

GIS-BASED PLANETARY GEOLOGIC MAPS: RECOMMENDATIONS FOR IMPROVED PREPARATION, REVIEW, AND PUBLICATION. T.M. Hare¹, J.A. Skinner, Jr.¹, K.L. Tanaka¹, C.M. Fortezzo¹, L.F. Bleamaster III², and R.M. Sucharski¹, ¹U.S. Geological Survey, Astrogeology Team, 2255 N. Gemini Drive, Flagstaff, AZ 86001, ²Planetary Science Institute, Tucson, AZ 85719. (thare@usgs.gov).

Introduction: The U.S. Geological Survey's (USGS) Astrogeology Team has historically provided coordination and guidance for the planetary geologic mapping program sponsored by NASA's Planetary Geology and Geophysics Program (PG&G). Under the auspices of NASA's Planetary Cartography and Geologic Mapping Working Group and its Geologic Mapping Subcommittee (GEMS), USGS provides (1) assistance with geologic mapping program plans, (2) collective management of all active projects, (3) generation of geologic base maps and databases for funded researchers, (4) guidance for achieving USGS cartographic standards, (5) editorial support in map reviews and revisions, and (6) preparation for and final printing of maps in the USGS Scientific Investigations Map (SIM) Series.

For several years, the USGS has required all Earth-based geologic maps to be submitted in Geographic Information Systems (GIS) compatible formats rather than in a digital graphic format (e.g., Adobe Illustrator). The GIS format requirement was instituted after recognizing that published geologic maps are more valuable if they are disseminated in a digital geospatial context. USGS regards these products as more valuable than printed maps due to their analytical utility, transportability, and versioning. To date, planetary mappers have been given leniency for meeting the USGS GIS requirements. However, the USGS Astrogeology Team, under the guidance of GEMS, is implementing steps to manage a transition from graphical to GIS-compatible files. While undeniably valuable, printed maps will become a supplementary benefit rather than the primary product. This has important ramifications for the strategies and methodologies with which planetary geologic mappers approach their respective mapping projects.

Migration: It has long been recognized that geospatial technologies are invaluable tools for efficient analysis of planetary data. This is important for geologic maps, which by definition provide spatial and temporal context for researchers. Such tools allow researchers to quickly digitize, update, integrate, analyze, and display all forms of geographic data. Most users can directly benefit from the ease with which GIS applications simultaneously handle and overlay memory-intensive files ranging from global (km/pixel) mosaics to highly-detailed local (cm/pixel) images.

This year, the GEMS panel voted to impose new requirements, beginning with the 2009 PG&G an-

nouncement of opportunity, that all PG&G funded geologic maps that are submitted in 2011 and later must be in a GIS-compatible format. Once reviewed, these digital GIS files will be re-released to the research community and used by USGS to create the published hard-copy maps on demand. This creates multiple complications that need to be addressed before a of GIS-based geologic map requirement is fully instituted. These affect all stages of geologic mapping: preparation, review, and publication. Herein, we discuss some of these complications and provide recommendations for how the new requirements can best be managed and incorporated.

GIS-based complications: Some of the most common difficulties encountered by researchers attempting to function in a GIS mapping environment include:

- Issue 1: Steep learning curve. This is generally the largest hurdle and includes not only complications in initial setup of GIS projects but also consistent, manageable, and correct use of the software.
- Issue 2: Unclear accountability for correcting spatial errors and complex projection issues in datasets that are acquired by various instruments.
- Issue 3: Poor management and maintenance of vector and raster files, which can lead to unfavorable drafting habits and poorly-compiled maps.
- Issue 4: Determining and maintaining consistent and applicable map scales between print and digital map files. GIS' ability to utilize all datasets at all scales, promotes inconsistent drafting and maps that may not be able to show information at the proposed scale.
- Issue 5: A "want-it-all" tendency. This arises from the monstrous increase in available map-related information. This often easily translates into a bottleneck of information and can burden data providers and mappers.

Recommendations: Each of these complications can be at least partly resolved through a variety of overlapping elements. We summarize these recommendations below. Complications that can be addressed by each element are listed parenthetically.

Element 1: GIS Base Images. (Issues 2 and 4, 5): For many years the USGS has supported geologists with GIS-compatible base images for their funded mapping area. In recent years, we have continued to include more layers that specifically benefit GIS users.

This includes preparing not only the base mosaic but supplying the individual image frames from the mosaic and when possible other images of interest. For example, currently funded Mars quadrangles are supplied with a THEMIS IR mosaic, MOLA topography, and possibly other image sets, depending on scale, in a GIS compatible GeoTiff or other GIS-ready format.

Element 2: Pre-built GIS Projects. (Issues 1 and 3): This year, we began constructing and delivering pre-built GIS projects and geodatabases that included pre-defined layers with attributes, projections, and standardized symbols. Commonly used attributes specific to the planet of interest are pre-defined as a starting place that can be expanded by the GIS-user. Pre-building helps ensure the mapper will have a correctly configured project that is ready to populate with map-based information. It also ensures that all mappers are receiving comparable products at the start of their project and not encumbered by the software.

Element 3. Bundled Global Projects (Issues 2 and 5): Another item that facilitates GIS mapping is the creation of a DVD that bundles all global datasets in common projection. These DVDs include global image mosaics, topography, mineral maps, and global vector layers like image footprints, existing digital geologic maps, crater and volcanic catalogs, and a nomenclature point layer. These ancillary layers can be used by the mapper to understand the areas immediately outside their mapping quads or for other research purposes. We currently have these bundled global projects for Mars, the Moon, Venus, Io and Europa. As other mapping projects are created for other bodies, we will supply the mapper with similar packages. These are updated routinely to ensure access to all available data.

Element 4. Planetary GIS Handbook (all issues): It is common for USGS to collaborate with several planetary mappers to release guidelines for mapping specific bodies. For example, the Venus Geologic Mappers' Handbook [1] was created to help those not intimately familiar with Venus. There is also an ongoing task to update lunar geologic mapping techniques using modern data sets and digital mapping techniques. Previous lunar mapping efforts essentially stopped after the Apollo and Lunar Orbiter missions. USGS will release this lunar geologic mappers' handbook with recommendations on the integration of chemistry, mineralogy, topography, and morphology within a digital domain.

As a companion to these planet specific handbooks, we have plans to draft a comprehensive, peer-reviewed manuscript that specifically addresses the application of GIS technologies for mapping and analysis. This undertaking will likely include methods on how to interpret orbital data and transition this

knowledge down to surface operations. It will also compile "best practices" such as establishing GIS databases, projections, data collection tips (e.g., vertex spacing, smoothing, etc.), and correct symbology.

Element 5. GIS Workshops (all issues): Two workshops in support of planetary mappers and researchers were held in 2008 and were well-attended [2]. We recommend continuance of these workshops along with release of associated tutorials, study guides, and work programs. The first workshop targeted funded PG&G mappers. We plan to hold these targeted workshops at least once every two years with updates or shorter classes every year. The second workshop was open to the general planetary research community, including students. While learning how to use GIS in a short two-day lesson is difficult, we hope the exposure will encourage the participants to continue their education via workbooks, university classes, or the many other available GIS-training outlets.

Element 6. Digital Reviews and Standard Submission Formats: This element doesn't necessarily address the issues above but will directly facilitate reviews and publication. We recommend using developing functionalities in Adobe PDF format which allows users to convert GIS files into a near publication-ready form. Other benefits by using this "geo-PDF" include the ability to read-out latitude/longitude, measure distances, turn layers on/off, and actually query feature attributes in the PDF file. This will allow non-GIS users to digitally review the maps outside of any GIS application.

An element that remains to be resolved is accommodation of all GIS vector formats. Ideally formats such as Geographic Markup Language (GML) or Environmental Systems Research Institute (ESRI) formats like the de-facto standard Shapefile or File Geodatabase would be preferred. Since nearly all GIS and remote sensing application support one of these formats, nearly any GIS application can be used.

Conclusion: The PG&G funding opportunity this year will require geologic maps submitted after January 2011 to be in a GIS-compatible format. To help alleviate this transition for the mapping community we have begun to implement GIS-ready bases, pre-built GIS projects, best practice handbooks, and planetary GIS workshops. If you have any concerns, recommendations, or require information for the upcoming PG&G opportunity please contact us.

References: [1] Venus Geologic Mappers' Handbook, URL: <http://tinyurl.com/82rp8a>. [2] GIS Workshop materials have been made available at the PIGWAD website, URL: <http://webgis.wr.usgs.gov/pigwad/tutorials/planetarygis/>

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