches have varied [32-34].

Lunar Science: The Copernicus crater region will be the major scientific focus of this pilot lunar mapping project, where geologic mapping will include an evaluation of the boundary between the Copernican and Eratosthenian systems using soil maturity information provided by Clementine multispectral data. An operational distinction of these two time-stratigraphic units is that Copernican craters larger than a few kilometers in diameter still exhibit visible rays, whereas Eratosthenian-aged craters do not [10, 35]. It is now known that crater rays are bright because of immaturity and/or compositional differences [36]. It has been determined that some "compositional" rays are associated with craters such as Autolycus and Pythagoras that are far older (2.1 Ga and ~3 Ga respectively) than the currently accepted age of the Eratosthenian/Copernican boundary (1.1 Ga) [37]. The presence of bright rays is clearly not a reliable indicator of crater age. It will be necessary to reevaluate and possibly redefine the Eratosthenian/Copernican boundary.

We will address this problem using the optical maturity (OMAT) images derived from Clementine multispectral data [20]. The results of Grier et al. [37] suggest that large craters with ejecta at the same level of immaturity or less should be considered to be of Copernican age because the OMAT profile of Copernicus indicates that the crater marks the edge of discernable ejecta immaturity. We will use the OMAT data, integrated with Clementine multispectral and topographic data and LP compositional data, to examine the apparent maturity of Copernican-age craters and to evaluate the possibility of redefining the C/E boundary. If the results of Grier et al. [37] are confirmed, it may be possible to use the radiometric ages of exotic materials from the Apollo 12 site to date the C/E boundary since a ray from Copernicus crosses the site. These analyses will be incorporated into a geologic mapping effort for the "Copernicus quad". Results of this work will help to constrain the assignment of relative ages (and absolute ages in some cases) to lunar geologic units using the new global, remote sensing data.

Summary: The major product of this work will be a renewed, reinvigorated lunar geologic mapping program. Such a program will take advantage of new data and new integrative analysis methods to advance the science of lunar geology. Products will include a systematic lunar mapping scheme, a tested method for formatting and releasing digital lunar map bases, geologic maps for two lunar quads (submitted for publication as USGS I-maps), and a draft lunar geologic mappers' handbook with recommendations on the integration of information such as spectral color, chemistry, mineralogy, elevation, morphology etc. in interpretation of lunar geologic map units. This work will also help to develop and test methodologies for mapping other planetary bodies with remote sensing data.

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