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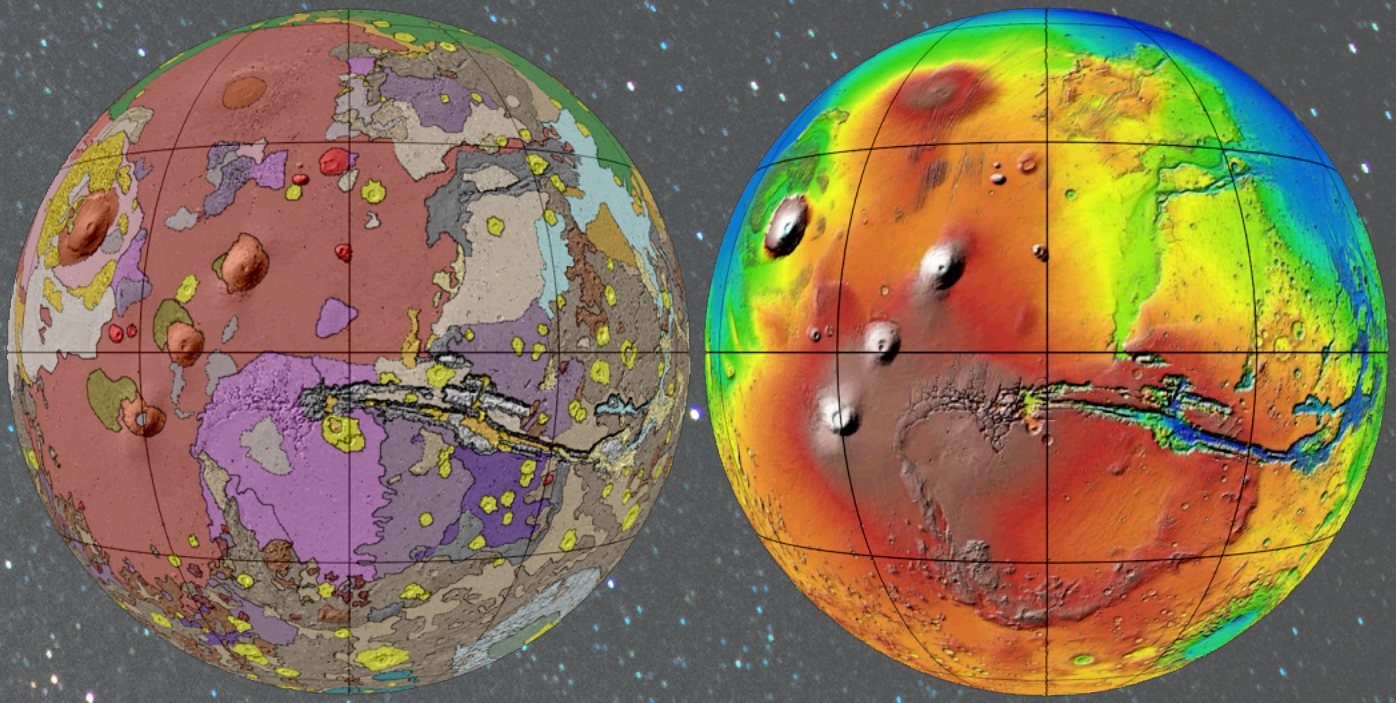
Planetary Geologic Mapping Protocol—2022

Chapter 13 of
Section B, U.S. Geological Survey Standards, of
Book 11, Collection and Delineation of Spatial Data



Techniques and Methods 11–B13

U.S. Department of the Interior
U.S. Geological Survey

Cover. Mars geology image by Astrogeology Science Center, 2016. Background space photo by Raphael Nogueira on Unsplash.

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Abbreviations

AI	Adobe Illustrator Artwork
ASC	Astrogeology Science Center
COMU	Correlation of Map Units
DOMU	Description of Map Units
dpi	dots per inch
EOMS	Explanation of Map Symbols
FGDC	Federal Geographic Data Committee
GIS	geographic information system
IAU	International Astronomical Union
MAPSIT	Mapping and Planetary Spatial Infrastructure Team
MRCTR	Mapping, Remote-sensing, Cartography, Technology, and Research
NASA	National Aeronautics and Space Administration
PDF	Portable Document Format
PDS	Planetary Data System
PI	Principal Investigator
PSC	Publishing Service Center
ROSES	Research Opportunities in Space and Earth Sciences
SIM	Scientific Investigations Map
USGS	U.S. Geological Survey
USGS MC	USGS Planetary Geologic Map Coordinator

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Abstract

The Planetary Geologic Mapping Protocol covers the idealized process of compiling a NASA-funded map product of a non-terrestrial solid surface planetary body for U.S. Geological Survey (USGS) publication and summarizes technical specifications of the Mapping Process for authors and reviewers. Directed by community and programmatic recommendations, the USGS Planetary Geologic Map Coordination Group assembled the content herein to aid the timely production of USGS map products. This document can be also used as a reference document by those researchers who are completing geologic maps that will be published outside the USGS.

Introduction

Geologic maps present, in a historical context, fundamental syntheses of interpretations of the materials, landforms, structures, and processes that characterize planetary surfaces and shallow subsurfaces. Such maps provide a contextual framework for summarizing and evaluating thematic research for a given region or body. Whereas most modern terrestrial geologic maps are constructed from regional views provided by remote-sensing data and supplemented by field-based observations and measurements, non-terrestrial planetary maps are largely based on analyses of a variety of orbital datasets, most commonly without assistance from direct contact in the field. As is the case with terrestrial geologic maps, the geologic representation in non-terrestrial planetary geologic maps provides a "snapshot" understanding of a given surface based on the data available at the time—meaning that additional data coverage, volume, type, and resolution can refine (but not replace) the current understanding when such additional data becomes available. The discipline of planetary geologic mapping is therefore continuously evolving because it spans multiple geoscience subdisciplines and must rapidly embrace new data and technology to accommodate the growing needs of planetary exploration. It must also take cues from strategies developed and employed by terrestrial mapping processes and products, to the extent possible.

Non-terrestrial planetary geologic maps have been funded by the National Aeronautics and Space Administration (NASA) and published by the U.S. Geological Survey (USGS) since 1961 (Hackman and Mason, 1961). From 1961 to 2022, the USGS has published more than 250 geologic maps of Mercury, Venus, the Moon, Mars, and some Jovian satellites at a variety of map scales and projections using the best available image and topographic bases. Early geologic map bases commonly consisted of hand-mosaicked photographs or airbrushed shaded-relief views, and geologic linework was manually drafted using mylar bases and ink drafting pens. Finalizing maps for publication required a tedious process of scribing, color peel-coat preparation, typesetting, and photo-laboratory work. Since the 1990s, inexpensive desktop computing, improved display capability, and user-friendly illustration software have allowed maps to be drawn using digital tools rather than pen and ink, and mylar bases have become almost entirely obsolete.

These technological advances allow modern planetary geologic maps to convey complex observations and interpretations of orbital data using traditional hard copy map products and digital products that use geographic information system (GIS) software and file formats (see, for example, Hare and others, 2009). GIS mapping tools also permit easy spatial comparison, generation, importation, manipulation, and analysis of multiple raster and vector datasets. GIS software enables the development of project-specific tools and the sharing of geospatial products among researchers. As a result, GIS software now plays a critical role in the preparation and production of standardized USGS geologic maps.

As the planetary mapping process has advanced with the development of new technology, the discipline-specific expectations of a planetary geologic mapper have increased to the point where the investigating scientist (or team) is often expected to be (or include) a geologist, image processor and analyst, GIS specialist, and cartographer. The production of standardized, peer-reviewed, and technically edited geologic maps is a complex process involving a wide range of data, software tools, technical procedures, mapping support specialists, review steps, and publication requirements. In summation, planetary geologic mapping is a dynamic and learned discipline that incorporates multiple scientific and technical sub-disciplines and requires those sub-disciplines to work in concert even as they continue to evolve independently.

Purpose of this Protocol

The USGS is critically involved in the entirety of the mapping process for producing USGS Scientific Investigations Map (SIM) series products on behalf of NASA. As a result, it is important for the USGS to describe an idealized Mapping Process, and this document lays out that process. However, it is also important for the USGS and the planetary science community to recognize that this idealized process may not always be achieved. Using this document as a starting point from which to incorporate community and programmatic recommendations, the USGS will establish author-specific timelines and then prompt authors to achieve these timelines. It is ultimately, however, the responsibility of the Principal Investigator (PI) and Author (if these are different) to facilitate the Mapping Process, fulfill timeline obligations, alert the USGS to changes in the process (as necessary), and adhere to Map Package Component specifications. To support this process and ensure a standardized, high-quality, objective product, authors are encouraged to (1) become familiar with and commit to the details outlined herein, (2) leverage USGS and community advice and expertise throughout their mapping project, and (3) emulate the format and content of recently published USGS maps.

The **Planetary Geologic Mapping Protocol**[1] (this document, hereafter referred to as the "**Protocol**") is produced by the **USGS Planetary Geologic Map Coordination Group** (hereafter "**USGS Planetary Mapping Group**") to describe the technical process of compiling a map product for USGS publication. The topics detailed herein are intended to summarize the technical specifications of the Mapping Process for the authors and reviewers of USGS-published maps. It does not, however, serve as a platform to explain the intricacies of planetary geologic mapping as a scientific discipline, and such matters are intentionally deemphasized herein. Therefore, reading and citing this document does not constitute proficiency in planetary geologic mapping. Readers who are interested in learning more about the geologic mapping process and the production and use of geologic maps are directed to Varnes (1974), Wilhelms (1987), Wilhelms (1990), Spencer (1993), Lisle and others (2011), and all references therein.

Updates in this Document

Continual changes in data availability and mapping techniques dictate that the Mapping Process must remain flexible and adaptable to meet time and budgetary constraints. Users are advised to see the latest edition of this document, which will be updated periodically and posted on the USGS Planetary Mapping Group web page. Note that the most current Protocol supersedes all previously released mapping guidelines and that the Author is subject to the Protocol version available at the time their Map Package is submitted for the Technical Review Process.

[1] Key terms and USGS programmatic jargon in **bold** are defined in the glossary at the back of this report; they are bolded and defined within the text where they are most relevant—not necessarily where they first appear. Abbreviations are defined in the text at first usage and in the "Abbreviations" section at the front of the report.

A version of this document was previously released in 2018. The following list describes changes to the 2018 version that are contained herein.

- General document changes
  - Reorganization of the "Abbreviations and Definitions" section into separate "Abbreviations" and "Glossary" sections (located in the front matter and at the back of the document, respectively) and general revisions therein for increased clarity and completion
  - Rearrangement of some sections to improve document flow and ease of navigation
  - References to various Standard Operating Procedures added throughout to connect readers with available resources
  - Reorganization of the "Useful Web Pages" section to be more descriptive of the purpose and resources available through each link
  - Expansion of the "Roles and Expectations" section to include description of the Technical Reviewer role
  - Addition of a new section, "Common Mapping Pitfalls," that identifies common pitfalls observed by the USGS Planetary Mapping Group in the Mapping Process and resulting Map Packages
- Additional Map Package information
  - Detailed information for generating and representing Nomenclature for the Geologic Map
  - Clarification on the use of foreign language for the Map Package in the "Geologic Map Text" section
  - Guidance on inclusion of cross sections in Map Packages
  - Details on Cover Art selection
- Updates to the Mapping Process
  - Guidance on how to appropriately scope projects over the course of funding cycles
  - Inclusion of an anticipated submit date in the Confirmation of Technical Specification Document for NASA proposals, and confirmation of anticipated date by the PI and USGS Planetary Geologic Map Coordinator (USGS MC) when the initial Map Package is delivered after NASA selection
  - Consistent colors and symbology across all Map Package Components added to Map Package Compliance Requirements
  - Overhaul of the Technical Review Process to a system that centers around a Review Collation Panel to

maximize efficiency between the Author, Technical Reviewers, and USGS Planetary Mapping Group

- Removal of the "Accept and publish as is" Review Recommendation, and addition of the "Resubmit with moderate revision" recommendation
- Updated publication evaluation of Map Packages during the Technical Review Process to be conducted by the USGS MC and USGS Planetary Mapping Group, as opposed to multiple iterations with each Technical Reviewer
- Change of Sunset Date definition from "the last day of the final funded year of the project OR the last day of the final No Cost Extension obtained by the PI/Author (whichever is later)" to a standard funding cycle plus two years to account for No Cost Extensions potentially obtained by the PI/Author

USGS Maps

Geologic maps are tools that report and facilitate planetary analyses. They are produced through varying methodologies and serve to convey the geology, structure, stratigraphy, composition, and relative rock ages for a selected area. Planetary scientists commonly create some kind of map product during the course of an investigation, whether that be in the form of a hand-sketched cross section or a digitally traced outcrop. The USGS Planetary Mapping Group identifies both Standardized and Non-Standardized Map products as higher-order map publications that serve to convey comprehensive and objective geologic context in an expected and predictable format.

In this document, we refer to **Standardized Maps** as those maps published by the USGS that conform to relatively rigid cartographic standards that are established by federal agencies, refined by the planetary mapping community (as necessary), and coordinated by the USGS Planetary Mapping Group on behalf of NASA. Standardized Maps are subject to a thorough Technical Review Process, wherein deviations from established standards are identified and corrected. These maps are produced to be scientifically objective and cartographically normalized. In contrast, **Non-Standardized Maps** are those published outside the USGS that are not required to conform to the rigid standards of the planetary mapping community nor subjected to a review process specifically intended to identify and correct deviations from those standards. The distinction this document makes between Standardized and Non-Standardized Maps is not meant to suggest that Non-Standardized Maps are any less valuable to the progression of planetary science than Standardized Maps. To the contrary, Non-Standardized Maps are flexible, exploratory products that can more easily respond to data influxes and innovation whereas Standardized Maps are rigid framework products that place exploratory results into larger, more comprehensive structures. The information in this document is intended to guide scientists who are producing NASA-funded Standardized Maps. This document can (and perhaps should) also be used as a resource and guide in the production of Non-Standardized Map products. However, the Technical Review Process described herein, which identifies and corrects deviations from established USGS standards, is not applicable to the production of non-standardized, topical geologic maps because Non-Standardized Maps, by definition, are not produced to USGS standards. The guidance offered herein is expected to gradually change to reflect the changing needs of the planetary mapping community; therefore, input from the community regarding potential content adaption and clarification is encouraged.

NASA-funded maps published by the USGS are coordinated by the USGS Planetary Mapping Group at the USGS Astrogeology Science Center (ASC) in Flagstaff, Arizona. The USGS Planetary Mapping Group, led by the **USGS Planetary Geologic Map Coordinator** (**USGS MC**), is responsible for setting and implementing planetary map standards, providing technical support to NASA-funded mappers, facilitating the Technical Review Process, and managing the publication process (including editing, cartographic layout production, large-format printing, hard-copy distribution, and digital posting and archiving). Funding for the support and publication of each NASA-funded geologic map is provided to the USGS Planetary Mapping Group from NASA funds separate from those appropriated to selected mapping projects. It is not possible at this time for the USGS to support planetary map products funded by non-NASA entities.

Standardized cartography and scientific objectivity are the benchmarks within which USGS-published geologic maps are prepared, reviewed, and promoted. In general, a USGS-published geologic map will conform to the following criteria:

- The map must be (a) directly supported by a proposal that has been competitively awarded through the NASA Research Opportunities in Space and Earth Sciences (ROSES) call for funding or (b) otherwise directed by NASA Program Officers.
- The map must be submitted for review in GIS format using standards, guidelines, and conventions established by the USGS Planetary Mapping Group and must include all required components identified in this document.
- The map must be produced and published with a single Primary Map Base, and the rationale for the selection of that primary dataset must be documented. The map can (but is not required to) use Supplemental Data to augment observations made in the Primary Map Base, and the reasoning for the use of that Supplemental Data must be explained.
- The map must not contain excessive interpretive detail that is not required to establish and convey the geologic framework (for example, excessive figures, hypothetical discussions).
- The map must be an accurate, concise, and clear representation of the geology of the selected region at

the Publication Map Scale, regardless of the resolution afforded by the Primary Map Base. An accurate depiction of the geology at full data resolution has the potential to result in linework that is far too dense to be legible at the Publication Map Scale. As such, it is critical for the Author to understand that a USGS Standardized Map is a representation only of the geology that is discernible and representable at the Publication Map Scale.

- The map will be subjected to the Technical Review Process, which consists of evaluations from three Technical Reviewers. In order for the Map Package to progress through the Technical Review Process and eventually be Accepted for publication, the Author is expected to thoughtfully consider and satisfactorily address reviewer-recommended corrections in a professional manner.
- The Author is expected to attend the Annual Planetary Geologic Mapper's Meeting and contribute to the Technical Reviews of other maps during the course of their project.
- The NASA-funded PI of the mapping project, who may or may not be the Author, is expected to attend the Annual Planetary Geologic Mapper's Meeting and is also responsible for contributing to the Technical Reviews of other maps during the course of their project.
- If a USGS or journal-based geologic map has already been published for a given region at a similar or different scale, the new map must clearly demonstrate that it fundamentally improves upon, enhances, and (or) refines the context established by previous maps (including those published in peer-reviewed journals).

Authors are encouraged to publish expanded, map-derived results in peer review journals, including results of analytical studies and assessments of local geologic environments and processes that might contribute to the broader understanding of the geologic framework beyond the USGS map or to enhance the science detail depicted in the map. If planned appropriately, these journal articles can (and should) be used as key references in the geologic map to avoid the need for expanded discussions that can bloat the Geologic Map Text, limit objectivity, and delay the Technical Review Process.

Roles and Expectations

The planetary Mapping Process involves a network of people and programs that must collaborate efficiently to successfully produce a timely and objective USGS planetary geologic map. In this section, we describe the roles and expectations of the Mapping Process participants (NASA, PI, Author, USGS Planetary Mapping Group, and USGS Publishing Service Center [PSC]).

NASA

NASA's role is primarily limited to the proposal stage. NASA organizes and conducts peer-reviews of mapping proposals submitted to existing Research and Analysis programs, selects proposals at their (NASA's) discretion, and provides funding for the PI. Upon proposal selection, NASA conveys authority in the Mapping Process to the USGS Planetary Mapping Group and thereafter provides input on an as-needed basis. We specifically note that NASA's selection of a mapping proposal does not necessarily guarantee USGS publication of the proposed Map Package—once a proposal is selected, it is then the PI's responsibility to fulfill all the obligations outlined herein that are required to publish the map as a USGS product.

Principal Investigator

The Principal Investigator (PI) is responsible to NASA for the generation of planetary geologic maps to be published by the USGS. The PI communicates with the USGS Planetary Mapping Group during the proposal stage and project initiation. In the case that the PI is the first author of a submitted Map Package, the PI will also assume the role of Author as the project progresses. The expectations of the PI with respect to completion of the proposed geologic map are as follows:

- The PI will contact the USGS Planetary Mapping Group with a formal intent to submit a map proposal to NASA at least two weeks prior to proposal deadline; the PI will work with the USGS MC to finalize a Confirmation of Technical Specification Document, which will be submitted with the final proposal and will include an anticipated Map Package submit date.
- The PI will notify the USGS Planetary Mapping Group of their proposal's acceptance for NASA funding; in return, the PI will receive the initial Map Package. The PI will update the anticipated Map Package submit date and confirm their commitment to the defined Sunset Date.
- The PI will, through timely completion of the Mapping Process, ensure the publication of a NASA-funded, USGS-published map product; this applies regardless of whether the PI is (or is not) also the Author.
- The PI will ensure that the designated Author (if different from PI) is adhering to all project responsibilities.

Author

Geologic mapping is often a group effort, and many people may contribute directly or indirectly to the compilation of a USGS map. Authorship of a USGS map, however, should be limited to only those individuals who contributed directly to a map's creation. Individuals who assisted with providing data or technical expertise but did not contribute directly to the drafting of linework

and (or) wholesale interpretation of mapped features should be listed in the Acknowledgments section of the Geologic Map Text. All co-authors should be intimately familiar with the preparation and content of the final product.

Herein, the term "**Author**" refers to only the first author of the submitted Map Package, and the USGS Planetary Mapping Group will confer exclusively with that author throughout the Mapping Process. The Author is solely responsible for addressing the requirements of the USGS Planetary Mapping Group and for satisfying Map Package Compliance for all Map Package Components, regardless of who produced any individual Map Package Component. Although the roles of Author and PI can overlap, the Author is responsible to the USGS Planetary Mapping Group whereas the PI is responsible to NASA. In the case that the PI and Author are separate, it is ultimately the responsibility of the PI to see that a NASA-funded USGS product is completed. In instances where the Author no longer actively participates in the Mapping or Technical Review Process, the PI should actively work to complete the project.

The Author's role is continuous throughout the Mapping Process until the Map Package has been Accepted for publication and is moved into the production phase, after which point the Author is consulted on an as-needed basis. The expectations of the Author are as follows:

- The Author will adhere to the Map Specification document.
- The Author will solicit scientific and technical guidance from the USGS Planetary Mapping Group and planetary mapping community as needed and use all available resources to assist and expedite the Mapping Process.
- The Author will ensure the Map Package is Compliant for submission into Technical Review.
- The Author will adhere to the timelines identified during the Technical Review Process.
- The Author will appropriately address and edit the Map Package according to recommendations from the Technical Reviewers until the Map Package is Accepted for publication.

USGS Planetary Mapping Group

The USGS Planetary Mapping Group's role is continuous throughout the Mapping Process. They provide base-map data, guidance for authors, standards for map components, Technical Review coordination, and publication support for each NASA-funded map. Expectations of the USGS Planetary Mapping Group are as follows:

- The USGS Planetary Mapping Group will maintain the **Planetary Geologic Mapping Program** through duties including (but not limited to) obtaining and managing program funds, reporting project status updates to USGS and NASA program officers, developing and maintaining standard procedures, managing map printing and distribution, maintaining a web presence, and promoting the creation and use of process guidelines and map products within the broader scientific community.
- The USGS Planetary Mapping Group will verify map proposal specifications from potential PIs for reasonability and feasibility, and then document those specifications in the Specification Document.
- The USGS Planetary Mapping Group will provide a Map Package, including a GIS project prepared to the specifications provided in the Specification Document, to the Author.
- The USGS Planetary Mapping Group will support the Author during active mapping efforts and in preparation for Map Package submission by providing scientific and technical guidance at the Author's solicitation.
- The USGS Planetary Mapping Group will verify Map Package Compliance, coordinate Technical Reviews, and conduct the MC and Nomenclature Reviews.
- The USGS Planetary Mapping Group will coordinate with the USGS PSC to finalize Map Package formatting and act as liaison between the USGS PSC and Author as needed.
- The USGS Planetary Mapping Group will post digital map products to the USGS Publications Warehouse, which serves as a Planetary Data System (PDS) equivalent, long-term archive.
- The USGS Planetary Mapping Group will distribute published hard copy map products to the USGS ASC.

Technical Reviewer

Technical Reviewers are solicited from the planetary geologic mapping community (including the USGS Planetary Mapping Group) and are responsible for contributing to the Technical Review Process of assigned Map Packages. The expectations of Technical Reviewers are as follows:

- Technical Reviewers will conduct a timely Pre-Panel Independent Review of the Map Package per the Technical Review Guidelines.
- Technical Reviewers will participate in the Review Collation Panel hosted either remotely or in-person at the USGS ASC in Flagstaff, Ariz.
- Technical Reviewers will provide information, commentary, or input on the Map Package and its Technical Review as solicited by the USGS MC post-Panel.

USGS Publishing Service Center

The USGS Publishing Service Center (PSC) is involved in the publication stage of the Mapping Process. The expectations of the USGS PSC are as follows:

- The USGS PSC will provide an editorial and cartographic review of the Map Package.
- The USGS PSC will advise the Author on USGS standards for matters including (but not limited to) coloring, symbology, Nomenclature, and layout.
- The USGS PSC will aid the USGS Planetary Mapping Group in compiling the Map Package for publication, particularly by ensuring the use of USGS approved layouts and formatting.
- The USGS PSC will facilitate bidding and printing through the Government Publishing Office.

Map Package Components

In the past, planetary geologic maps have varied slightly in content (for example, inclusion or absence of figures and cross sections) and arrangement (for example, map sheet organization and inclusion of map pamphlet) based on the amount of material being represented and Author preferences. Although some flexibility is desirable to account for the different needs of each geologic map, unnecessary divergences from standards and guidelines come at a cost. Deviations from specified community standards regarding symbology, layout, colors, and Map Package Components undermine the ability of the user to easily compare one map to another. In addition, these deviations potentially require significantly more effort from mappers, reviewers, editors, and cartographers. In this section, we define the template for completing standardized planetary geologic maps that ensures these products have a consistent format that is simple for users to assimilate and use, and that they are easier, faster, and more cost effective to produce. The Mapping Process, including the Technical Review and publication steps, is outlined and described in the "Mapping Process" section. The criteria by which Map Package Components will be evaluated during the Technical Review Process are detailed in the section "Technical Review Guidelines."

For examples of formatting and content, the Author will refer to recently published geologic maps. In all cases, the final content and format of a USGS SIM series geologic map will be guided by Technical Review, USGS MC oversight, and USGS PSC cartographic and editorial commentary. At no time will non-Author personnel make unilateral scientific or substantive cartographic edits to the Map Package. With respect to USGS PSC cartographic and editorial efforts (which take place after the Map Package has been Accepted for publication by the USGS MC), the Author will be contacted for input when necessary. Final decisions related to map content and format are the responsibility of the USGS MC, who will coordinate with the Author. It should be noted that if, at any time, the Author feels that standardization and editing has significantly altered the intent of the map, they are free to remove the map from USGS review and (or) production and submit the product (or a derived version thereof) for publication outside the USGS.

The Author is requested to restrict **Map Package Components** to the following elements: GIS Files, Geologic Map, Geologic Map Text, Description of Map Units (DOMU), Correlation of Map Units (COMU), Explanation of Map Symbols (EOMS), Figures, Captions, Tables, Cover Art, and Metadata. The maximum size of a map sheet printed as a USGS SIM series product is 40 by 56 inches (about 100 by 140 centimeters); if space on the map sheet is a concern, the Geologic Map Text (and potentially Tables and Figures) can be included as a separate pamphlet (see the "Geologic Map Text" section for more information on pamphlet content). All Map Package Components described herein are required except where noted.

The Author must receive prior approval from the USGS MC on supplemental digital products they wish to include in the Map Package, and, if approval is granted, the Author will follow all related guidelines for supplemental digital products. Supplemental digital products include Supplemental figures, Supplemental tables, Supplemental GIS layers, and Supplemental GIS maps. The Author is advised to use discretion when including supplemental files, as only those files that directly support the geologic history conveyed by the map will be approved and the inclusion of additional products may slow down review and publication. Supplemental products will be released as part of the digital publication of the Map Package and will not be included with the hard-copy product. Nevertheless, all supplemental products are subject to Technical Review.

GIS Files

Planetary geologic maps published by the USGS have a digital component that, at the time of this publication, is released in conjunction with the hard copy product and hosted online by the USGS Publications Warehouse and (or) ScienceBase. For Map Packages being submitted for Compliance Review and Technical Review, the **GIS Files** will include the Primary Map Base, coordinate system file, layer files, clean geodatabase, and digital map document file (such as the ".mxd" file created from Esri ArcGIS software). All references to coordinate systems within the Map Package must match a single system, which is typically selected during the development stage and identified in the Specification Document. Upon Acceptance, the Author will work with the USGS Planetary Mapping Group to produce the final GIS Files, Map plates, Metadata, and README files.

It is possible to include digital material that will only be posted with the digital data products through the USGS Publications Warehouse and (or) ScienceBase. These might include supplemental image mosaics, local thematic map products, and larger-scale (that is, smaller area) maps. However, supplemental materials will be considered part of the Map Package and will therefore be reviewed in detail in tandem with the other Map Package Components. Note that the USGS Map

Package is not the venue to publish associated but not directly contributory data products such as feature catalogs. Digital supplements should be limited as much as possible to assist with timely review and publication.

Geologic Map

The **Geologic Map** component comprises the geologic units, contacts, and features of the selected region, as well as Unit Labels, Nomenclature, grids, graticules, Figure locations, and other relevant attributes. The Geologic Map, superimposed on the Primary Map Base, is the fundamental product of any NASA-funded map published by the USGS. The Geologic Map must be prepared at the **Publication Map Scale** using the map projection determined in the proposal stage and identified in the Specification Document. Geologic units must be clearly colored and labeled, contacts must separate individual unit boundaries, and features must be consistently represented. Unit Labeling should be sufficient enough to assist review, but not so extensive as to overcrowd the map. A recommended method for avoiding the overuse of Unit Labels is to label only those polygons above a certain area threshold. The Author will adjust label formatting to emulate previously published maps as closely as possible. A grid and (or) graticule must be displayed to assist review; the "GIS Tutorials" web page of the Mapping, Remote-sensing, Cartography, Technology, and Research (MRCTR) GIS Lab website (see the "Useful Web Pages" section) offers Standard Operating Procedures that can aid in the creation of grids and graticules. The Author should note that final formatting of the Geologic Map will be conducted by the USGS PSC after Acceptance.

The symbology of the Geologic Map (such as the symbols representing contacts, linear features, and point features) must use Federal Geographic Data Committee (FGDC) approved symbols. The GIS geodatabase that is provided by the USGS at the start of the project is populated with the most frequently used symbols in planetary geologic maps. However, if a desired FGDC symbol is missing, or an FGDC symbol cannot be identified to accurately represent a particular geologic feature, the Author will work with the USGS MC to identify and incorporate the appropriate symbol into the GIS geodatabase. Though the USGS PSC will cosmetically refine map symbols, they will not complete or attempt to decipher incomplete or unclearly prepared symbols.

Nomenclature

Planetary **Nomenclature** is used to uniquely identify geographic features on the surface of a planet or satellite so that they can be easily located, described, and used as a geographic reference for other map elements and discussions. The International Astronomical Union (IAU) names and approves Nomenclature, and the IAU Gazetteer of Planetary Nomenclature (see the "Useful Web Pages" section) contains detailed information about all IAU-approved names of topographic and albedo features on planets and satellites. Maps published by the USGS are required to display Nomenclature completely and accurately (with minor exceptions; for example, features that are too small to be significant to the geologic context at Publication Map Scale). Named features mentioned anywhere in the Map Package will be capitalized and spelled correctly (including the Latin plural forms for descriptor terms) for text components and represented correctly on the Geologic Map. Note that the descriptor term "crater" is not part of the Nomenclature of an officially named crater; therefore, the term "crater" should not appear in the Nomenclature feature class on the Geologic Map, nor should it be capitalized when mentioned in text components.

The Author should submit a name request to the IAU if there is a need to single out for identification as-yet unnamed features within the map area (the name request form is hosted on the IAU Gazetteer of Planetary Nomenclature homepage included in the "Useful Web Pages" section). The Author may include a suggested name in the request; however, suggested formal names should not be used in maps or publications until the approval process is complete. Nomenclature needs can be addressed at any time during the Mapping Process prior to publication Acceptance, but the Author should note that it generally takes one to two months for a name to be approved (sometimes longer). When Nomenclature issues arise, the Author should consult with the USGS Nomenclature Specialist (see the "Support Personnel and Facilities" section).

As with labeling, the cartographic position of approved Nomenclature needs to be sufficient to assist review. Although Nomenclature is generated as an annotation feature class within the geodatabase submitted in the Map Package GIS Files, it must be additionally represented on the Geologic Map file. Feature formatting and placement will be cosmetically refined during USGS PSC review, but any steps the Author can take to ease this process will expedite review and production of their map.

We recommend the Author download the global planetary Nomenclature feature location GIS ZIP file from the IAU Gazetteer of Planetary Nomenclature website (see the "Useful Web Pages" section). Once imported into the Author's GIS, the nomenclature dataset can be clipped to the map project study area. The Author can then generate the Nomenclature annotation feature class by following the Standard Operating Procedures for Labels provided on the "GIS Tutorials" web page of the MRCTR GIS Lab website (see the "Useful Web Pages" section).

USGS maps employ different font types and sizes to identify IAU-named features in the map area. Table 1 shows the font type that must be used for each general feature type. For brief explanations of these feature types, see the IAU Gazetteer of Planetary Nomenclature Descriptor Terms web page (listed in the "Useful Web Pages" section). Feature size in the map area will determine which font size and capitalization to use—large features will be 20 point and all capitalized case, medium features will be 14 point and title case (only the first letter of each word is capitalized), and small features will be 10 point and title case. Typically, large features extend beyond the map area, whereas medium features cover a large part of the study area and small features are only locally identifiable. Text for Nomenclature features should overlie most of the named feature (for example,

Table 1. Required font types for IAU-named features on USGS-published maps and the geographic feature types to which they apply.

[Feature types are shown in "Singular, Plural" forms unless otherwise noted. IAU, International Astronomical Union]

Font type	Feature type
Arial	Arcus, Arcūs
	Planitia, Planitiae
	Planum, Plana
	Terra, Terrae
	Tessera, Tesserae
	Vastitas, Vastitates
	Albedo feature (no plural)
	Crater feature (no plural)
	Eruptive centers
Arial Oblique	Catena, Catenae
	Linea, Lineae
	Cavus, Cavi
	Mare, Maria
	Chaos, Chaoses
	Oceanus, Oceani
	Chasma, Chasmata
	Palus, Paludes
	Farrum, Farra
	Promontorium, Promontoria
	Flexus, Flexūs
	Fluctus, Fluctūs
	Rima, Rimae
	Flumen, Flumina
	Scopulus, Scopuli
	Fossa, Fossae
	Serpens, Serpentes
	Fretum, Freta
	Sinus, Sinus
	Labes, Labēs
	Sulcus, Sulci
	Labyrinthus, Labyrinthi
	Unda, Undae
	Lacus, Lacūs
	Vallis, Valles
	Lingula, Lingulae
Times New Roman Italic	Collis, Colles
	Corona, Coronae
	Dorsum, Dorsa
	Facula, Faculae
	Insula, Insulae
	Macula, Maculae
	Mensa, Mensae
	Mons, Montes
	Patera, Paterae
	Regio, Regions
	Tholus, Tholi
	Corona, Coronae

crater names should fall in the center of the crater, scarp and valley names should curve with the feature). Character spacing (kerning) can be increased to improve text coverage of Nomenclature features. It is strongly recommended to see published maps for additional examples and guidance on Nomenclature placement and styling.

Geologic Map Text

Historically, the Geologic Map Text has appeared on the map sheet in instances where space permitted. However, increases in the diversity of mapping methods and the volume and types of data used to create a planetary geologic map often make modern map texts too long to be included on the map sheet, therefore requiring the Geologic Map Text to be published as an accompanying map pamphlet. In general, the **Geologic Map Text** will include the following sections: Introduction, Methods and Data, Mapped Features, Age Determinations, Geologic History, Acknowledgments, and References Cited. Although there is some flexibility regarding the organization and naming of sections in the Geologic Map Text, all content described herein for each of the aforementioned sections must be included somewhere in the Geologic Map Text. The Geologic Map Text will be formatted as double-spaced, single-columned, and line-numbered for Map Package submission. Organization will be subject to review during the Technical Review Process.

Foreign words and phrases are generally not used in USGS scientific publications. The Author will use "and others" instead of "et al.," "for example" instead of "e.g.," and "in other words" (or "that is") instead of "i.e." (Donlin and others, 2020).

Introduction

The **Introduction** section of the Geologic Map Text introduces the map area, including its geography and general geologic setting. The Introduction also summarizes previous contextual and scientific work, particularly published geologic maps (Standardized and Non-Standardized), for the map region and establishes why a new map is warranted for the region at the Publication Map Scale. Established units of previous USGS maps need to be stated and critiqued. The Introduction can expound on existing scientific controversies but needs to remain objective and avoid overt bias toward one evolutionary scenario. The Introduction section will discuss the rationale and purpose of the map. The Author can choose to split the Introduction into multiple sections if they believe the text is extensive enough to warrant subdivision. For example, in addition to the Introduction, an author can include "Background" and (or) "Physiographic Setting" sections (or similar).

Methods and Data

The **Methods and Data** section of the Geologic Map Text summarizes all datasets (including the Primary Map Base and Supplemental Data) and methods (drafting, organizational, or

other) that were used to construct the map or needed to identify and discriminate map units and features critical to determining the geologic character and history. Additional datasets that were consulted must also be mentioned, along with how they benefitted the mapping (if at all). Data that was not directly used to create a Map Package Component should not be cited. The Author should be aware that not all available data can be reasonably (and equally) employed to construct a geologic map in a timely and repeatable manner. Data documentation should include references to datasets, instruments, and products (for example, mosaics) as necessary. The delivery of GIS files from the USGS does not need to be cited.

A variety of techniques can be used to document the methods used to convey Unit Names, unit groupings, Unit Labels, unit colors, and contact and feature types; brief descriptions of techniques for each of these methods are provided in the bulleted list below. All methods used must be clearly described in the text and applied consistently across the map. Drafting parameters—vertex spacing, the **Digital Mapping Scale** (that is, the scale used to display the Primary Map Base when mapping geology and features in GIS), line smoothing and generalization methods (if used), and any other important digital controls and processing that were applied—must be identified. The Author can determine whether the text is extensive enough to warrant subdivision of the Methods and Data section into separate "Methods" and "Data" sections (or similar). As always, the Author should consult recently published USGS planetary geologic maps for guidance on organizational strategies and content examples.

- *Unit Names* — Typical approaches to unit naming include naming units by their morphologic type (for example, "corona material," "crater material"), geographic name ("Utopia Planitia material"), relative age or stratigraphic position ("older" or "lower crater material"), and combinations thereof. Closely related units (for example, units in a sequence or morphologic variations of otherwise similar units) may be mapped as members (for example, "lower member of the Utopia Planitia material") or as units with names that show their close temporal association with other units ("Utopia Planitia 1 unit, Utopia Planitia 2 unit," and so on). The Author's choice of approach needs to be carefully considered and will depend on the style of map preparation. The Author has flexibility to employ a reasonable unit naming scheme, but all schemes will be subject to review.

- *Unit groups* — Units are commonly grouped by their geographic occurrence (for example, "highland materials") or morphologic type (for example, "lobate materials"). Only proper nouns in unit and group names are capitalized (for example, "Alba Patera Formation," "Utopia basin unit," "western volcanic assemblage"). The Author has flexibility to employ a reasonable unit grouping scheme, but all schemes will be subject to review.

- *Unit Labels* — Labeling can indicate chronostratigraphic age (for example, "A" for "Amazonian"), unit group ("p" for "plains materials"), specific unit designations (such as morphology, albedo/reflectivity, and associated geographic feature name), and unit member (commonly indicated as a subscript; may include numbered sequences, as in "member 1," "member 2," and so on). Small capital letters have been used for unit groupings (for example, "e" for "Elysium province"), but this method can cause problems with citation and typesetting and is therefore discouraged. Some labels may be queried on the geologic map to show the unit assignment is highly uncertain. The Author has flexibility to employ a reasonable Unit Label scheme, but all schemes will be subject to review. Unit labels, in general, must remain short and succinct; five letters/numbers or less is preferred. The Author is directed to follow unit naming and organization precedents from published USGS maps where applicable and relevant.

- *Unit colors* — Coloring must be applied according to precedent, although subtle variations can be employed. Unit color may be used to reflect unit grouping (for example, warm colors for volcanic materials, cool colors for sedimentary rocks, yellows for crater materials, browns for ancient highland materials). Color saturation can be used to reflect the general areal extent of unit outcrops; by using low color saturation for extensive units and high saturation for small units, smaller outcrops become more apparent on the geologic map sheet. Colors are subject to alteration and refinement after submission to the USGS PSC, usually only with Author consent. However, the Author should note that some color combinations, hues, or saturations are simply not legible and will not be supported. The Author has flexibility to employ a reasonable unit coloring scheme, but all schemes will be subject to review.

- *Contact types* — The quality of contacts varies considerably on most maps. There are technical and philosophical issues that arise from consistently using different kinds of geologic contacts within a single geologic map, particularly when mapping is based solely on remotely sensed datasets. Contact types need to be defined and used consistently for a given map. In general, the Author will use a "certain" contact where a contact is known to exist and is confidently located; an "approximate" contact where the contact is presumed to exist but its location is not confidently identified at the Digital Mapping Scale (perhaps because of insufficient data quality or obscuration by an overlying surficial unit); a "concealed" contact where surficial material buries the contact, but morphologically the contact is still traceable (though subdued); and an "inferred" contact where the validity of the map unit or distinction between the units is hypothetical. Although "gradational" contacts have been used in past maps, this type of contact should be reserved for cases where other contact types are insufficient and, even in such cases, should be used sparingly, if at all. Provided the Author explicitly defines the contact types and applies them consistently throughout the map, the Author has flexibility to employ a reasonable geologic

contact scheme, though all schemes will be subject to review.

- *Feature types* — Mapping geologic features accurately and consistently is a challenge for every map project. In addition to describing the methods used to map geologic features, the Author must explain the reasoning behind the symbology (such as line and point symbols and stipple patterns) chosen to portray those geologic features. It is important to describe the parameters and characteristics by which each feature was mapped—for example, "scarp bases are mapped along the topographic inflection point at the base of cliff-like features," or "shield points are used to map the low-relief apex of dome-like, circular features that are 1–5 kilometer(s) in diameter." Authors have flexibility to employ a reasonable feature type scheme, but all schemes will be subject to review.

Mapped Features

The **Mapped Features** section provides detailed descriptions of all linear features, point features, and stipple patterns. The title of this section can be changed to be more descriptive of what features are being represented (for example, Geomorphology, Structure, or other). Examples of Mapped Features include (but are not limited to) wrinkle ridges, graben, sublimation pits, surface units, landing sites, and traverse routes. This section must include expanded descriptions of Mapped Features that are identified in the Explanation of Map Symbols. The Author will also identify in this section any features that are associated with particular geologic units. Relevant characteristics (feature trends, feature lengths or areas, concentrations in geographic locations, numbers of mapped features per type, and so on) must be described for all Mapped Features. If appropriate, the Author will state which Supplemental Data was used to aid identification and description of feature types. The Author can determine whether the text is extensive enough to warrant subdivision of the Mapped Features section into separate Geomorphology and Structure sections (or similar).

Age Determinations

A discussion of techniques behind relative and absolute **Age Determinations** for map units must be included because the techniques employed—and their reliability—can vary widely according to data quality and the preservation and (or) exposure state of key features. Techniques for relative dating may include superposition and cross-cutting relationships as well as impact crater size-frequency distributions (where available and relevant). For quantitative approaches to dating, the Author will provide error analysis and (or) summarize the integrity and robustness of the approach. Because absolute age models are based on cratering theory, lunar sample dating, and empirical data on bolide populations, these models are subject to high uncertainty, and discussions of these models must therefore contain appropriate reference citations throughout. Where possible, crater statistics can be summarized in tabular form (see the "Tables" section).

Geologic History

A summary of the **Geologic History** of a map area provides context for the entire Geologic Map and is required. The synthesis is intended to be a succinct yet informative review of unit development, deformation, and erosion; other modifications of the surface and shallow subsurface; and first-order interpretations on geologic and climate histories where appropriate. The Author should exclude lengthy considerations of previous and new hypotheses and other interpretive discussions that go beyond immediate mapping results and implications.

Acknowledgments

At a minimum, the **Acknowledgments** section will include the NASA program and award number(s), as well as other relevant funding avenues. The Author can also use this section to identify people that provided information but did not directly participate in the construction of the map (that is, those not listed as authors).

References Cited

The **References Cited** section should be inclusive of the current body of literature (Non-Standardized and Standardized Maps as well as topical studies) and formatted per USGS style guidelines (see Donlin and others, 2020, p. 225–279). All references listed in the Geologic Map Text must be included in the References Cited section, and vice versa.

Description of Map Units

The **Description of Map Units** (DOMU) is a concise description of the map units, their stratigraphic relations, interpretations, and other pertinent information. The DOMU will be submitted for review in a tabular format consisting of four columns of information for each unit: a "Unit Label" column, a "Unit Name and Unit Definition" column, an "Additional Characteristics" column, and an "Interpretations" column. To conserve space and promote brevity, Unit Definitions, Additional Characteristics, and Interpretations will not be prepared in full sentences. Thumbnail images of unit type localities are discouraged because they complicate the Technical Review and publication processes, but type locality coordinates in the Unit Definitions are appropriate. Although the use of a tabulated DOMU has been normal practice for publication in recent years, the Author has the option during USGS PSC production to select a prose-based, columnar format. As stated above, however, the tabular format is required for the Technical Review Process.

Each geologic unit must have a unique **Unit Name** and **Unit Label** that is logical and representative of the unit's age, grouping, and (or) distinguishing characteristics. Units that form groups closely related in provenance and (or) definitive

characteristics may have similar Unit Names and Unit Labels. The DOMU is organized based on grouping and (or) in chronological order (youngest first). The Unit Names, Labels, and colors must be consistent across all Map Package Components (that is, the Geologic Map, Geologic Map Text, Correlation of Map Units, and Figures).

Geologic units have **Unit Definitions** that are based on widely occurring and (or) unique, primary (depositional) and secondary (erosional or modificational) characteristics observed in the Primary Map Base. These definitions should be succinct yet sufficient to identify and discriminate each map unit from all others. In most cases, characteristics sufficient to define a unit include (but are not limited to) morphology and texture, albedo, stratigraphic position or relative age, relative elevation, regional occurrence, and (or) closely associated landforms. It is common to associate frequency (rare, common, pervasive), spatial density (sparse, closely packed), and proximity descriptors (adjacent to, within, around) with relevant definition categories. Type locality coordinates are optional and should be placed at the end of the definition. To the extent possible, the Author will use a similar sequence of description for each unit in order to promote clarity between units.

Additional Characteristics are those key characteristics that are observed in Supplemental Data. This column includes a brief assessment of additional aspects such as relation to units in previous and adjacent maps, local anomalies in unit character, local character of contact relationships, and prominent secondary features that may obscure or be partly controlled by primary features.

Interpretations will focus mainly on Author-preferred, observation-based interpretation, but will also include all plausible origins of mapped units based on the listed definitions and Additional Characteristics, including primary (depositional) features, secondary (erosional or modificational) features, and stratigraphic relationships. Because USGS maps are meant to be contextual, objective, and enduring products, the Interpretations must reflect their degree of uncertainty where possible (for example, “lava flows” versus “possible lava flows” versus “uncertain; may be lava flows, pyroclastic or impact-related deposits, or tabular sedimentary deposits”), understanding that most geologic Interpretations cannot be definitive.

Correlation of Map Units

The **Correlation of Map Units** (COMU) chart shows how mapped geologic units are oriented in space and time relative to one another and established geologic time scales (where known). In general, each unit identified on the Geologic Map is represented in the COMU by a box that is colored to correspond to the unit’s color on the geologic map and that extends vertically to various degrees to reflect the unit’s known temporal associations (as determined through superposition, cross-cutting relationships, and [or] crater size-frequency statistics). The COMU is organized horizontally with younger units and unit groups placed toward the left of the chart and older, more diverse, or widespread units placed toward the right. Unit boxes represented in the COMU that are contiguous indicate a close formative association. The nature of the top and bottom of each unit box represented in the COMU provides an interpretation about the nature of temporal sequencing between units (for example, time transgressive or erosional), the certainty of temporal correlation, and (or) the onset and cessation of the geologic event that deposited the unit. The Author may explain these details in an associated key (see, for example, Young and Hansen, 2003). At the Author’s discretion, the COMU may also contain a listing of geologic events (see, for example, Tanaka and others, 2005) and crater density relationships. All aspects of the COMU must be substantiated by and correlated with other Map Package Components to ensure a high level of consistency across the Map Package. A template for the COMU, to be adapted as necessary, will be included in the original Map Package delivered to the Author.

Explanation of Map Symbols

The **Explanation of Map Symbols** (EOMS), or map key, is a chart on the map sheet that includes all line, point, and stipple symbols alongside the feature type name, a brief explanation, and a basic interpretation (see recently published maps for examples). Complete symbol definitions and descriptions as well as interpretations belong in the Geologic Map Text. The features are required to follow official, published USGS cartographic symbols (see FGDC web page as well as examples recently published in planetary geologic maps). Accurate and complete compilation of the EOMS is the responsibility of the Author.

Figures

Figures are an important part of planetary geologic maps and should be used to show examples of critical geologic unit and feature characteristics and temporal relationships. However, the number of Figures allowed will be limited to only those necessary to show characteristics and relationships that cannot be identified by map readers using the Primary Map Base and Supplemental Data provided and that are critical to demonstrating geologic sequencing and unit association. All Figures must be thoroughly annotated and captioned, and each must be justifiable. Non-annotated Figures are not effective for demonstrating critical relationships.

Although USGS SIM series maps can include color Figures, cost limitations may require these to be placed on the map sheet (rather than in accompanying pamphlet). Therefore, the number of color Figures should be minimized. A color shaded relief figure of the map area with IAU-approved Nomenclature is often useful to establish context and is commonly presented as the first figure in a map product (that is, as “figure 1”). Figures may include, for example, reduced-scale images of the map area showing key datasets, the orientation of mapped tectonic features as rose diagrams, distributions of key features, contact relationships, or geologic cross sections. Figures need to be prepared at intended publication size with consistent label font types and sizes. A template for Figures, to be adapted as necessary, will be included in the original Map Package delivered to the Author.

Although geologic cross sections can be included within the Figures Map Package Component, they should not be referenced in the Geologic Map Text as a "figure." A limited number of geologic cross sections can be shown on the map. Unit Labels, unit colors, and other symbology and Nomenclature need to be identified on all geologic cross sections and must be identical to those represented on the map. All symbols and geologic units that appear in geologic cross sections must also appear in the EOMS and COMU, respectively. Cross sections must be produced at the same horizontal scale as the map, and the amount of vertical exaggeration must be indicated and adequate to show necessary detail (but not excessive).

Locations of Figures, including geologic cross sections, must be accurately and clearly identified on the map sheet as a separate GIS layer. Because Figure locations are not known at the beginning of the map project, these cannot be included in the USGS-prepared GIS Map Package. It is the responsibility of the Author to create a GIS layer for inclusion.

Tables

Tables can be used to provide details about various aspects of the map or features contained within the map boundary that are relevant to establishing the geologic context and history. Such details might include (but are not limited to) summaries of impact crater unit morphologies within the map area, stratigraphic relationships between mapped units, zonal statistics of gridded elevation data per geologic unit, crater size frequency relationships, and correlations with previously published geologic units. Tables will be prepared at the Author's discretion. Layout details (including cosmetic refinements) will be addressed during USGS PSC map production. If room is available, tables may be included on the map sheet but otherwise will be placed in the accompanying pamphlet.

Captions

Captions are required for all included Figures and Tables and must be concise and supplemental to Figure annotations. Cross sections do not require Captions but should be discussed in the Geologic Map Text instead. Captions must include (but are not limited to) the following information: data source, data type, image number, ground sampling distance (for example, "THEMIS daytime infrared mosaic at 100 meters/pixel"), solar or incoming energy incidence angle and azimuth, north direction, and latitude and longitude locations.

Cover Art

The published map sheet (and pamphlet, when applicable) will be contained within an envelope. In addition to standard publication citation information, the envelope will feature some kind of **Cover Art**. If the map boundary is part of an established quadrangle scheme (including multiple quadrangles represented on a single sheet), the cover art will be an index map showing the map area (typically on a hemispherical view of the planet). If the map boundary is not part of an established quadrangle scheme, the Cover Art will be determined through consultation with the Author and may be an original image related to the map area and (or) Primary Map Base (for example, a three-dimensional view of the study area). The USGS Planetary Mapping Group will oversee Cover Art preparation and will contact the Author for information as needed. Note that the Cover Art is not required for a map to enter or proceed through the Technical Review Process.

Metadata

Metadata is the necessary ancillary documentation that describes each GIS layer in a geologic map, including the rationale, authorship, attribute descriptions, spatial reference, data lineage (including geoprocessing) and other pertinent information as required by the FGDC metadata standard. This information is archived with and becomes part of the map layer. The Metadata is not required for a map to enter or proceed through the Technical Review Process. The USGS Planetary Mapping Group will oversee metadata preparation and will contact the Author for information on an as needed basis and will oversee the incorporation of Metadata for the mapped layers according to USGS publication and FGDC standards.

Mapping Process

Planetary geologic maps, as supported by NASA and published by the USGS, are most commonly released under the USGS Scientific Investigations Map (SIM) publication series (note that the SIM series was formerly named "Geologic Investigations Series" and "Miscellaneous Investigations Series", both of which used "I" for the publication series abbreviation). In this section, we summarize the **Mapping Process** for USGS SIM series planetary geologic maps, from proposal submission to publication. These processing steps are subject to change, as they are dictated in many cases by higher level organizational policies, budget constraints, and other circumstances.

Mapping projects must have an appropriate scope when they are proposed, and development of the Specification Document helps ensure this need is met. The expected timeline for the Mapping Process is three years: two years allocated to mapping, interpretation, map package preparation, and submission for Compliance Review; and one year allocated to Technical Review and revisions (three months) and USGS PSC editing, production, and publication (nine months). Maximum timelines are less than 7 years, including potential No Cost Extensions from NASA—five years for mapping interpretation, map package preparation, and submission for Compliance Review before the project's Sunset Date; a maximum of one year for Technical Review and revisions; and nine months for USGS PSC editing, production, and publication.

Each project will be designed differently based upon science and mapping goals. Therefore, it is the responsibility of the PI, not the USGS, to determine the appropriate scope of a project. The progress of each map project is actively tracked by the USGS Mapping Group, and delayed timelines should be jointly addressed by the Author and the USGS Mapping Group to prevent Rejection of the Map Package.

Proposal Specifications

In general, NASA funding that supports geologic mapping investigations for USGS SIM series products is competitively awarded to individual researchers at various institutions through programs advertised within the NASA ROSES annual announcement of proposal opportunity. Multiple NASA programs support geologic mapping investigations as described in the **Planetary Science Research Program Overview** (hereafter referred to as **NASA ROSES Appendix C.1**).

Researchers who are considering proposing for a grant to produce a standardized planetary geologic map product should examine advisory documentation per NASA ROSES Appendix C.1 and visit the USGS Planetary Mapping Group web page. Although a variety of map areas, scales, and projections are potentially feasible for publication, technical constraints may make a proposed map untenable for publication (for example, maps larger than 40 by 56 inches or about 100 by 140 centimeters, or maps that require multiple sheets). Therefore, per NASA ROSES Appendix C.1, mappers are required to contact the USGS MC regarding the proposed map at least two weeks prior to Step-2 proposal deadline to develop a **Confirmation of Technical Specification Document** (hereafter **Specification Document**) with the USGS MC. The Specification Document ensures that preparation of the desired Primary Map Base, proposed technical mapping specifications, and publication of the final product are all feasible and in conformity with USGS Planetary Mapping Group established Protocol, to the extent known at the time of proposal.

The Specification Document is not a confirmation that the USGS endorses the proposal or that the final map product will be Accepted for USGS publication. In order to receive the final Specification Document, the Author will be asked by the USGS MC through email to (1) confirm the specifications within the Specification Document draft, (2) acknowledge that, if selected for funding by NASA, the PI and Author (if different) will adhere to the Protocol established by the USGS Planetary Mapping Group throughout the duration of the project, and (3) to provide an anticipated submission date of the Map Package for Compliance Review.

In addition to including the Specification Document, the Author should also consider all factors of the Mapping Process described herein when compiling a Step-2 proposal for a mapping investigation, including:

- *Digital production* — The Author must consider how the map will be generated in GIS formats compatible with ESRI's ArcGIS (or similar GIS) software (as per NASA ROSES Appendix C.1).
- *Map reviews* — Proposers are required to provide peer reviews for two other planetary geologic maps for each intended map publication (as per NASA ROSES Appendix C.1). It is appropriate to budget time to review maps in each new mapping proposal that is submitted (40 hours per map review, 80 hours total, is a tractable amount of time, though this time can vary). This is subject to change, per NASA programmatic decisions.
- *Annual Planetary Geologic Mappers Meetings* — Attendance at the **Annual Planetary Geologic Mappers Meeting** to present a progress report on the mapping, ongoing science tasks, and (or) results is required (as per NASA ROSES Appendix C.1). It is appropriate to budget attendance for each year that funding is received for a mapping project.
- *Additional analyses and products* — Detailed and interpretative analyses outside of the scope of the proposed USGS map product may be desired (for example, to test existing and construct new hypotheses, to model observations), but these should be expressed as tasks independent of USGS SIM series map generation (for publication in science journals, not the Geologic Map Text). USGS maps will not contain excessive interpretive detail that is not wholly required to establish and convey the geologic context (for example, excessive figures, hypothetical discussion).

Map Package Receipt

Once NASA has selected a project for funding, the PI must contact the USGS MC with notification of selection. The USGS Planetary Mapping Group will then compile a Map Package per the Specification Document (see below) and provide this to the Author. Through email, the USGS MC will confirm the final, funded technical specifications of the selected map project, as well as the anticipated Map Package submit date, and will define the project's Sunset Date. The Author must confirm through email to the USGS MC that they have received the Map Package and will adhere to the Sunset Date as defined.

The **Map Package** is a digital file system that contains the folder structure required by Compliance Review and that will be populated by the Author with all Map Package Components. The preliminary Map Package provided by the USGS Planetary Mapping Group will contain the Primary Map Base and Supplemental Data (as outlined in Specification Document), an ArcGIS project populated with GIS data layers, and a map-ready geodatabase containing the foundational geologic map feature classes attributed with Federal Geographic Data Committee (FGDC) derived map symbols. The most current map symbol templates available at the time of Map Package compilation will be delivered with the GIS packages. However, because map symbol templates are being continuously refined

and updated, later versions of the symbol templates may become available for download from the USGS Planetary Mapping Group website during the Mapping Process. The Author may apply updated symbol templates to previously delivered GIS packages at their discretion.

Generally, Map Packages will be delivered to the Author within one month of selection notification by the PI. However, the USGS Planetary Mapping Group is typically responsible for generating multiple Map Packages within a given year. If additional time is needed to generate a more complex map with higher data volumes, delivery specifics will be worked out between the USGS MC and funded PI.

A single controlled (or semi-controlled) cartographic product (typically an orthoimage, image mosaic, or topographic hillshade) serves as the **Primary Map Base** for each geologic map, whereupon geologic units and features are defined and delineated. This singular dataset is identified separately from other **Supplemental Data** that are beneficial to the identification and investigation of geologic elements during the Mapping Process and are provided by the USGS Planetary Mapping Group per the Specification Document. In some cases, there are adequate data available from a particular dataset, but the Primary Map Base itself does not yet exist when the mapping proposal is submitted, requiring the USGS Planetary Mapping Group to generate the map base. The proposer may construct their own Primary Map Base with advance permission from the USGS MC; this product will be provided to the USGS Planetary Mapping Group to be quality tested and integrated into the Map Package. Sometimes, minor gaps in data coverage can be filled in with lower quality (yet still useful) data. Even if a derivable dataset is released, there may be as-yet unresolved issues in radiometric and geometric processing and (or) in data volume that prevent the USGS Planetary Mapping Group from producing a map base with that particular dataset. For example, the number and volume of images may be too large to generate a map base with available resources. Alternatively, such data may be used as Supplemental Data and readily viewable as individual frames by using image-location footprints as GIS shapefiles having web links to data repositories.

Digital Mapping

Digital mapping methods can vary significantly. In general, the USGS Planetary Mapping Group advises that contact and feature mapping be completed first as polyline features. At an advanced stage in mapping, the polylines can be cleaned, smoothed, and converted to polygons. Vertex snapping is important and facilitates the generation of polygons from polylines with minimal errors. It is recommended that the final GIS linework have a vertex spacing of about 0.25 millimeters at Publication Map Scale (equivalent to 250 meters for a 1:1,000,000-scale map). This vertex spacing is generally set in the USGS-delivered GIS project. It is expected that a consistent scale will be used as the Digital Mapping Scale to digitize linework, usually a factor of 4 larger than the published map, to ensure adequate precision and representation (equivalent to 1:250,000 for a 1:1,000,000-scale map). This will prevent overly detailed linework that is not only onerous for Technical Review and production but which also may be imprudent at the Publication Map Scale, as it can obscure contact (or other) relationships. GIS tools can be applied to generalize and smooth linework to achieve the desired result, such as rounded corners. Also, reasonably sized minimum thresholds for line feature lengths and unit polygons must be applied (for example, 1 centimeter and 5 square millimeters, respectively). These thresholds are defined at the Author's discretion, but must give an accurate, clear, and concise representation of the geology at the Publication Map Scale. Threshold values are subject to scrutiny and revision during Technical Review, and maps that are deemed over- or under-detailed by peer review will be required to increase or decrease their threshold, respectively, to a number specified by the USGS MC and to adjust the Map Package accordingly in order to proceed through the Technical Review Process. Point features can be used to show the distribution of important features such as impact craters and volcanic constructs that are too small to represent in detail at the selected print scale (their size ranges will be indicated in the Geologic Map Text). For clarity and completeness, the Author will summarize and rationalize the drafting parameters that were used to produce the Geologic Map in the Methods and Data section of the Geologic Map Text.

GIS workshops and the Annual Planetary Geologic Mappers Meeting

These meetings are announced by the Geologic Mapping Representative on the Mapping and Planetary Spatial Infrastructure Team (MAPSIT) and are typically posted on community pages, such as the Lunar and Planetary Institute's Planetary Sciences Community Meetings Calendar. The meeting convener alternates between the USGS Planetary Mapping Group and volunteers from the planetary geologic mapping community (meetings are hosted at the USGS ASC in Flagstaff, Ariz., or the community member institution, respectively). While an active recipient of NASA mapping grants, and prior to map Acceptance, the Author is expected (as per NASA ROSES Appendix C.1) to attend the Annual Planetary Geologic Mappers Meeting, which is typically held in June. Additionally, scientists who conduct geologic mapping as part of their research but do not intend to publish as a USGS map are encouraged to attend in order to expand the mapping community, present various topical results, improve communication between disciplines, help inform mapping protocols, and receive guidance.

At these meetings, mappers will demonstrate their progress and discuss mapping issues and results. Preliminary map compilations will also be displayed and informally reviewed by other attendees during poster sessions. In addition, programmatic updates, mapping standards and guidelines, and related scientific and technical information will be presented and discussed. Technical workshops are sometimes attached to the Annual Planetary Geologic Mappers Meeting.

Map Package Submission

The USGS Planetary Mapping Group has compiled the following Map Package Submission Guidelines and Compliance Requirements and Review to continue refining and streamlining the Technical Review and publication processes. These guidelines should be used in tandem with the information provided in the "Map Package Components" section. The Author is solely responsibility for being aware of and adhering to these guidelines and requirements; failure in this area will risk delay and possible removal of USGS support regarding Technical Review and publication. The Author is required to assess the consistency and accuracy of all Map Package Components, individually and as a whole, prior to submission. Cross comparison and corroboration of all Map Package Components is one of the most critical aspects of the preparation process. Technical Reviewers will be instructed to evaluate how well the Map Package Components corroborate and correspond to one another.

Map Package Submission Guidelines

The Author is required to use the specified folder structure outlined below to submit the digital Map Package for Compliance Review. This folder structure is contained in the original Map Package delivered by the USGS Planetary Mapping Group to the Author at the onset of the project. All files in all folders are expected to be named similarly to show author, area, scale, component, and date (for example, SKINNER_UTOPIA_1M_COMU_NOV21_2014.ai), or a similar consistent method. The folder structure, including GIS templates, is available for download in the Current Mapping Guidelines section of the USGS Planetary Geologic Mapping Program website. The specified folder structure consists of the following folders and files (folders labeled "[REQUIRED]" are mandatory):

- 00_GIS_Files — [REQUIRED] This folder will contain the GIS Files for the geologic map, including the map geodatabase and base materials. Please include only the final GIS Files and not the interim versions. The folders and contents placed in 00_GIS_Files will mimic the content and structure that was delivered in the original Map Package from USGS:
  - Base Maps — This folder will be populated with the Primary Map Base and Supplemental Data, as originally provided by the USGS Planetary Mapping Group. If there are additional datasets that were not provided by the USGS Planetary Mapping Group but were used to compile a Map Package Component, they will also be included.
  - Coordinate System — This folder will be populated with the projection (.prj) file from the coordinate system used in the data frame.
  - Layer Files — This folder will be populated with the layer (.lyr) files from all feature classes submitted (for example, GeoContacts, GeoUnits, LinearFeatures).
  - *.gdb — This folder will be populated through ArcCatalog and will have only one feature dataset and only the final versions of feature classes to be submitted (for example, GeoContacts, GeoUnits, LinearFeatures).
  - At least one Esri map document (.mxd or .aprx) file will be included in the 00_GIS_Files folder. However, it is recommended to have two map document files, one saved in ArcGIS version 10.0 format and one saved in the ArcGIS version used by the Author, so that Technical Reviewers can easily open the project regardless of which ArcGIS version they have.
- 01_GEOMAP — [REQUIRED] This folder will contain the final geologic map in an Adobe Illustrator Artwork (AI) and (or) a Portable Document Format (PDF) file, generated via export from the GIS. Please ensure that all layers of the Geologic Map are included (for example, contacts, linear features, location features, grids). The map will include Nomenclature and Unit Labels sufficient for Technical Review, though the placement (with regard to linework and symbols) and font type, size, and subscripts do not have to be in "final" format. The USGS PSC will address standardized labelling during the final production phases.
- 02_MAP_TEXT — [REQUIRED] This folder will contain the Geologic Map Text in a Microsoft Word document (.docx) file and (or) PDF file. A template is included for assistance, to be adapted as necessary for the selected map area. This document will be in a single column, double spaced, with lines and pages numbered in order to facilitate Technical Review comments. A USGS reference style document is included in the original Map Package.
- 03_DOMU — [REQUIRED] This folder will contain the tabulated Description of Map Units in Microsoft Word document (or similarly editable) format. A template is included in the original Map Package for assistance, to be adapted as necessary for the selected map area.
- 04_COMU — [REQUIRED] This folder will contain the Correlation of Map Units in an AI and (or) PDF file. A template is included in the original Map Package for assistance, to be adapted as necessary for the selected map area.
- 05_EOMS — [REQUIRED] This folder will include the Explanation of Map Symbols in an AI and (or) PDF file. A template is included in the original Map Package for assistance, to be adapted as necessary for the selected map area.
- 06_FIGURES — This folder will include map figures, as necessary, in AI and (or) PDF files. A template is included in the original Map Package for assistance, to be adapted as necessary for the selected map area. Images must be 300 dots per inch (dpi) TIFF, JPG, or PNG files.

- 07_CAPTIONS — This folder will contain the Figure and Table Captions, as necessary, in Microsoft Word document (or similarly editable) format, as necessary.
- 08_TABLES — This folder will contain Tables, as necessary, in Microsoft Word document (or similar editable) format, as necessary. A template is included in the original Map Package for assistance, to be adapted as necessary for the selected map area.
- 09_COVER_ART — This folder will contain Author preferred pamphlet cover art, as appropriate. This folder may remain empty if the Author does not wish to provide preferred cover art.
- 10_METADATA — This folder will remain empty at the time of submission.
- 11_README — This folder will remain empty at the time of submission.
- 12_WEB_ABSTRACT — This folder will remain empty at the time of submission.
- Author Submission Letter — The official submission of the Map Package will be accompanied by an author-signed letter addressed to the USGS MC. The letter will indicate that the current USGS standards have been employed in the preparation of the submitted Map Package. If necessary, the letter should describe where current standards were deviated from and why. At a minimum, the letter will contain the map name, scale, authors, and itemized contents of the submitted Map Package. The letter will also contain points the author feels should be considered during review and production, including preference (or non-preference) of selected map colors, symbol styles, figure placement, and anticipated or preferred map sheet and pamphlet contents. A template is included in the original Map Package for assistance, to be adapted as necessary.

Compliance Requirements and Review

The management and production of USGS SIM series products by the USGS Planetary Mapping Group constitute a lengthy and meticulous process that is unique to each mapping project. To facilitate a high quality, timely, and fair Technical Review Process, the USGS Planetary Mapping Group has implemented a Compliance Requirement prior to initializing Technical Review of the Map Package. Each Compliance Requirement also serves to streamline the Technical Review Process, not only for the USGS Planetary Mapping Group, but for the Technical Reviewers and Author as well, by identifying and correcting basic formatting errors early in the process.

The **Compliance Review** is a quantitative evaluation of strictly the folder structure and file content of the Map Package as dictated by the **Compliance Requirements** (described below). It is the Author's responsibility to prepare and collate a Map Package that is in accordance with the Compliance Requirements and submit this package for Compliance Review. Instructions for how to compile this folder structure are outlined in the "Map Package Submission Guidelines" section. These requirements will be updated regularly, and the Author should visit the USGS Planetary Mapping Group website to obtain the most current Protocol document. Note that a Map Package deemed to be **Compliant** (or in **Compliance**) has only been examined to the extent that all Map Package Components have been verified to exist and are in the appropriate format. Thorough scientific and technical assessment of the Map Package will be conducted during Technical Review.

The Map Package must meet the following requirements to pass Compliance Review:

1. The Map Package uses the specified folder structure. Compliance requires, but is not limited to, all specified folders being present and in the specified order, and all folders following the specified naming convention.
2. The Map Package is fully and correctly populated. Compliance requires, but is not limited to, all specified Map Package Components being present and in the specified format, all folders being populated, and all templates being removed.
3. The Map Package includes only the specified GIS Files. Compliance requires, but is not limited to, a clean geodatabase that does not have extraneous GIS Files (for example, versions, topologies, summary tables, empty feature classes, extra [unused] symbols), in addition to only the Primary Map Base, Supplemental Data, and any additional datasets cited in the Map Package.
4. The Geologic Map PDF file in the Map Package is exported at the specified publication scale and includes grids/graticules, Unit Labels, Nomenclature, and Figure locations.
5. The Figures in the Map Package are exported in the specified format and include distance and color scale bars (as necessary) and annotations (as necessary). Compliance requires, at minimum, that figures are in an editable format and have 300 dpi resolution; in cases where a figure features color variance but lacks a color scale bar, the figure must be accompanied by a written explanation of what the color variance represents.
6. The Geologic Map Text is formatted to specification and has the required sections. Compliance requires, at minimum, that documents are double-spaced, single-columned, and line-numbered, and have all required text sections.
7. Colors and symbols are consistent across all Map Package Components. Compliance requires, at minimum, that unit colors and feature colors and symbols to be consistent across the Geologic Map, DOMU, COMU, EOMS, and Figures.

Once the Map Package is compiled according to current requirements, the Author will submit the Map Package in

digital form to the USGS Planetary Mapping Group and provide official notice of the first submission for Compliance Review. The USGS Planetary Mapping Group will audit the Map Package to ensure Compliance. If the Map Package is determined by the USGS Planetary Mapping Group as Compliant, it will enter the Technical Review Process. If the Map Package is determined by the USGS Planetary Mapping Group to be **Non-Compliant** (or in **Non-Compliance**; that is, the Map Package does not conform to one or more Compliance Requirements), it will be returned to the Author without Technical Review and with citation of all Compliance Requirements that require correction. The Map Package will then need to be corrected and resubmitted in full.

If a Map Package is deemed Non-Compliant after first official submission, the Author has one more opportunity to satisfy the Compliance Requirements and submit for Compliance Review. If the Map Package fails to receive Compliance status after the second official submission, the Map Package has the potential to be rejected for USGS publication on grounds of Non-Compliance. If an Author is unsure how to satisfy one or more of the Compliance Requirements, they can solicit help from the USGS Planetary Mapping Group before submitting their Map Package for Compliance Review.

Technical Review Process

The **Technical Review Process**, which begins once the Map Package has been determined Compliant, consists of Technical Review, Author Responses, and USGS MC Verification. The Technical Review Process is coordinated and facilitated by the USGS Planetary Mapping Group, and timelines are established to encourage timely progression of the Map Package toward potential publication. The USGS MC will communicate with the Author and Technical Reviewers regarding timelines, instructions, and expectations.

The previous Technical Review Process, which was used until 2019, consisted of two Technical Reviewers, solicited from within the planetary geologic mapping community, who were advised to use approximately 40 hours to independently complete Technical Reviews of a Map Package and submit the review documents to the USGS MC. The two reviews they produced were then collated with the USGS MC's review into a single review document that was provided to the Author. The Technical Review Process could have repeated these steps a total of three times for one Map Package. Moving forward, we are no longer conducting reviews using this process.

To reduce the amount of time taken to review Map Packages, and to increase the consistency and clarity of Technical Reviews, we have tested and are now implementing a new Technical Review Process. The new process for handling reviews will consist of three parts: (1) Technical Review, comprising Pre-Panel Independent Reviews and the Review Collation Panel, conducted by two Technical Reviewers and the USGS MC; (2) Author Responses to the Technical Review; and (3) USGS MC Verification of the Author Responses to determine whether the required revisions were adequately implemented for the map to be Accepted for USGS publication. Detailed information follows in the next section.

The benefits of this new process are threefold. First, the Author is provided a single document, compiled from all Technical Reviewer comments, which contains thoughtful feedback and recommendations on how to remedy issues pointed out by the Review Collation Panel. This new process removes the need for the Author to address multiple reviewer documents and eliminates the potential for disparate or duplicative review comments. Second, through the Panel review, presentation of initial compiled review, and subsequent discussions, the USGS MC is better able to answer Author questions that may arise during revision of the Map Package in response to a particular comment. Third, the process of USGS MC Verification limits back-and-forth communication between the Author and Technical Reviewers, which expedites the Technical Review Process for the Author and constrains the time commitment required of the Technical Reviewers.

Technical Review

The new **Technical Review** procedure involves two required steps in sequence: (1) **Pre-Panel Independent Reviews** consisting of thorough reviews and documentation by two Technical Reviewers and the USGS MC, and (2) a **Review Collation Panel** that conducts an in-person or virtual teleconference discussion of the Pre-Panel Independent Reviews, generates a compiled review document that is consistent and thorough, and provides a Review Recommendation for the Map Package.

The Pre-Panel Independent Reviews work much like the previous review process. The USGS Planetary Mapping Group requests an initial review and complete documentation by three reviewers. The first Technical Reviewer will be a targeted member of the planetary geologic mapping community with expertise in geologic mapping, the body being mapped, and (or) the theme, unit types, or environment within the geologic map being reviewed. The second Technical Reviewer will be personnel from the USGS Planetary Mapping Group with expertise in planetary geologic mapping, USGS map publication standards, and the Protocol. Lastly, the USGS MC will simultaneously conduct an independent review to be incorporated during the Panel. The USGS MC, with assistance from other USGS Planetary Mapping Group specialists as needed, evaluates if the Map Package conforms to specified USGS Planetary Mapping Group conventions or not.

The **Technical Reviewers** are responsible for reviewing the entirety of the Map Package, as per the Technical Review Guidelines, for the Pre-Panel Independent Review. Technical Reviewers are allowed and encouraged to make recommendations regarding refinement of contact placement, unit division, and unit definition; such recommendations may necessitate remapping of specific areas by the Author. Using the most current Technical Review Guidelines and the provided template **Technical Review Form**, reviewers will generate an itemized list of detailed comments to the Author regarding the adequacy of all Map Package Components. This step is

expected to take about 16 to 24 hours of effort, and Technical Reviewers will typically have a lead time of at least 2 weeks to prepare comments before the Panel convenes.

The Review Collation Panel works in a very similar way to NASA ROSES panel reviews. The date of the Panel will be determined and agreed upon by all Technical Reviewers prior to receipt of the Map Package for review. During this second part of Technical Review, the external reviewer will travel to the USGS ASC in Flagstaff, Ariz., to spend three to four days (on average) discussing and collating their reviews with the USGS Planetary Mapping Group Technical Reviewer. In some cases, the Review Collation Panel can be conducted via teleconference software, if necessary. Depending on time zone differences and the possible length of workdays, the teleconference option can take up to 5 days to complete. When the Technical Reviewers have reached consensus and finished their compiled review, typically on the second day, they present their findings to the USGS MC, who will add any comments or suggestions from their own independent review. Nomenclature review will be addressed during the Panel by the USGS MC and USGS Nomenclature Specialist (see the "Support Personnel and Facilities" section). Once the reviewers and USGS MC agree on a Review Recommendation, the USGS MC notifies the Author of the Review Recommendation and provides the finalized Technical Review Form for Map Package edits and Author Responses.

Approaching submission, the Author can communicate with the USGS Planetary Mapping Group to organize an expected submit date. This provides the ability to schedule the Review Collation Panel in advance, which means that turnaround of the Technical Review can occur as quickly as two weeks after Compliance Review.

Technical Review Guidelines

The USGS Planetary Mapping Group created the **Technical Review Guidelines** provided here as a guide for formal Technical Review of Map Packages submitted for publication under the USGS SIM series. The "Map Package Components" section defines the template for completing standardized planetary geologic maps to ensure these products have a consistent format that is simple for users to assimilate and use. For the Pre-Panel Independent Review, Technical Reviewers identify both general and specific comments for each Map Package Component in comment-response form. These will then be discussed, agreed upon, and collated during the Review Collation Panel. The guidelines are as follows:

- Technical Reviewers are required to assess the accuracy of all components of the assigned Map Package, both individually and in total, prior to the Review Collation Panel. The process of cross comparison and corroboration of all components of a Map Package is one of the most critical aspects of a Technical Review.

- Technical Review comments will be explicitly listed per Map Package Component, allowing authors to respond directly to individual comments. Detailed commentary facilitates revision.

- Technical Reviewers, when examining the Map Package Components, may encounter issues for which they are uncertain whether community guidelines and standards, as published by the USGS, are consistently followed. When uncertainty exists, reviewers should recommend the Author consult with the USGS MC for clarification.

- Technical Reviewers need to substantiate their technical and scientific comments with the same care with which they report their own work; such substantiation includes (but is not limited to) the following examples.

  - GIS Files — GIS Files are examined for technical (not scientific) completeness prior to Technical Review. GIS Files are included in the Technical Review primarily as a means for reviewers to digitally examine the base maps and linework in detail. Reviewers are encouraged to examine, evaluate, and comment on the organization and completeness of the GIS Files. However, the bulk of the review will focus on the content of the other Map Package Components. Any changes recommended to non-GIS Map Package Components will likely require some changes in the GIS by the Author.

  - Geologic Map — The Geologic Map sheet (and accompanying base map prints) provides the basis for the Technical Review. As a supplement to the comments provided in the Technical Review Form, Technical Reviewers are encouraged to itemize general and specific comments through hand annotation of the map sheet, using leader lines to identify areas and features of commentary. Alternatively, reviewers can digitally annotate the included Geologic Map PDF file using comment markers.

    - Geologic contacts need to be clearly and consistently portrayed on the Geologic Map, and must corroborate and correspond with descriptions, justifications, and spatial and temporal associations presented in other Map Package Components. The consistent application of geologic contact types needs to be generally and specifically reviewed. Any inconsistencies will be explicitly denoted, with locations of the problem noted on the map sheet.

    - The use of different contact types must make cartographic and scientific sense. The contact symbology must be rooted in FGDC standard symbols. Any deviation from standard symbology will be justified by the Author and assessed by Technical Reviewers to ensure that the deviation is meaningful and well-applied.

    - Triple junctions should be assessed throughout the map to ensure stratigraphic relationships are

accurately represented. Stratigraphic relationships depicted by triple junctions should correspond with temporal associations presented in other Map Package Components.

- Contacts, units, and feature symbols should be consistently detailed across the entirety of the map. The density of linework should be representative of what is observed but must not be so overly dense as to obscure clear conveyance of map information.
- Unit Names and Labels should be applied consistently throughout the Map Package Components.
- Geographic Nomenclature should be based on IAU-approved names. The GIS annotation should be thorough (for the scale and bounding area of the map). Placement should be accurate.
- Unit colors should be consistently applied and visually appealing. Cross sections, if they exist, must be reviewed and corroborated with other Map Package Components for accuracy of observation and interpretation.
- Strike-dip orientation symbols, if they exist, need to be reviewed and corroborated with other Map Package Components for accuracy of observation and interpretation.

- Geologic Map Text — This text component is the basis for justifying the goal of the map with respect to past research, describing mapping methods and strategies, and integrating map observations (depicted in the collection of Map Package Components) into a broader geologic history. Technical Reviewers can include suggested edits and commentary within a "Track Changes" version of the Geologic Map Text .docx file, but only in support of comments listed in the provided Technical Review Form.
  - The writing should be clear and comprehensive, yet succinct. Objectivity should pervade the map document to the greatest extent possible. The Geologic Map Text should avoid excessive topical science results unless they are critical to establishing the geologic observations and interpretations. Existing literature, including peer-reviewed documents published in support of the Geologic Map, should be leveraged.
  - Sections and sub-sections should reasonably conform to current guidelines and (or) recently published maps. Deviations from guidelines and (or) recently published maps should be explicitly justified in the Geologic Map Text.
  - The rationale for the Geologic Map should be succinctly summarized and compared and (or) contrasted with geologic units published in previous maps of the region.
  - The physiographic setting should be described and reference only IAU-approved Nomenclature. All IAU-approved names used in the Geologic Map Text should be listed on the map, and vice versa.
  - The Primary Map Base and Supplemental Data should be described.
  - Methods and Data should be described, including software used to digitize, display, and analyze map-related data. Digital Mapping Scale and vertex spacing should be noted. Mapping strategy (and variants thereof) can be mentioned insofar as it is helpful for users to understand how the map was compiled.
  - Age Determinations should be clearly described.
  - A Geologic History must be included; it should be parsed by appropriate geologic time scale and comprehensively integrate all of the mapped units and features. Reasonable alternatives (including those that relate to existing literature) should be denoted.
  - References should be inclusive of the current body of literature and formatted as per USGS guidelines. All references listed in the Geologic Map Text should be included in the References Cited section, and vice versa.
- Description of Map Units — The DOMU component provides the basis for graphically conveying the spatial and temporal relationships of the mapped geologic units.
  - Descriptions should be tabulated, separating out Unit Label, Name, Definition, **Additional Characteristics**, and Interpretations.
  - All parts of the DOMU should be evaluated for succinctness. Complete sentences are not recommended. Rather, individual characteristics should be separated by period or semicolon (for similar themes).
  - Definitions should describe the major and spatially consistent characteristics of geologic units as identified on the Primary Map Base. Definitions can include a type locality. Characteristics of units should be presented in consistent order.
  - **Additional Characteristics** can include other (non-definition) characteristics, including local variations identified in Supplemental Data.

  - Interpretations should be reviewed to ensure they reasonably follow observations, and any inconsistencies should be explicitly noted by Technical Reviewer. Interpretations should include reasonable alternatives.
  - Units should be presented in corresponding order to the COMU, including unit groupings.
  - Unit groupings can contain brief summaries of geographic occurrence and bulk characteristics.
  - Thumbnail images per geologic unit are not recommended. Inclusion of thumbnail images requires justification in the Geologic Map Text.
  - DOMU content must be consistent with content presented in other Map Package Components, including the Geologic History of the Geologic Map Text.
  - Major features that are mapped within units must be sufficiently integrated into the Unit Definitions and Interpretations.
- Correlation of Map Units — Technical Reviewers are encouraged to provide general and specific review comments regarding the stratigraphic correlation of geologic units, structures, and events related to the COMU. The Technical Review Form can be augmented, as necessary, through hand annotation of the COMU.
  - Unit Names, Labels, and colors must be complete and consistent with what is presented in other Map Package Components.
  - Any unit groupings (and sub groupings) must be depicted.
  - The temporal associations implied by a unit's vertical placement and length accurately correspond to and are compatible with cross-cutting relationships, Unit Names, Unit Labels, DOMU, Geologic Map Text, Figures, and Tables.
  - Units are organized in chronologic order with youngest units (or groups of units) shown on the left.
  - A geologic time scale is included and accurately depicted on the left-hand side of the COMU.
  - A "Key" (if included) must depict all facets of the COMU.
  - An "Event Column" (if included) must depict all facets of the Geologic History, DOMU, and other Map Package Components, and must accurately correspond to all other Map Package Components.
- Explanation of Map Symbols
  - All symbols applied on the map must be listed and described.
  - Symbols must be rooted in FGDC geographic standards.
  - Symbols must be clearly described, justified, and consistently applied.
  - Symbols must be used to delineate discrete features.
- Figures and Captions — Geologic Maps can include Figures on the map sheet as well as in the accompanying pamphlet. However, the number of Figures (especially color figures) should be minimized. The Author is responsible for using Figures when necessary to clearly convey aspects of the geologic mapping and interpretation that are not apparent in the scaled Geologic Map and associated Map Package Components.
  - The number of Figures will be reviewed to ensure that the content they display is well justified for inclusion in the Geologic Map. Technical Reviewers will ascertain whether the number and content of Figures are fully warranted for inclusion in the Geologic Map document. Extraneous Figures are discouraged in the Map Package.
  - Black and white figures should be used where possible and the number of color figures should be minimized.
  - Cross sections must have Unit Labels and colors, symbology, and Nomenclature identified and identical to those represented on the map. All symbols and geologic units in cross sections must be included in the EOMS, COMU, and DOMU.
  - Cross sections must have the same horizontal scale as the Geologic Map; the vertical exaggeration must be indicated; and degree of vertical exaggeration should be adequate to show necessary detail, but not excessive.
  - Figure locations (extents and identifiers) must be included on the map sheet.
  - Scale bars must be included.
  - By default, north is toward the top; the use of any other orientations must be denoted.
  - Figures must be clearly and thoroughly annotated.
  - Captions must be comprehensive yet succinct and include grid and graticule (or center latitude and longitude) and reference to data sources (including image number, as necessary).

- Figures must be referenced in order of their appearance within the Geologic Map Text.

- Tables
  - Tables must include a title that summarizes the table contents.
  - Tables must be referenced in order of their appearance within the Geologic Map Text.
  - A time stratigraphic relationships table (if included) should accurately reflect the temporal occurrence of units as depicted in the COMU.
  - Notations (if present) must be succinctly described underneath the table.

Technical Review Recommendations and Timelines

The USGS MC, as part of the Review Collation Panel, will evaluate the scope of recommended changes to the Map Package as a whole and assign a Review Recommendation. This will determine next steps for the Author and Map Package. The **Review Recommendation** is based on map accuracy, conciseness, representation, and scientific substantiality. These factors are defined as follows:

- Accuracy — The Author has correctly documented the mapping methods and the discrete geologic units and features that result from these methods, as well as how these mapped units and features relate within a temporal and spatial framework.
- Conciseness — The Author has constrained the map product to only what is required to establish and convey the geologic context and has avoided (where possible) detailed and interpretative analyses that reside outside the scope of the map product.
- Representation — The Author uses appropriate classifications, spatial densities, and cartographic symbols to represent geologic elements (for example, point and line features, contacts, and units) discernable at the publication scale.
- Scientific substantiality — The Author has generated a map product that provides a notable improvement and (or) refinement of the context established by previously published maps (including Standardized and Non-Standardized Maps and other topical studies) or has sufficiently defined context in instances where no geologic maps currently exist.

We expect that every reviewed Map Package will have some degree of revisions recommended by the Panel. Minor revisions encompass changes that require low-level revision of the Map Package such as altering part of the Geologic Map Text, annotating a Figure, changing phrasing within the DOMU, or changing the symbology of a geologic element. Moderate and major revisions encompass higher-level revision of the Map Package that must be integrated across multiple Map Package Components and significant changes to the GIS Files. Based upon the amount of revision recommended, the Review Recommendation options are defined as follows:

- "Accept and publish with minor revision" — The Author has presented an accurate, concise, and (or) representative geologic map product that is scientifically substantial. Therefore, the Panel recommends the Map Package be Accepted for USGS publication, pending minor revisions.
- "Resubmit with moderate revision" — The Author has presented a geologic map product that is mostly accurate, concise, representative, and (or) scientifically substantial, and which has the potential for USGS publication. Therefore, the Panel recommends moderate Map Package Component revision by the Author and reevaluation in total by the USGS MC.
- "Resubmit with major revision" — The Author has presented a geologic map product that is not an accurate, concise, and (or) representative geologic map product, and (or) is not clearly scientifically substantial, but which has the potential for USGS publication pending major structural revisions. Therefore, the Panel recommends major Map Package changes by the Author and reevaluation in total by the USGS MC.

The Review Recommendation a Map Package receives will dictate the subsequent steps in the Technical Review Process. For Map Packages that receive an "Accept and publish with minor revision" recommendation, the Author will incorporate all Review Collation Panel feedback and provide the updated Map Package to the USGS MC by a Target Date set within two months. If a Map Package receives a "Resubmit with moderate revision" or "Resubmit with major revision" recommendation from the Review Collation Panel, the Author must provide the entire updated Map Package for resubmission by a Target Date set within four months.

For instances where the USGS MC deems Review Collation Panel comments have not been sufficiently addressed by Author Responses, the resubmitted Map Package will not be reevaluated and will be returned to the Author with a summary of how the responses were inadequate. The Author will have a single opportunity to readdress Review Collation Panel recommendations and resubmit the Map Package and Author Responses to the USGS MC for verification before the Map Package is eligible for rejection on grounds of failure to complete Technical Review.

Author Responses

Following completion of the Review Collation Panel, the USGS MC will provide the complete Technical Review Form to the Author, who is responsible for addressing and

incorporating all recommended changes from the Panel into and across all Map Package Components, including the GIS, via **Author Responses**. The Author needs to be prepared to alter linework (points, lines, polygons), description, interpretation, or documentation based on Panel comments and (or) to provide commentary on why particular Panel comments were or were not incorporated into the resubmitted Map Package. The Author will compile an Author Responses document that responds to each itemized Technical Review comment, providing information on how the comment was addressed. Across-the-board rejection of Panel comments will not be accepted. The Author will then submit the updated Map Package along with Author Responses to the USGS MC.

USGS MC Verification

The **USGS MC Verification** is the assessment of the resubmitted Map Package to ensure that all Technical Review comments are fully addressed and the required changes have been integrated into the Map Package. This verification by the USGS MC is completed with support from the USGS Planetary Mapping Group and with as-needed input from the Technical Reviewers. The USGS MC will examine every comment-response line and evaluate if changes or other appropriate responses were made to the Map Package and whether such efforts sufficiently address both the explicit recommendation and the "spirit" of each comment (that is, the intention behind each comment made by the Panel). Based on this evaluation, the USGS MC will either (1) notify the Author that the Map Package has been Accepted (commonly pending minor itemized revisions), (2) return the Map Package with itemized Panel comments that were not sufficiently addressed and require resubmission within two months, or (3) reject the Map Package for USGS publication.

Map Package Acceptance or Rejection

To receive **Acceptance** (be **Accepted**) for publication, Map Packages must have been submitted as Compliant and entered the Technical Review Process before its Sunset Date and must have been satisfactorily reviewed by Review Collation Panel and updated by the Author within the specified timeline. During USGS MC Verification, the USGS MC will assess if changes made to the Map Package based on Panel recommendations resulted in an accurate, concise, and representative geologic map product that is scientifically substantial. In positive cases, the USGS MC will make the decision to accept the Map Package for USGS publication.

There are four factors that affect whether a Map Package will be **Rejected** (receive **Rejection**) for USGS publication:

- Compliance — If the Map Package fails to successfully pass Compliance Review after the second official submission, the Map Package has the potential to be rejected for USGS publication on grounds of Non-Compliance.
- Sunset Date — If the Map Package fails to enter the Technical Review Process by the Sunset Date, the Map Package has the potential to be rejected for USGS publication on grounds of Sunset Date violation.
- Delinquency — If, during the Technical Review Process, the Map Package is not received by the USGS MC by the agreed upon Target Date, the Map Package has the potential to be rejected for USGS publication on grounds of Delinquency.
- USGS MC Verification — If the USGS MC deems the resubmitted Map Package has not been changed enough to reach USGS publication standards based upon Author Responses to Panel comments, then the Map Package has the potential to be rejected for USGS publication on grounds of failure to complete Technical Review.

If an Author has been notified of Rejection by the USGS MC, they can appeal rejection. The Author should submit a letter to the USGS MC that explains why the map deserves additional consideration for publication as a USGS SIM series map product. The USGS MC will engage in a discussion with the Geologic Mapping Representative to MAPSIT to consider the concerns of the appeal letter and correspond with the Author to resolve the appeal. Decisions made by the USGS MC to resolve the appeal are final.

Sunset Date and Target Dates

The Sunset Date and Target Dates prevent funded geologic maps from stalling during the mapping and (or) Technical Review Process. The **Sunset Date** is established by the Author and USGS MC after a proposal is selected for funding and indicates the date whereby the Author will have passed the Map Package successfully through Compliance Review and into the Technical Review Process. The Sunset Date is typically the last day of the final funded year of the project plus two years to account for No Cost Extensions potentially obtained by the PI and (or) Author. The sunset date extension is subject to change per NASA programmatic decisions. Projects that are nearing the Sunset Date should closely coordinate with the USGS Planetary Mapping Group in order to maintain timely submission and review of the Map Package. Map Packages that do not enter the Technical Review Process by the defined Sunset Date have the potential to be rejected for USGS publication. In such cases, USGS support for that particular project will cease.

When a Compliant Map Package enters the Technical Review Process, the Author must follow the timelines throughout the process (see the "Technical Review Recommendations and Timelines" section). These timelines are facilitated by setting **Target Dates**. For instances where physical materials are mailed, the USGS MC will adjust the Target Date accordingly. If an Author does not meet a Target Date, the Map Package has the potential to be rejected for USGS publication on grounds of **Delinquency** (being **Delinquent**).

We all acknowledge that unforeseen and extraneous circumstances may affect the timely progression of the Mapping Process. Though the USGS Planetary Mapping Group will assist in coordinating and following up on Mapping Process timelines throughout the funding cycle of the project, it is ultimately the PI's and Author's joint responsibility to contact the USGS MC prior to the Sunset Date and Target Date to request an extension. In general, the Author may only receive one extension. As always, communication is key to moving through the process.

Editing and Production

After Acceptance, the USGS Planetary Mapping Group will confirm to the Author that the Map Package is complete before forwarding the entire package to the USGS PSC for editing and production. The project is considered complete with respect to NASA's timeline when the USGS MC has Accepted the Map Package for publication. Any correspondence needed from the Author after Map Package submission to the USGS PSC is minimal and intermittent. To reduce communications and expedite the production process, the USGS Planetary Mapping Group will work closely with the USGS PSC to address first-order needs without direct input from the Author. These needs are generally related to nonscientific aspects of the Geologic Map (for example, grid and graticules, scale bars, symbols, Nomenclature and Unit Label placement). If there are content specific and (or) scientific changes to the map that arise during production and require input from the Author, USGS Planetary Mapping Group personnel will contact the Author directly to receive guidance and input. During production, the Author will be contacted for input on map layout and pamphlet content, as well as to proof the map layout before it is finalized for publication. Proof edits will be restricted to broad-scale formatting issues (for example, label completeness and placement). No significant content changes are allowed after the Map Package has been Accepted and delivered to the USGS PSC.

The USGS PSC editing and production process enhances USGS map products by ensuring all USGS products look and feel the same for user familiarity. This includes making sure all fonts, lines, and symbols are the correct size, color, and shape across the map product, and that the map product meets Explanation Standards by size and content (such as coordinate tick marks and scale bars).

Printing and Web Posting

Once the map proof has been approved by the Author and USGS Planetary Mapping Group, the USGS PSC submits the completed map to the Government Publishing Office for bid and printing. Copies of the map are produced according to anticipated demand (as directed by the USGS MC) with a portion sent directly to the Author and the rest received by both the USGS ASC in Flagstaff, Ariz., and the USGS Publications Warehouse in Denver, Colorado. The USGS ASC will distribute the map, and additional copies can be requested by both the scientific community and the general public through the USGS Planetary Mapping Group. Digital files of map materials— including PDF files of all printed materials produced by the USGS PSC as well as the GIS database, metadata, readme, and Supplemental Data files—are posted to the USGS Publication Warehouse and (or) ScienceBase for download (which, importantly, are PDS-equivalent archives because of their long-term, archival nature).

Common Mapping Pitfalls

The following list identifies common pitfalls that the USGS Planetary Mapping Group has observed in the Mapping Process and resulting Map Packages.

- The Author did not clearly separate observations from interpretations, specifically within the DOMU and Geologic Map Text.
- The Geologic Map Text is missing sections and (or) is written like a proposal or journal manuscript.
- The DOMU does not have consistent wording and content order from unit to unit, or language is not consistent between the DOMU and other Map Package Components.
- The GIS Files are not clean; they may include extraneous files, versioned feature classes, unused attribute fields, topology layers.
- Figures are excessive, unannotated, or too large.
- The list of authors is excessive and includes scientists who did not make notable contributions to the map and are therefore not familiar with the content of each Map Package Component.
- Symbols are used that are not from the FGDC standard symbol set.
- Use of more than one Primary Map Base; there should only be one dataset that all linework is drawn on and from which all units are defined.
- Naming or descriptive language is not consistent across all Map Package Components.
- No minimum threshold is applied to lines and (or) polygons.
- The Author uses the Technical Review Process as a copy edit.
- The Author references "variable" or "various sources" in their interpretations.
- Interpretations within the Map Package and specifically the DOMU do not match with—and clearly follow from—observations.

- The text does not use first person, past tense, active voice.
- The organization of units uses numeric names and labels for non-temporal sequencing.

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Useful Web Pages

For the most current guidance and resources, visit the Planetary Geologic Mapping website (https://planetarymapping.wr.usgs.gov/). This site maintains information on all published and in-progress USGS planetary maps, details on the USGS mapping process, meeting notes, guidelines, and resources that may be useful for mappers.

For GIS and data-specific resources, visit the MRCTR GIS Lab website (http:/astrogeology.usgs.gov/facilities/mrctr-gis-lab). This site hosts tools, tutorials (targeting ArcMap and ArcGIS Pro) as well as links to the GIS Forum. This should be the first stop for questions about planetary GIS, common mapping workflows, and best practices.

For GIS tools, symbols and data management resources, mappers may find the following web pages useful:

- USGS Astrogeology GitHub Repository (https://github.com/USGS-Astrogeology)
- FGDC Digital Cartographic Standard for Geologic Map Symbolization (https://ngmdb.usgs.gov/fgdc_gds/)
- USGS Metadata Creation (https://www.usgs.gov/products/data-and-tools/data-management/metadata-creation)
- QGIS introductory planetary tutorial (https://github.com/USGS-Astrogeology/QGIS_tutorials)
- Planetary Geologic Symbols Library for QGIS (https://github.com/afrigeri/geologic-symbols-qgis)

For general mapping resources, mappers may find the following web pages useful:

- Projection Wizard, for determining an appropriate map projection based on latitude and scale (https://projectionwizard.org/)
- Astrogeology Cloud Processing, for cloud-hosted imagery processing (“Map a Planet” and “Map Projection on the Web”; https://astrocloud.wr.usgs.gov/)
- USGS Astropedia search portal (http://astrogeology.usgs.gov/search)

For general planetary science community resources, mappers may find the following web pages useful:

- IAU Gazetteer of Planetary Nomenclature Descriptor Terms (https://planetarynames.wr.usgs.gov/DescriptorTerms)
- IAU Gazetteer of Planetary Nomenclature KML and Shapefile Downloads (feature location GIS downloads; https://planetarynames.wr.usgs.gov/GIS_Downloads)
- IAU Gazetteer of Planetary Nomenclature Feature Name Request Form (https://planetarynames.wr.usgs.gov/FeatureNameRequest)
- IAU Naming of Astronomical Objects (https://www.iau.org/public/themes/naming/#spelling)
- Lunar and Planetary Institute’s Planetary Sciences Community Meetings Calendar (https://www.hou.usra.edu/meetings/calendar/)
- NASA Research Opportunities (http://nspires.nasaprs.com)
- Planetary Exploration Newsletter Meeting Calendar (http://planetarynews.org/meetings.html)

Support Personnel and Facilities

The following personnel and points of contact are current as of the date of publication. On the basis of programmatic needs, however, personnel and points of contact are subject to change.

- Jim Skinner, USGS Mapping Coordinator

  jskinner@usgs.gov
  (928) 556-7043

- Corey Fortezzo, Alternate USGS Mapping Coordinator

  cfortezzo@usgs.gov

- Tenielle Gaither, USGS Nomenclature Specialist

  tgaither@usgs.gov

- USGS Planetary Mapping Group
- For Mapping Process help, contact pgm_help@usgs.gov
- The MRCTR GIS Lab at the USGS ASC is available for funded mappers and provides both in-person and web-based resources for the planetary research community. The lab supports GIS graphical, statistical, and spatial tools for analyses of planetary data, including the distribution of planetary GIS tutorials, tools, programs, and information. Authors are recommended to use the MRCTR GIS Lab as a resource for starting map projects. An Author who wishes to visit the MRCTR GIS Lab and receive GIS help or USGS SIM product guidance should contact the USGS Planetary Mapping Group to organize a time to visit. Please note that workstations in the lab are limited, as are the availabilities of USGS Planetary Mapping Group personnel. The MRCTR GIS Lab should be used by an Author who wishes to apply their fundamental knowledge of GIS to a planetary geologic mapping setting; the lab should not be the venue for an Author to learn the fundamentals of GIS.

Glossary

Acceptance/Accepted the status a Map Package receives from the USGS MC based on the assigned Review Recommendation; Map Packages exit Technical Review when they receive this status.

Acknowledgments the section of the Geologic Map Text where funding and other relevant information are cited.

Additional Characteristics the section of the Description of Map Units with geologic unit characteristics described using Supplemental Data; can include local observations that are consistently observed and (or) important to the Interpretations of geologic units; may include image numbers, where appropriate.

Age Determinations the section of the Geologic Map Text that discusses dating techniques used for map units and reliability of the derived relative and (or) absolute model ages.

Annual Planetary Geologic Mappers Meeting the required venue through which mappers with active NASA-funded mapping projects will report on the progress of mapping, ongoing science tasks, and (or) results (as per NASA ROSES Appendix C.1).

Author the first author of the Map Package who is responsible for ensuring the Map Package adheres to all requirements and who is the sole correspondent to the USGS Planetary Mapping Group.

Author Responses the second step of the Technical Review Process where the Author will submit to the USGS MC (1) the revised Map Package and (2) a document of responses listing how all recommended changes from Technical Review were addressed and incorporated into and across all Map Package Components, including the GIS.

Captions the Map Package Component where caption information for Figures and Tables are provided.

Compliance/Compliant the status a Map Package receives when it has satisfied all Compliance Requirements, and which allows it to enter the Technical Review Process.

Compliance Requirements specific conditions that the Map Package must satisfy in order to be deemed Compliant and which pertain to Map Package formatting and Map Package Component existence and formatting.

Compliance Review a quantitative evaluation of strictly the folder structure and file content of the Map Package as dictated by the Compliance Requirements.

Confirmation of Technical Specification Document the document required in a Step-2 proposal to confirm technical reasonability and feasibility of a mapping investigation (as per NASA ROSES Appendix C.1).

Correlation of Map Units the Map Package Component that is a visual representation of how mapped geologic units are oriented in space and time, relative to one another and established geologic time scales (where known).

Cover Art the Map Package Component that is the art displayed on the envelope which contains the final, published Map Package.

Delinquency/Delinquent the status a Map Package receives when it is not submitted by a Target Date.

Description of Map Units the Map Package Component that is a concise description of the map units, their stratigraphic relations, interpretations, and other pertinent information.

Digital Mapping Scale the scale used to display the Primary Map Base when mapping geology and features in GIS; the Digital Mapping Scale is usually a factor of 4 larger than the published map, to ensure adequate precision and representation (for example, 1:250,000 for a 1:1,000,000-scale map).

Explanation of Map Symbols the Map Package Component that is a chart on the map sheet which includes all line, point, and stipple symbols, with a feature name, brief explanation, and basic interpretation.

Figures the Map Package Component used to show examples of critical geologic unit and (or) feature characteristics and temporal relationships.

Geologic History the section of the Geologic Map Text that provides an interpretive context for the entire geologic map.

Geologic Map the Map Package Component that has the geologic contacts, units, and features overlain with transparency on the Primary Map Base and includes Unit Labels, Nomenclature, grids/graticules, Figure locations, and other relevant attributes; the fundamental product of any NASA-funded mapping investigation for USGS publication.

Geologic Map Text the Map Package Component that contains the following sections: Introduction, Methods and Data, Mapped Features, Age Determinations, Geologic History, Acknowledgments, and References Cited.

GIS Files the Map Package Component that includes the Primary Map Base, Supplemental Data, coordinate system file, layer files, clean geodatabase, and digital map document file.

Interpretations the section of the Description of Map Units that addresses plausible origins of mapped units based on the Unit Definitions and Additional Characteristics, including primary (depositional) features, secondary (erosional or modificational) features, and stratigraphic relationships; USGS maps are contextual, objective, and enduring products, and the Interpretations section must reflect the degree of uncertainty the Author places on the interpretation, where possible, understanding that most geologic interpretations cannot be definitive.

Introduction the section of the Geologic Map Text that introduces the map area (including its geography and general geologic setting), summarizes previous contextual and scientific work for the map region, and establishes why a new map is warranted for the chosen region at the chosen Publication Map Scale.

Map Package a digital file system containing the folder structure required by Compliance Review, and to be populated by the Author with all Map Package Components.

Map Package Components the components that define the Map Package: GIS Files, Geologic Map, Geologic Map Text, Description of Map Units, Correlation of Map Units, Explanation of Map Symbols, Figures, Captions, Tables, Cover Art, Metadata.

Mapping Process the steps by which NASA-funded USGS-published maps are generated, including but not limited to: proposal specifications, Map Package receipt, digital mapping, Map Package submission, Compliance Review, the Technical Review Process, editing and production, and printing and web posting.

Mapped Features the section of the Geologic Map Text that provides detailed description of all linear features, point features, and stipple patterns.

Metadata the Map Package Component that provides the necessary ancillary documentation that describes each GIS layer in a geologic map, including rationale, authorship, attribute descriptions, spatial reference, data lineage (including geoprocessing), and other pertinent information as required by the FGDC metadata standard; generally completed by the USGS PSC personnel in the editing and production stage of the Map Process.

Methods and Data the section of the Geologic Map Text that summarizes all datasets (including the Primary Map Base and Supplemental Data) and methods (drafting, organizational, or other) that were used to construct the map or needed to identify and discriminate map units and features critical to determining the geologic character and history.

NASA ROSES Appendix C.1 Planetary Science Research Program Overview.

Nomenclature official names approved by the IAU that are used to uniquely identify geographic features on the surface of a planet or satellite so that it can be easily located and described, and used as a geographic reference.

Non-Compliance/Non-Compliant the status a Map Package receives when it does not conform to at least one Compliance Requirement.

Non-Standardized Map a map product that is not required to adhere to strict content and formatting standards for publication (for example, map products published in a peer-reviewed journal article).

Planetary Geologic Mapping Protocol the document produced by the USGS Planetary Geologic Map Coordination Group that sets standards and defines requirements for the USGS SIM series map production process (this document); also referred to in the text as the "Protocol."

Pre-Panel Independent Review the first part of Technical Review which involves individual reviews and documentation of the Map Packages by Technical Reviewers in preparation for in-person discussion during the Review Collation Panel.

Primary Map Base the single controlled (or semi-controlled) cartographic product whereupon geologic units and features are defined and delineated; sometimes referred to as Map Base Layer.

Principal Investigator the Principal Investigator is responsible to NASA for the generation of planetary geologic maps to be published by the USGS and for communicating with the USGS Planetary Mapping Group during the proposal stage and project initiation. In the case that the Principal Investigator is the first author of a submitted Map Package, the Principal Investigator will also assume the role of Author as the project progresses.

Protocol see entry for Planetary Geologic Mapping Protocol.

Publication Map Scale the scale used to display the Geologic Map on the hard-copy map sheet used for publication; will be decided between the PI/Author and USGS MC at the proposal stage when finalizing the Specification Document.

References Cited the section of the Geologic Map Text that lists all documents and resources cited throughout the Map Package.

Rejection/Rejected the status a Map Package receives when it is deemed Non-Compliant, misses its Sunset Date, becomes Delinquent during the Technical Review Process, or is determined as such by the USGS MC based on the assigned Review Recommendation.

Review Collation Panel the second part of Technical Review which involves an in-person discussion of the Pre-Panel Independent Reviews hosted at the USGS ASC in Flagstaff, Arizona, and where the Technical Reviewers and USGS MC will generate a compiled, consistent, and thorough Technical Review Form for the Author, and provide a Review Recommendation for the Map Package.

Review Recommendation the recommendation provided by the Review Collation Panel based upon accuracy, conciseness, representation, and scientific substantiality of the Map Package to determine publication status; the three recommendations are "Accept and publish with minor revision", "Resubmit with moderate revision", and "Resubmit with major revision."

Specification Document refers to the Confirmation of Technical Specification Document.

Standardized Map a map product that is required to adhere to strict content and formatting standards (that is, USGS-published planetary geologic map products).

Sunset Date established between the PI and the USGS MC and is the final date whereby the Map Package must pass through the Compliance Review and enter into the Technical Review Process; typically defined as the last day of the final funded year plus two years to account for No Cost Extensions potentially obtained by the PI/Author; a lack of adherence to this date jeopardizes USGS support and potential publication of Map Packages.

Supplemental Data datasets used in tandem with the Primary Map Base to enhance the identification and investigation of geologic elements during the Mapping Process; derived observations are incorporated into the Additional Characteristics column of the Description of Map Units.

Tables the Map Package Component that provides details about various aspects of the map and (or) features contained within the map boundary that are relevant to establishing the geologic context and history.

Target Dates due dates that facilitate a timely Technical Review Process.

Technical Review the two-part process, Pre-Panel Independent Review and Review Collation Panel, by which Technical Reviewers evaluate and provide comments to the Author on each Map Package Component and determine a Review Recommendation for the Map Package.

Technical Review Process the three-step process by which a Compliant Map Package is technically evaluated for potential USGS publication: (1) Technical Review, (2) Author Responses, and (3) USGS MC Verification.

Technical Reviewer peers of the planetary geologic mapping community assigned by the USGS MC who are responsible for reviewing the entirety of the Map Package during the Technical Review Process.

Technical Review Form an itemized list of detailed comments regarding the adequacy of all Map Package Components; this is initially generated by Technical Reviewers during the Pre-Panel Independent Review, then discussed and consolidated into a single document during the Review Collation Panel, and then provided to the Author.

Technical Review Guidelines the set of guidelines provided by the USGS Planetary Mapping Group for Technical Reviewers during the Technical Review Process.

Unit Definitions the section of the Description of Map Units that provides a unique definition for each geologic unit based on widely occurring and (or) unique, primary (depositional) and secondary (erosional or modificational) characteristics made in the Primary Map Base; these definitions are succinct yet sufficient to identify and discriminate each map unit from all others.

Unit Label each geologic unit must have a unique series of letters and (or) numbers which forms a Unit Label that is logical and representative of the unit age, grouping, and (or) distinguishing characteristics.

Unit Name each geologic unit must have a unique name that is logical and representative of the unit age, grouping, and (or) distinguishing characteristics.

USGS MC Verification the third step of the Technical Review Process which involves the USGS MC, with support from the USGS Planetary Mapping Group and as-needed input from the Technical Reviewers, assessing changes to the Map Package to ensure that all Technical Review comments are fully addressed and the required changes are integrated.

Planetary Geologic Mapping Program the NASA-funded, USGS-coordinated program that facilitates the production of USGS SIM series planetary geologic map products and supports the broader planetary geologic mapping community.

USGS Planetary Mapping Group see entry for USGS Planetary Geologic Map Coordination Group.

USGS Planetary Geologic Map Coordination Group the group of people located at the USGS ASC who are funded by NASA to coordinate the USGS-NASA Planetary Geologic Mapping Program; also referred to in the text as the "USGS Planetary Mapping Group."

USGS Planetary Geologic Map Coordinator the head of the USGS Planetary Geologic Map Coordination Group; abbreviated as USGS MC.

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