DIGITIZATION OF THE 1:5,000,000-SCALE MARINER 9-BASED GEOLOGICAL MAPS OF MARS: PACKAGING, DEPLOYMENT AND ANALYSIS. A. E. Huff[1], M. A. Hunter[2], J. A. Skinner Jr.[2], T. M. Hare[2]. [1]School of Earth Sciences and Environmental Sustainability, Northern Arizona University, Flagstaff, AZ, 86011 (ahuff@usgs.gov). [2]Astrogeology Science Center, U.S. Geological Survey, 2255 N. Gemini Drive, Flagstaff, AZ, 86001 (mahunter@usgs.gov).

Introduction: The methods, products, and utilization of planetary geologic maps are constantly evolving as new instruments are introduced, more data are collected, and deeper analyses of regions are conducted (e.g., [1]). As this research progresses, it is important to pay attention not only to what the current data are showing, but also how the maps and methods have evolved over time. Evaluating historical maps, mapping methods, and mapper's interpretations from different eras and data sets can support modern conclusions or generate new scientific questions to be investigated.

It is this concept of scientific evolution over time that has driven Planetary Geologic Mapping (PGM) community demand for a workflow with which printed historical maps can be imported into ArcGIS to produce GIS data sets for the community. We have developed this workflow through digitization of the 1:5,000,000-scale, Mariner-9 geological maps of Mars [2]. Both the digitization workflow and geologic map GIS packages support modern scientific investigation by establishing temporal and spatial context as well as the evolution of thought with increasing volumes and types of data sets.

Background: When approaching a project that involves formatting historical maps to fit current technology, the decision whether to "digitize" or "renovate" the maps is crucial. The advantages to pure digitization lie with the preservation of the mapper's original interpretations of the geology at the time it was mapped. This is in contrast to renovating historical maps to help past geologic maps conform to modern data sets. Each method can benefit a project differently and it is the first choice to be made after selecting the region to format.

The 1:5,000,000-scale, Mariner-9 geological maps were the first to divide mars into 30 discrete latitudinal and longitudinal areas called the 'Mars Charts' (MCs) [3-4]. We chose these maps based on their historical significance as the first community-wide effort to show our early understanding of martian geology. The ability to compare these Mariner 9-based MCs with modern geologic mapping would be the clearest way to demonstrate the evolution of both our understanding of martian geology and the process of PGM.

Methodology: In order to maintain historical accuracy, these maps were digitized instead of renovated. The MCs were georeferenced to the Mars Odyssey Thermal Emission Imaging System (THEMIS) Daytime Infrared (IR) mosaic (100 m/pixel), but the mapper's contact locations and unit interpretations were preserved as originally intended [5].

The following workflow is not meant to serve as a one-size-fits-all approach; rather, they are to aide in the planning and delegation of tasks to ensure a coordinated, consistent product. User experience with managing GIS data should dictate the amount of variance in an individual project workflow.

Workflow. Strict digitization of historical maps does not require any new interpretation of geologic features (as renovation does). As such, the same general work-flow can be employed by multiple editors, as was done in this project. However, there are subjective elements of the process that can affect the working consistency and preservation of the original mapping intent which must be identified and clearly documented, if not fully mitigated (**Figure 1**; [2]). The most common example of this is transition points between contact types where feature symbology cannot be differentiated. Unless described explicitly in map text, such determinations should be made by the supervising researcher if possible, and if in doubt coincide with boundaries of map units or geologic structures. Such a workflow is an ideal introduction to geologic mapping for those new to, or outside, the PGM community.

Experienced GIS users will be able to digitize contacts at the recommended streaming tolerance and use snapping techniques to ensure topological integrity. However, new users can benefit greatly from Esri's topology feature class capabilities, available in their ArcMap GIS application, which support rules of connectivity, contiguity and area definition. By setting rules for spatial relationships between and within feature classes any problems (referred to as dirty areas) can be easily identified and corrected, optimizing the quality control process for the supervising researcher as well. No matter the method, it is strongly recommended that contacts are digitized before creating polygons of map units as it is much more efficient to alter lines than adjacent polygons. It is important to note that topology is supported only in an ESRI file geodatabase, not with the standalone shapefile format.

Most importantly, a thorough workflow must be adopted by all involved to ensure a consistent product. Like interpretation itself, renovation of historical maps can be accomplished differently by individuals and any variance in workflow can make documentation inconsistent or inaccurate. This can be expanded to include naming conventions and working folders for larger projects, as geodatabases are often cluttered with derivative or redundant datasets that make collaborative work difficult. Quantifying processing parameters and specifying outputs is also good practice to include in accompanying metadata. Additional resources for planetary mapping can be found at: http://planetarymapping.wr.usgs.gov/Page/view/Guidelines.

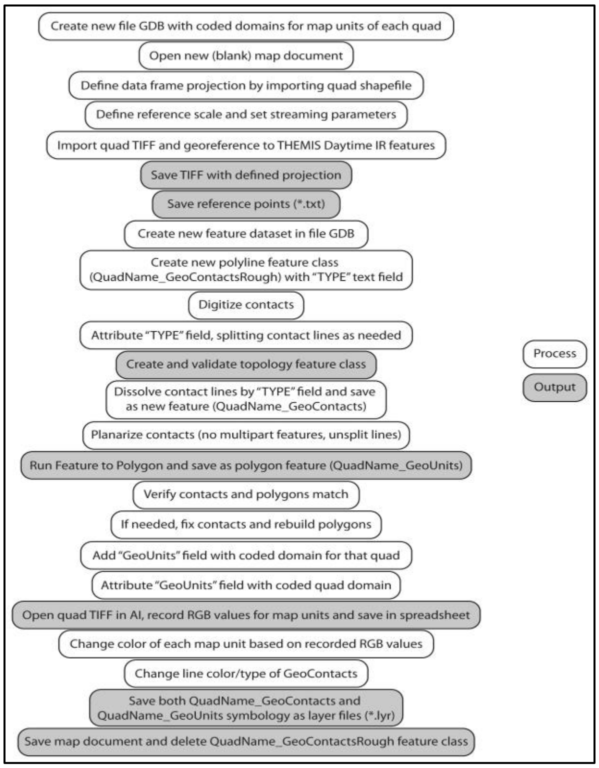

Figure 1. Workflow model used for digitization of 1:5,000,000-scale Mariner 9-based maps of Mars.

Supporting Documentation. To support the independent use of these data in a GIS environment, especially layer symbology (*.lyr) files, supporting documentation and Federal Geographic Data Committee (FGDC)-standard metadata must be included with dataset downloads. Because each map in the Mariner-based MC geologic map series was authored independently, an exhaustive description of the author's original mapping process cannot be included. As such, we focused our documentation to describe data processing and manipulation, such as geo-referencing to a more current control network. Other materials that will be included in the package documentation are georeferenced points for each MC (*.txt), spreadsheets of contact and map unit symbology used for layer files, reference abstracts and the process workflows.

Packaging. All elements of the project were organized as a compressed (*.zip) package with four folders: (1) Data, containing the geodatabase (*.gdb) in both ArcMap 10.0 and 10.3 versions, layer files and any related shapefiles such as quad boundaries; (2) Documents, with metadata, abstracts and supporting information; (3) Map Documents, containing projects (*.mxd) in 10.3 and 10.0 versions; (4) Source Maps, holding georeferenced scans of original maps (*.tiff). We recommend that package downloads be compatible with versions of ArcMap back to 10.0. Archived projects will be maintained periodically to remain compatible with software upgrades.

Though the uncompressed package for this project was 7.25 GB (2.65 GB compressed), the vast majority of the file size – 7.05 GB – were rectified TIFF's of source maps. If download size is an issue, these images can be packaged separately with a link provided in the metadata or in the quadrangle boundary shapefile.

Future Work: The completed package for this map series is under internal review and will be made available for community use by April, 2016 at: http://astrogeology.usgs.gov. With its use of the THEMIS Daytime IR control network these GIS-ready maps, and others like them, can be used for a variety of spatial and temporal analyses. For example, direct comparative analyses between 1:5,000,000 scale regional maps can be made in area and feature counts, and can be used to illustrate changes between different mapping scales and/or missions. They can also be used collectively as a global mosaic for comparison to larger datasets. We note that georeferencing has altered the alignment of quadrangles so gaps and overlaps occur at boundaries in addition to existing discrepancies in geologic units between maps. Such studies should also account for the scanned resolution of source maps since resolution (dpi) dictates the scale at which they are digitized, and associated standard error.

Future work to renovate MCs would entail adjusting contact locations to where the original mapper would have placed it based on the more accurate THEMIS IR base map. Additionally, map units may be extrapolated or adjusted in order to be consistent across MC boundaries, and ages could be applied to geologic units.

References: [1] Tanaka K. L. et al. (2010) *Ann. Meeting of Planet. Geol. Mappers*. [2] Huff, A. E. et al. (2015) *Ann. Meeting of Planet. Geol. Mappers*. [3] Gaither T. A. et al. (2015) *LPSC XLVI*, Abstract #2522. [4] Baston R. M. (1973) *JGR*, *78*, 4424-4435. [5] Christensen P. R. et al. (2004) *Space Sci. Rev.*, 110.

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