Planetary Geologic Mapping Protocol–2018

Skinner, J. A., Jr., Huff, A. E., Fortezzo, C. M., Gaither, T. A., Hare, T. M., and Hunter, M. A.

The Planetary Geologic Map Coordination Group
Astrogeology Science Center
U. S. Geological Survey
2255 N. Gemini Dr.
Flagstaff, AZ 86001

This document covers the idealized process of compiling a map product for 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 by other, non-USGS, venues. This is a reference document for planetary geologic mapping community members to consult as needed for specific information regarding the Mapping Process. This contains internal hyperlinks for quick navigation.

https://planetarymapping.wr.usgs.gov/Page/view/Guidelines

Please forward comments and (or) suggestions to: pgm_help@usgs.gov

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0. Abbreviations and Definitions

Within this text, abbreviations are defined and bolded at the location of their first reference. In contrast, key definitions are bolded at the location they are defined, which may or may not be their first reference. We compiled this to be a reference document instead of a "read-through" document, meaning users will seek specific sections depending on what information they need. Therefore, we felt that defining terms where they are most relevant, instead of at first instance, would generally be more useful.

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

Acknowledgements – the section of the Geologic Map Text where funding and other relevant information are cited

Additional Characteristics – geologic unit characteristics described in the DOMU using Supplemental Data; can include local observations that are consistently observed and (or) important to the Interpretation of the geologic unit; may include image numbers, where appropriate

Age Determinations – the section of the Geologic Map Text where the techniques used and the reliability of the derived relative and (or) absolute model ages for map units are discussed

Annual Mappers Meeting – refers to the Annual Planetary Geologic Mappers Meeting

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 Section 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

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

COMU – refers to the Correlation of Map Units

Confirmation of NASA Selection – the document provided to the Author by the USGS MC after the proposal has been selected for funding by NASA

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

Correlation of Map Units – 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 art displayed on the envelope that 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 – a concise description of the map units, their stratigraphic relations, interpretations, and other pertinent information

Digital Mapping Scale – the scale used for displaying the Primary Map Base when mapping geology and features in GIS

DOMU – refers to the Description of Map Units

EOMS – refers to the Explanation of Map Symbols

Explanation of Map Symbols – a chart on the map sheet that includes all line, point, and stipple symbols, with a feature type name, brief explanation, and basic interpretation

FGDC – Federal Geographic Data Committee

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 which has the geologic contacts, units, and features overlain with transparency on the Primary Map Base and includes Unit Labels, Nomenclature, grids/graticules 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, Acknowledgements, References

GIS – geographic information system

GPO – General Printing Office

IAU – International Astronomical Union; this union names and approves Nomenclature

Interpretation – the section of the DOMU that addresses plausible origins of the mapped unit based on the Unit Definition 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 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 area, and establishes why a new map is warranted for this region and at this 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, DOMU, COMU, EOMS, Figures, Captions, Tables, Cover Art, Metadata

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

MC Review – the step in the Technical Review Process where the USGS MC reviews the Map Package

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

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

NASA – National Aeronautics and Space Administration

NASA ROSES – NASA Research Opportunities in Space and Earth Sciences

NASA ROSES Section C.1 – Planetary Science Research Program Overview

NCE – no cost extension (NASA protocol)

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/-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 (e.g., map products published in a peer-reviewed journal article)

Planetary Geologic Mapping Protocol – the document produced by the USGS Planetary Geologic Map Coordination Group which set standards and defines requirements for the USGS SIM series map production process (this document)

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

Protocols – refers to the Planetary Geologic Mapping Protocol document and the content therein

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 – the section of the Geologic Map Text that lists all documents and resources cited throughout the Map Package

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 as determined by the USGS MC based on Review Recommendations

Review Recommendation – the recommendation provided by peers in the Technical Reviews which are used by the USGS MC to determine publication status (i.e., Acceptance or Rejection)

ROSES – Research Opportunities in Space and Earth Sciences

RPIF – Regional Planetary Image Facility; an international system of planetary image and information libraries that serves to store historical and on-going information relative to space sciences

Selection Document – refers to the Confirmation of NASA Selection document

SIM – Scientific Investigations Maps; the series through which NASA-funded USGS planetary geologic maps are published

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 (i.e., USGS-published planetary geologic map products)

Sunset Date – defined by the USGS MC in the Selection Document at the beginning of the project (and acknowledged by the PI/Author) as the final date whereby the Map Package must pass through the Compliance Review and enter into the Technical Review Process; typically 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)

Supplemental Data – data sets used in tandem with the Primary Map Base to enhance the identification and investigation of geologic elements during the Mapping Process; these observations can be incorporated into the Additional Characteristics column of the DOMU

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 Date – the dates that facilitate the timelines of the Technical Review Process

Technical Review Process – the cycles of Technical Reviews, MC Reviews, and Author Responses that are required to review a map for publication

Technical Reviewer/Reviews – 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 and providing a Review Recommendation

Technical Review Guidelines – **t**he set of guidelines provided by the USGS Planetary Mapping Group for Technical Reviewers during the Technical Review Process

Unit Definition – the section of the DOMU where 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 – United States Geological Survey

USGS ASC – USGS Astrogeology Science Center in Flagstaff, AZ, where the USGS Planetary Mapping Group is based

USGS MC – USGS Planetary Geologic Map Coordinator

USGS-NASA 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 – refers to the USGS Planetary Geologic Map Coordination Group

USGS Planetary Geologic Map Coordination Group – the group of people located at the USGS Astrogeology Science Center who are funded by NASA to coordinate the USGS-NASA Planetary Geologic Mapping Program

1. 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, in detail, by field-based observations and measurements, planetary maps are largely based on analyses of a variety of orbital data sets, most commonly without assistance from direct contact in the field. As with any geologic map (but particularly relevant to non-terrestrial planetary geologic maps), the geologic representation provides a "snapshot" understanding of a given surface at that time based on available data (meaning that additional data volume, type, and (or) resolution can refine the understanding if and when it becomes available). As a result, the discipline of planetary geologic mapping is continuously evolving and must rapidly embrace the use of new data and modern technology in order to accommodate the growing needs of planetary exploration. It must also take its cues from strategies developed and employed by terrestrial mapping processes and products, to the extent possible.

Planetary geologic maps have been funded by the **National Aeronautics and Space Administration (NASA)** and published by the **United States Geological Survey (USGS)** since 1961 (Hackman and Mason, 1961). Between 1961 and 2018, the USGS has published over 240 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. Map publishing required a tedious process of scribing, color peel-coat preparation, typesetting, and photo-laboratory

work. Beginning in the 1990s, inexpensive desktop computing, display capability, and user-friendly illustration software allowed maps to be drawn using digital tools rather than pen and ink, and mylar bases became almost entirely obsolete.

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

As the planetary mapping process has evolved 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/analyst, GIS specialist, and cartographer. Therefore, 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, which requires planetary geologic mapping to be a learned discipline that continues to evolve.

2. Purpose of this Protocol

The USGS is critically involved in the entirety of the mapping process for producing USGS Scientific Investigations Maps (SIM) series products. As such, it is important for the USGS to describe an idealized process, which is what follows in this document. However, it is also important for the USGS and the community to recognize that this idealized process may not always be achieved. Starting with this document, and based on community and programmatic recommendations, USGS will more specifically establish timelines and then prompt authors to achieve these timelines. It is ultimately, however, the responsibility of the PI and map author (if these are different) to facilitate the process, fulfill timeline obligations, alert USGS to changes in the process (as necessary), and adhere to map component specifications. To facilitate the process and ensure a standard, high-quality, objective product, authors are encouraged to become familiar with and commit themselves to the process outlined herein, leverage USGS and community advice and expertise throughout their mapping project, and emulate the format and content of recently-published USGS maps.

The **Planetary Geologic Mapping Protocol** document (hereafter **Protocols)**, produced by the **USGS Planetary Geologic Map Coordination Group** (hereafter **USGS Planetary Mapping Group)**, covers the technical process of compiling a map product for USGS publication. The topics covered 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. Because aspects that are related to planetary geologic mapping as a scientific discipline are intentionally de-emphasized, reading and citing this document does not constitute planetary geologic mapping proficiency. Readers who are interested in the process, product, and use of geologic maps are directed to Varnes (1974), Wilhelms (1987), Wilhelms (1990), Spencer (1993), and Lisle and others (2011) (and all references therein).

Continual changes in data availability and mapping techniques dictate that the planetary geologic 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 webpage (http://astrogeology.usgs.gov/Projects/PlanetaryMapping/). Note that the most current Protocols

supersedes all previously released mapping guidelines, and that the Author is subject to the Protocols in the version available at the time their Map Package is submitted for the Technical Review Process.

3. USGS Maps

Geologic maps are tools that both report and facilitate planetary analyses. They are produced through varying methodologies and serve as products that convey geology, structure, stratigraphy, composition, and relative ages. In general, planetary scientists often create some kind of map product during their investigations, whether that is in the form of a hand-sketched cross-section or 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.

For this document, we refer to **Standardized Maps** as those published by the USGS, which conform to a relatively rigid cartographic standard that is established by federal agencies, refined by the planetary mapping community as necessary, and coordinated by the USGS Planetary Mapping Group on behalf of NASA. These products are subjected to a thorough Technical Review Process, wherein deviations from standard are identified and corrections to this standard are maintained. These maps are intended to be scientifically objective and cartographically normalized. By contrast, **Non-Standardized Maps** are those published by other venues that are not required to conform to rigid community standards and are not subjected to a review that is specifically intended to identify deviations from–and ensure corrections to meet–those standards. This does not mean that Non-Standardized Maps are less valuable to the progression of planetary science. Quite to the contrary: non-standardized products 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 in a larger, more comprehensive structure. The information presented herein should guide scientists who are producing NASA-funded, standardized USGS maps. It can (and perhaps should) also be used as a resource and guide to aid the content and production of Non-Standardized Map products. However, the Technical Review Process that identifies and implements correction to standards means that non-standardized, topical geologic maps cannot, by definition, be produced to USGS standards. The guidance offered herein is expected to gradually change in order to best fit community needs; input from the community regarding content, potential 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 (USGS 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 Technical Reviews (including a Map Coordinator review), and managing publication (including editing, cartographic layout, large-format printing, hard-copy distribution, and digital posting and archiving). Support tasks and publication costs for each NASA-funded geologic map is provided to the USGS Planetary Mapping Group through NASA funds separate from those appropriated to selected mapping projects. To date, it is not possible for USGS to support map products funded by non-NASA entities.

Standardized cartography, Technical Review, and objectivity are the benchmarks within which USGS-published geologic maps are prepared and promoted. These products will conform to the following characteristics:

- The map must be 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 otherwise directed by NASA Program Officers.

- The map is required to 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 that primary data set selection must be documented. The map can, but is not required to, use strategically selected data (or a small set of data) to augment observations made in the Primary Map Base, and the reasoning for that Supplemental Data must be explained in the Geologic Map Text.
- The map will not contain excessive interpretive detail that is not required to establish and convey the geologic framework (e.g., excessive figures or hypothetical discussions, etc.).
- The map will 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 selected Publication Map Scale. As such, it is critical for the Author to understand that a USGS Standardized Map is a representation of the geology that is discernible and representable at the selected Publication Map Scale.
- The map will be subjected to the Technical Review Process, which includes evaluations from two or more external reviewers, and the Author is expected to thoughtfully consider and satisfactorily address reviewer-recommended corrections in a professional manner in order for the Map Package to be Accepted for publication.
- The map Author is expected to attend the Annual Planetary Geologic Mapper's Meeting, and to conduct two external Technical Reviews of other maps over the course of their project.
- If a USGS or journal-based geologic map has already been published for a map 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 depicted in the map. If planned appropriately, these journal articles can be used as key references in the geologic map while avoiding the addition of expanded discussions that can bloat the Geologic Map Text and cause delays in review.

4. Roles and Expectations

The planetary Mapping Process involves a network of people and programs that must work efficiently together to successfully produce a timely and objective USGS planetary geologic map. In this section, we describe the roles and expectations of the participants in the process (i.e., NASA, Principal Investigator (PI), Map Author, USGS Planetary Geologic Mapping Group, and USGS Publication Services Center (PSC)).

4.1 NASA

NASA's role is primarily at the proposal stage. NASA organizes and conducts peer-review of mapping proposals submitted to existing Research and Analysis programs, selects proposals at their discretion, and provides funding for the PI. After proposal selection, NASA conveys authority in the Mapping Process to the USGS Planetary Mapping Group and is consulted for input on an as-needed basis.

4.2 Principal Investigator (PI)

The Principal Investigator (PI) is responsible to NASA for 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. As the project progresses, the PI may or may not transition to be the Author (see below). The expectations of the PI with respect to completion of the proposed geologic map are as follows:

- Contact the USGS Planetary Mapping Group with a formal intent to submit a map proposal to NASA at least two weeks in advance prior to proposal deadline; in return, the PI will receive a Confirmation of Technical Specification Document to be included in the final proposal.
- Contact the USGS Planetary Mapping Group with notification of proposal acceptance for NASA funding; in return, the PI will receive a Confirmation of NASA Selection document and the initial Map Package.

4.3 Map Author

Geologic mapping is often a group effort and multiple people may contribute directly or indirectly to the compilation of a USGS map. Herein, the term **Author** refers exclusively to the first author of the submitted Map Package and the USGS Planetary Mapping Group will confer solely with that Author throughout the Mapping Process. The Author is solely responsible for addressing USGS Planetary Mapping Group established requirements and satisfying Map Package Compliance, regardless of who produced any individual Map Package Component. Though the project PI may or may not be the Author, the PI is responsible to NASA while the Author is responsible to the USGS Planetary Mapping Group. Co-authorship should be limited to only those individuals who contributed directly to the production of the geologic map. Those 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 Acknowledgements section of the Geologic Map Text. All co-authors should be intimately familiar with the preparation and content of the final product.

The Author's role is continuous through the Mapping Process until the stage where the Map Package has been Accepted for publication. The Author will be consulted in the publication phase on an as-needed basis. The expectations of the Author are as follows:

- Adhere to the Map Specification and Map Selection documents,
- Solicit scientific and technical guidance from the USGS Planetary Mapping Group and community as needed, and use the resources available to assist with and expedite the Mapping Process.
- Ensure Map Package is Compliant for submission into Technical Review.
- Adhere to the timelines identified during the Technical Review Process.
- Appropriately address and edit the Map Package based on Technical Reviews and MC Review until Accepted for publication.

4.4 USGS Planetary Mapping Group

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

- Maintain the planetary geologic mapping program, including (but not limited to) obtaining and managing programmatic funds, reporting status and updates to USGS and NASA program officers, developing and maintaining standard procedures, managing printing and distribution, maintaining a web presence, and promoting the creation and use of process and products within the broader scientific community.

- Verify map proposal specifications from potential PIs for reasonability and feasibility, and document those in the Specification Document.
- Provide a Map Package, including a project GIS prepared to specification provided in the Specification Document, to the Author.
- Support the Author during active mapping en route to Map Package submission by providing scientific and technical guidance, as solicited by the Author.
- Verify Map Package Compliance; coordinate Technical Reviews and conduct the MC Review and Nomenclature Review.
- Coordinate with USGS PSC to finalize Map Package formatting and act as liaison between the USGS PSC and Author as needed.
- Post digital map products to the USGS Publication Warehouse, which serves as a Planetary Data System (PDS)-equivalent long-term archive.
- Distribute published hardcopy map products to **Regional Planetary Image Facility (RPIF)** nodes.

4.5 USGS Publication Services Center (PSC)

The USGS PSC is involved in the publication stage of the process. The expectations of the USGS PSC are as follows:

- Provide an editorial and cartographic review of the Map Package.
- Advise on USGS standards including, but not limited to, colors, symbology, Nomenclature, and layout.
- Aid the USGS Planetary Mapping Group with compiling the Map Package for publication, particularly by ensuring use of USGS approved layouts and formatting.
- Facilitate bidding and printing through the **General Printing Office (GPO)**.

5. Map Package Components

In the past, planetary geologic maps have varied slightly in content (e.g., inclusion or absence of figures, cross sections, etc.) and arrangement (e.g., map sheet organization, inclusion of map pamphlet, etc.) based on the amount of material being represented as well as author preferences. Though some flexibility is desirable to convey the geologic data and interpretation in ways that are suitable for each particular geologic map, unnecessary divergences and details come at a cost. Deviations from specified community standards regarding symbology, layout, colors, and Map Package Components undermines the ability of the user to easily compare one map to another. In addition, these deviations potentially require significantly more effort from mappers, reviewers, cartographers, and editors. This section defines the template for completing standardized planetary geologic maps in order to ensure these products have a consistent format that is simple for users to assimilate and use, as well as easier, faster, and more cost effective to produce. The Mapping Process itself, including review and publication steps, are outlined and described in subsequent sections.

The Author will refer to recently published geologic maps for examples of formatting and content. In all cases, the final content and format of a USGS SIM series geologic map will be guided by the Technical Review, MC Review (which includes the Nomenclature Review), and USGS PSC cartography/editor commentary. With respect to USGS PSC cartography/editor commentary, the Author will be contacted for input when necessary. Final decisions related to map content and format are the responsibility of the USGS MC. It should be noted that if, at any time, the Author feels that standardization and edit 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) to an alternative, non-USGS publication venue.

To keep the printed map sheet as small as possible, the Author is requested to restrict **Map Package Components** to the following: 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 40x56 in.; 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 (more information on content of pamphlet is in Section 5.2 Geologic Map Text). All components described below are required except where noted.

The Author must receive prior approval from the USGS MC on supplemental products to be included in the Map Package. The Author will follow all related guidelines for these supplemental digital products. These digital data products include Supplemental Figures, Supplemental tables, Supplemental GIS layers, and Supplemental GIS maps; use discretion when including supplemental files as these will be limited and additional products may slow down or delay timely publication. These supplemental products will be released as part of the digital Map Package to be published and will not be associated with the hard-copy product. However, all supplemental products must be evaluated during Technical Review and edited/adapted based on comments made therein.

5.0 GIS Files

USGS-published planetary geologic maps are released digitally and hosted by the USGS Publications Warehouse. For a Map Package being submitted for Compliance Review and the Technical Review Process, the GIS files will include the Primary Map Base, coordinate system file, layer files, clean geodatabase, and digital map document file ("*.mxd" for ArcGIS). 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 Publication Warehouse. These might include supplemental image mosaics, local thematic map products, and larger-scale (i.e., 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.

5.1 Geologic Map

The **Geologic Map**, overlain with transparency on the Primary Map Base, is the fundamental product of any NASA-funded mapping investigation for USGS publication. The Geologic Map will be prepared at the **Publication Map Scale** and projection, as determined by the PI/Author and the USGS MC at the proposal stage and identified in the Specification document. The geologic units must be clearly colored and labeled, contacts must separate individual unit boundaries, and features must be consistently represented. Unit Labeling needs to be sufficient to assist review. A recommended method is to label only those polygons above a certain area threshold so as not to overcrowd the map. The Author will adjust label formatting to emulate previously published maps as closely as possible. However, the Author should note that final formatting will be conducted by USGS PSC after Acceptance.

Symbology, including those 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 decipher any aspects prepared incompletely or unclearly.

5.1.1 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 and described, and used as a geographic reference for other map elements and discussions. The **International Astronomical Union (IAU)** Gazetteer of Planetary Nomenclature contains detailed information about all names of topographic and albedo features on planets and satellites that the IAU has named and approved. Published USGS maps are required to display Nomenclature completely and accurately (with minor exceptions, such as features that are too small to be significant to the geologic context at Publication Scale), and named features mentioned anywhere in the Map Package will be capitalized and spelled correctly (including the Latin plural forms for descriptor terms).

If a feature needs a name, the Author should submit a name request to the IAU based on the need to single out for identification as-yet unnamed features in the map area (request form is hosted on the IAU Gazetteer of Planetary Nomenclature Homepage; Section 8 Useful Webpages); the Author may include a suggested name in the request. 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 over the course of mapping prior to publication Acceptance, but the Author should keep in mind that it generally takes one to two months for a name to be approved (sometimes longer). Consult with the USGS Nomenclature Specialist when Nomenclature issues arise. As with labeling, the cartographic position of approved Nomenclature needs to be sufficient to guide review. Nomenclature will be cosmetically refined during USGS PSC review, but any steps the Author can take to facilitate this process will expedite review and production.

5.2 Geologic Map Text

Historically, the Geologic Map Text has appeared on the map sheet when room is available. However, increases in data volume and type and the diversity of mapping methods employed to create a planetary geologic map often makes modern map texts too long to be included on the map sheet and therefore requires 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, Acknowledgements, and References. The Author should note that they have some flexibility regarding the organization and section titles included in the Geologic Map Text (as noted below). However, all content described herein must be included somewhere in the Geologic Map Text. Organization will be subject to review during the Technical Review Process.

5.2.1 Introduction

The **Introduction** section of the Geologic Map Text introduces the map area, including its geography and general geologic setting. It also summarizes previous contextual and scientific work for the map area, particularly any published geologic maps, both standardized and non-standardized, and establishes why a new map is warranted for this region and at this 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 include a discussion on the rationale and purpose of the map. The Author can choose whether there is extensive enough text to warrant subdivision into Introduction, Background, and (or) Regional/Physiographic Setting sections (or similar).

5.2.2 Methods and Data

The **Methods and Data** section of the Geologic Map Text summarizes all data sets (including the Primary Map Base and Supplemental Data) and methods (drafting, organizational, or other) that were employed to construct the map and (or) were needed to identify and discriminate map units

and features critical to determining the geologic character and history. Additional data sets that were consulted also need to be mentioned, along with how they benefitted the mapping (or not), though 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. A variety of techniques can be used to document methods to convey Unit Names, groupings, Unit Labels, colors, and contact and feature types (discussed below). Methods used need to be clearly described and those methods need to be consistently applied across the map. Drafting parameters will be identified, including vertex spacing, the **Digital Mapping Scale** used for displaying the Primary Map Base when digitizing (mapping) geology and features in GIS, line smoothing and generalization methods (if used), and any other important digital controls and processing applied. The Author can choose whether there is extensive enough text to warrant subdivision 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 morphologic type (e.g., "corona material," "crater material"), geographic names ("Utopia Planitia material"), relative age/stratigraphic position ("lower/older crater material") and combinations thereof. Closely related units (e.g., units in a sequence or morphologic variations of otherwise similar units) may be mapped as members (e.g., "lower member of the Utopia Planitia material") or units having names showing their close association with other units ("Utopia Planitia 1 unit, Utopia Planitia 2 unit…"). The approach employed by the Author 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, though such schemes will be subject to review.

Unit groups: Units are commonly grouped by their geographic occurrence (e.g., "highland materials") or morphologic type (e.g., "lobate materials"). Capitalize only proper nouns in unit and group names (e.g., "Alba Patera Formation," "Utopia basin unit," "western volcanic assemblage"). The Author has flexibility to employ a reasonable unit grouping scheme, though such schemes will be subject to review.

Unit Labels: These can indicate chronostratigraphic age (e.g., "A" for "Amazonian"), unit group (e.g., "p" for "plains materials"), specific unit designations (including morphology, albedo/reflectivity, and associated geographic feature name), and unit member (commonly as subscripts; may include numbered sequences, as in "member 1," "member 2," …). Small capital letters have been used for unit groupings (e.g., "E" for "Elysium province"), though this method can cause problems with citation and typesetting. On the geologic map, some labels may be queried to show the unit assignment is highly uncertain. The Author has flexibility to employ a reasonable Unit Label scheme, though such schemes will be subject to review.

Unit colors: Unit colors will be applied according to precedent though subtle variations can be employed. The color may be used to reflect the group they are in (e.g., warm colors for volcanic materials, cool colors for sedimentary rocks, yellows for crater materials, browns for ancient highland materials). Also, color saturation can be used to reflect general areal extent of unit outcrops (low saturation for extensive units and high saturation for small units), which assists in locating smaller outcrops on the geologic map sheet. Colors are subject to alteration and refinement after submission to USGS PSC with Author consent. The Author has flexibility to employ a reasonable unit coloring scheme, though such schemes will be subject to review.

Contact types: The quality of contacts varies considerably on most maps. Contact types need to be defined and used as consistently as possible for a given map. 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 data sets. In general, (1) a "certain" contact is used when a contact is known to exist and is confidently located; (2) an "approximate" contact indicates that the contact is presumed to exist but its location is not confidently identified at Digital Mapping Scale (perhaps due to data quality and (or) obscuration by

an overlying surficial unit); (3) a "concealed" contact indicates that surficial material buries the contact but morphologically the contact is still traceable, although subdued; and (4) an "inferred" contact, which may be used to delineate map units where the validity of the map unit or distinction between the units is hypothetical. "Gradational" contacts have been used in past maps, though this contact should be reserved for cases where other contact types are insufficient and, even in such cases, should be applied sparingly (if at all). As long as the Author is explicit in defining the contact types and consistent in applying such definitions throughout the map, the Author has flexibility to employ a reasonable geologic contact scheme, though such schemes will be subject to review.

Feature types: Accurate and consistent mapping of geologic features is a challenge for every map project. The methods used to map geologic features need to be described, as well as the reasoning behind using line and point symbols and stipple patterns. Authors have flexibility to employ a reasonable feature type scheme, though such schemes will be subject to review.

5.2.3 Mapped Features

The **Mapped Features** section provides detailed descriptions of all linear features, point features, and stipple patterns. This title of this section can be changed so as to be more descriptive of what features are actually being represented (e.g., Geomorphology, or Structure, or other). Mapped Features are not contact or unit related, examples of which include wrinkle ridges, graben, sublimation pits, surface units, landing sites, and traverse routes. This section will include expanded descriptions of Mapped Features that are identified in the Explanation of Map Symbols (EOMS). It is important to describe the parameters and characteristics by which each feature was mapped. For example, a map text might state "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 km in diameter." The Author will also identify whether certain features are associated with particular geologic units. The Author will need to describe concentrations in geographic locations, trends, lengths or areas, number of mapped features per type, and other relevant characteristics. If appropriate, state which Supplemental Data set was used to aid identification and description of feature types. The Author can choose whether there is extensive enough text to warrant subdivision into separate Geomorphology and Structure sections (or similar).

5.2.4 Age Determinations

Techniques and reliability of relative and absolute **Age Determinations** for map units need to be discussed, as they vary widely according to data quality and preservation and exposure state of key features. These include superposition and cross-cutting relationships as well as impact crater size-frequency distributions, where available and relevant. For quantitative approaches, error analysis will be included. As absolute-age models are based both on cratering theory, lunar sample dating, and empirical data on bolide populations, they are subject to high uncertainty and therefore appropriate references will be cited throughout. Where possible, crater statistics can be summarized in the unit stratigraphic relations table (described below).

5.2.5 Geologic History

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

5.2.6 Acknowledgements

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

5.2.7 Format of References

References should be inclusive of the current body of literature (both Non-Standardized and Standardized Maps as well as topical studies) and formatted per USGS style guidelines (Hansen, 1991). All references listed in the Geologic Map Text should be included in the References list (and vice versa). The USGS Suggestions to Authors (STA-7 pp. 234-241) is provided as a link in Section 8 Useful Web Pages and the document is typically included in the original Map Package provided by the USGS Planetary Mapping Group.

5.3 Description of Map Units (DOMU)

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 tabular format, consisting of four columns of information for each unit: Unit Label, Unit Name and Unit Definition, Additional Characteristics, and Interpretation. 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 not encouraged as these complicate Technical Review and publication, though type locality coordinates in the Unit Definitions are appropriate. Although in recent years a tabulated DOMU has been normal practice for publication, the Author has the option to select a prose-based, columnar format during USGS PSC production. As stated above, however, the tabular format is required for the Technical Review Process.

Each geologic unit will have a unique **Unit Name** and **Unit Label** that is logical and representative of the unit 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 need to be consistent across all Map Package Components (i.e., Geologic Map, Geologic Map Text, COMU, and Figures).

Geologic units have **Unit Definitions** that are based on widely occurring and (or) unique, primary (depositional) and secondary (erosional or modificational) characteristics made in the Primary Map Base. These definitions need to be succinct yet sufficient to identify and discriminate each map unit from all others. In most cases, 2 to 5 characteristics may be sufficient to define a unit and may include (but are not limited to) aspects such as morphology/texture, albedo, stratigraphic position or relative age, relative elevation, regional occurrence, and (or) closely-associated landforms. Type locality coordinates are optional and should be placed at the end of the definition.

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, the local character of contact relationships, and prominent secondary features (that may obscure or be partly controlled by primary features).

Interpretations will focus mainly on 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 will reflect the degree of uncertainty where possible (e.g., “lava flows” vs. “possible lava flows” vs. “uncertain; may be lava

flows, pyroclastic or impact-related deposits, or tabular sedimentary deposits"), understanding that most geologic Interpretations cannot be definitive.

5.4 Correlation of Map Units (COMU)

Each map will include a **Correlation of Map Units (COMU)** chart, which 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). In general, each unit identified on the Geologic Map is represented in the COMU by a box that is colored (corresponding to the geologic map) and that extends vertically to various degrees based on the known temporal associations (as determined through superposition, cross-cutting relationships, and (or) crater size-frequency statistics). The COMU is organized horizontally, left to right, with younger units and unit groups being placed toward the left and older, more diverse, or widespread units being 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 (e.g., time transgressive, 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 (e.g., Young and Hansen, 2003). The COMU may also contain a listing of geologic events (e.g., Tanaka and others, 2005) and crater density relationships, though these are at the Author discretion. 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 will be included in the original Map Package delivered to the Author, to be adapted as necessary.

5.5 Explanation of Map Symbols (EOMS)

The **Explanation of Map Symbols (EOMS)**, or map key, is a chart on the map sheet that includes all line, point, and stipple symbols, with 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 EOMS is the responsibility of the Author.

5.6 Figures

Figures are an important component of planetary geologic maps and will be used to show examples of critical geologic unit and (or) feature characteristics and temporal relationships. However, the number of Figures needs to be limited to only those characteristics and (or) relationships that cannot be identified by map users using the Primary Map Base and Supplemental Data provided. All Figures will be thoroughly annotated and captioned, and be well justified. Non-annotated Figures are not effective for demonstrating critical relationships. Though 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. Figures may include, for example, a few reduced-scale images of the map region showing key data sets, the orientation of mapped tectonic features as rose diagrams, distributions of key features, contact relationships, and geologic cross-sections. Figures need to be prepared at intended publication size with consistent label font types and sizes.

Geologic cross-sections can also be provided as Figures. A limited number of geologic cross-sections can be shown on the map. Unit Labels and colors, and other symbology and Nomenclature need to be identified on any included geologic section and be identical to those represented on the map. All symbols and geologic units that appear in geologic cross-sections also need to appear in the

EOMS and COMU, respectively. The cross-sections will be at the same horizontal scale as the map, and the amount of vertical exaggeration will be indicated and adequate to show necessary detail, but not excessive.

Locations of Figures, including geologic cross-sections, will 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.

5.7 Captions

Captions are required for all included Figures and Tables and will be concise and supplemental to Figure annotations. Captions will include (but are not limited to) the following information: data source, data type, image number, and ground sampling distance (e.g., "THEMIS daytime infrared mosaic at 100 m/pixel"), solar/incoming energy incidence angle and azimuth, north direction, and latitude/longitude grid.

5.8 Tables

Tables can be used to provide 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. Such details might include (but are not limited to) summaries of impact crater unit morphologies within the map region, 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 Author 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, otherwise they will be placed in the accompanying pamphlet.

5.9 Cover Art

The map sheet (and pamphlet, when applicable) is contained within an envelope. In addition to standard publication citation information, the envelope will include 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 region (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 (e.g., a three-dimensional view of the study area). **The Cover Art is not required for a map to enter into or proceed through the Technical Review Process.** The USGS Planetary Mapping Group will oversee Cover Art preparation and will contact Author for information when needed.

5.10 Metadata

Metadata is 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. This information is archived with and becomes part of the map layer. The Metadata is not required for a map to enter into or proceed through the Technical Review Process. The USGS Planetary Mapping Group will oversee metadata preparation and will contact Author for information when needed and will oversee the incorporation of Metadata for the mapped layers according to USGS publication and FGDC standards.

6. Mapping Process

Planetary geologic maps, as supported by NASA and published by USGS, are currently released under the USGS **Scientific Investigations Maps (SIM)** series; note that the SIM series was formerly named "Geologic Investigations Series" and "Miscellaneous Investigations Series", and both used 'I' for the publication series abbreviation. In this section, we summarize the process of completing 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.

6.1 Proposals

In general, the NASA funds that support geologic mapping investigations for USGS SIM series products are competitively awarded to individual researchers at various institutions through programs advertised within the **NASA Research Opportunities in Space and Earth Sciences (NASA ROSES)** annual announcement of proposal opportunity. Multiple NASA programs support geologic mapping investigations as described in the **Planetary Science Research Program Overview (NASA ROSES Section C.1)** of NASA ROSES.

Those considering proposing for a grant to produce a standardized planetary geologic map product should examine advisory documentation per NASA ROSES Section C.1 and visit the USGS Planetary Mapping Group webpage. Though a variety of map areas, scales, and projections are potentially feasible for publication, technical constraints may make a proposed map untenable for publication (e.g., maps larger than 40×56 in or ~100×140 cm, or maps that require multiple sheets). Therefore, per NASA ROSES Section C.1, mappers are required to contact the USGS MC regarding the proposed map prior to Step-2 proposal submission to obtain a **Confirmation of Technical Specification Document**, (hereafter **Specification Document**), which ensures preparation of the desired Primary Map Base, proposed technical mapping specifications, and publication of the final product are feasible and conform to USGS Planetary Mapping Group established Protocols, 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 be published by the USGS, the Author must ensure the final product is Compliant with submission requirements, completes the Technical Review Process, and is Accepted for 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, and (2) acknowledge that, if selected for funding by NASA, the PI/Author will adhere to the Protocols established by the USGS Planetary Mapping Group throughout the duration of the project.

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, a subset of which include:

- Digital production: How the map will be generated in GIS formats compatible with ESRI's ArcGIS (or similar GIS) software (as per NASA ROSES Section 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 Section 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).
- Annual Mappers Meetings: Attendance at Annual Mappers Meetings to present a progress report on the mapping, ongoing science tasks, and (or) results is required (as per NASA ROSES Section C.1). It is appropriate to budget attendance for each year that funding is received in each new mapping proposal submitted (offsetting costs where attendance is duplicative for multiple projects, as needed).

- Additional analyses and products: Detailed and interpretative analyses outside of the scope of the map product may be desired (e.g., to test existing and construct new hypotheses, model observations, etc.), 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 (e.g., excessive figures, hypothetical discussion, etc.).

6.2 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 **Confirmation of NASA Selection** document (hereafter **Selection Document)** and will forward this document, along with the Map Package (see below) to the Author. The Selection Document will contain the final, funded technical specifications of the selected map project and will define the project's Sunset Date. Through email, the Author must confirm to the USGS MC 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. Because map symbol templates are being continuously refined and updated, the most current templates will be delivered with the GIS packages. Later versions of the symbol templates are available for download from the USGS Planetary Mapping Group website and incorporation to previously-delivered GIS packages.

In general, Map Packages will be delivered to the Author within one month of selection notification by PI. However, the USGS Planetary Mapping Group is typically responsible for generating multiple Map Packages in 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 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 data set 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 data set, 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 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 other lower-quality yet useful data. Even if a derivable data set 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 data set. 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 readily viewable as individual frames by using image-location footprints as GIS shapefiles having web links to data repositories.

6.3 Digital Mapping

Contact and feature mapping are generally 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. It is recommended that the final GIS linework have a vertex spacing of ~0.25 mm at Publication Map Scale (equivalent to 250 m for a 1:1,000,000-scale map). This vertex spacing is generally set in the USGS delivered ArcMap project. It is expected that a consistent scale will be used 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 also may not be a significant addition 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 (e.g., 1 cm and 5 mm^2, respectively). These thresholds are defined at the Author's discretion, but 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 MC, and 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 section of the Geologic Map Text.

6.4 Annual Mappers Meeting and GIS Workshops

These meetings are announced by the USGS Planetary Mapping Group and are typically posted on community pages, such as the Lunar and Planetary Institute (LPI) Planetary Sciences Community Meetings Calendar. While under active NASA mapping grants, and prior to map Acceptance, the Author is expected to attend the **Annual Planetary Geologic Mappers Meeting** (as per NASA ROSES Section C.1), hereafter **Annual Mappers Meeting**, 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 as a means to expand the mapping community, present various topical results, improve communication between disciplines, and receive and help inform mapping protocols and 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 issues, mapping standards and guidelines, and related scientific and technical issues will be presented and discussed. Technical workshops are sometimes attached to the Annual Mappers Meeting.

6.5 Map Package Submission

The USGS Planetary Mapping Group has compiled the following Map Package Submission Guidelines and Compliance Requirements and Review in an effort to continue refining and streamlining the Technical Review and publication processes. (These guidelines should be used in tandem with the information provided in Section 5 Map Package Components.) The Author bears sole responsibility for being aware of and capable of adhering to these guidelines and requirements or risk delay and possible removal of USGS support in regard to Technical Review and publication. The Author is required to assess the accuracy of all Map Package Components, both 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.

6.5.1 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 will be named similarly to show author, area, scale, component, and date (e.g., SKINNER_UTOPIA_1M_COMU_NOV21_2014.ai). The folder structure, including GIS templates, is available for download. The specified folder structure is as follows:

- **00_GIS_FILES [REQUIRED]:** This folder will contain the final 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 Sets, as originally provided by the USGS Planetary Mapping Group. If there are additional data sets not provided by the USGS Planetary Mapping Group but that were used to compile a Map Package Component, they will also be included.
    - Coordinate System: this folder will be populated with the *.prj file from the coordinate system used in the data frame.
    - Layer Files: this folder will be populated with the *.lyr files from all feature classes submitted (e.g., GeoContacts, GeoUnits, LinearFeatures, etc.).
    - *.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 (e.g., GeoContacts, GeoUnits, LinearFeatures, etc.).
    - At least one *.mxd file will be included in the 00_GIS_FILES folder. However, it is recommended to have two *.mxd files, one saved in ArcGIS version 10.0 format and one with the current ArcGIS version the Author used, 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 Adobe Illustrator and (or) PDF format, generated via export from GIS. Please ensure that all layers of the Geologic Map are included (e.g., contacts, linear features, location features, grids, etc.). The map will include 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. USGS PSC will address standardized labelling during final production phases.
- **02_MAP_TEXT [REQUIRED]:** This folder will contain the Geologic Map Text in Microsoft Word DOC and (or) PDF format. A template is included for assistance, to be adapted as necessary for the particular map area. This document will be in a single column, double spaced, with lines and pages numbered in order to facilitate Technical Review comments. Included in the original Map Package is a USGS reference style document.
- **03_DOMU [REQUIRED]:** This folder will contain the Description of Map Units (DOMU) in Word DOC (or similar editable) format. A template is included for assistance, to be adapted as necessary for the particular map area.
- **04_COMU [REQUIRED]:** This folder will contain the Correlation of Map Units (COMU) in Illustrator and (or) PDF format. A template is included for assistance, to be adapted as necessary for the particular map area.
- **05_EOMS [REQUIRED]:** This folder will include the Explanation of Map Symbols (EOMS) in Illustrator and (or) PDF format. A template is included for assistance, to be adapted as necessary for the particular map area.

- **06_FIGURES:** This folder will include map figures, as necessary, in Illustrator and (or) PDF format. A template is included for assistance, to be adapted as necessary for the particular map area. Images will be 300 dpi TIFF, JPG, or PNG. Note: A color-shaded relief figure of the map area with IAU-approved Nomenclature is often useful, perhaps as Fig. 1, to establish context.
- **07_CAPTIONS:** This folder will contain the Figure and Table Captions, as necessary, in Word DOC (or similar editable) format, as necessary.
- **08_TABLES:** This folder will contain Tables, as necessary, in Word DOC (or similar editable) format, as necessary. A template is included for assistance, to be adapted as necessary for the particular 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 particular 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 for assistance, to be adapted as necessary.
- The most recent version of this Protocols document will also be included in the original Map Package provided by the USGS Planetary Mapping Group. That document may be left in (or removed from) the submitted folder structure at the Author's discretion.

6.5.2 Compliance Requirements and Review

The management and production of USGS SIM series products by the USGS Planetary Mapping Group involve a time intensive and meticulous process that is unique to each mapping project. In order 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 also for the Technical Reviewers and Author 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 Compliance Requirements and submit this package for Compliance Review. Instructions for how to compile this folder structure are outlined in Section 6.5.1 Map Package Submission Guidelines. These requirements will be updated regularly and the Author should visit the USGS Planetary Mapping Group website to obtain the most current Protocols document. Note that a Map Package deemed **Compliant** has only been examined to the extent that all Map Package Components 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 in order 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 folder, 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 (e.g., versions, topologies, summary tables, empty feature classes, extra (unused) symbols), and only the Primary Map Base and Supplemental Data, and any additional data sets cited in the Map Package.
4. The Geologic Map PDF in the Map Package is exported at the specified publication scale and includes grids/graticules, Unit Labels, and Nomenclature.
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, but is not limited to, figures that are in an editable format and have 300 dpi resolution, and which define what the color variance represent when lacking a color scale bar.
6. The Geologic Map Text is formatted to specification, and has the required sections.
    - Compliance requires, but is not limited to, documents that are double-spaced, single-columned, line-numbered, and have all required text sections.

Once 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 Acceptance. 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 into the Technical Review Process. If the Map Package is determined by the USGS Planetary Mapping Group to be **Non-Compliant** (i.e., 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 need to be corrected and re-submitted in full.

If a Map Package is deemed Non-Compliant after first official submission, the Author has one more opportunity to submit for Compliance Acceptance. 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 on how to satisfy a Compliance Requirement, they can solicit help from the USGS Planetary Mapping Group before submission for Compliance Review. Note that, starting with the release of this Protocol, there will be no unofficial "pre-reviews" offered by the USGS Planetary Mapping Group.

6.6 Technical Review Process

The **Technical Review Process,** which begins once the Map Package has been determined to be Compliant, consists of Technical Reviews, Author Responses, and the USGS MC Review. The Technical Review Process is coordinated and facilitated by the USGS Planetary Mapping Group, and timelines are established for the Author and reviewers to expedite this process. The USGS MC will communicate with the Author and Technical Reviewers regarding details, including timelines. Note that the timelines cited in this section are the maximum amount of time permitted and taking less than the maximum time will accelerate the Technical Review Process.

The USGS MC assigns two planetary geologic mapping community peers to provide **Technical Reviews** and who are responsible for reviewing the entirety of the Map Package, as per the **Technical Review Guidelines**. Technical Reviewers are able, and encouraged, to make recommendations regarding refinement of contact placement, unit division, and unit definition, which may necessitate re-mapping of specific areas by the Author. Using the most current Technical

Review Guidelines, both reviewers will provide an itemized list of detailed comments back to the Author regarding the adequacy of all Map Package Components. Technical Reviewers will submit this list, as well as a Review Recommendation to the USGS MC, within two months. The USGS MC will ensure the completeness of the Technical Review and has the option to return the review to the Technical Reviewer if not sufficiently thorough. Once completed, the USGS MC assesses the review and augments and (or) guides editorial instructions to Author as necessary. The Author is responsible for addressing and incorporating all recommended changes into and across all Map Package Components, including the GIS. The Author needs to be prepared to alter linework (points, lines, polygons) based on reviewer comments and (or) to provide commentary on why particular reviewer comments were or were not incorporated into the re-submitted map. Across-the-board rejection of Technical Review comments will not be permitted. The Author will compile an Author Responses document that responds to each itemized Technical Review comment, providing information on how the comment was addressed. In rare cases, a third Technical Reviewer may be assigned to help resolve reviewer conflicts and facilitate adjudication of discrepant reviews.

After the first round of Technical Review, the Author will submit an updated Map Package along with Author Responses to the USGS MC, who will assess the changes. As needed, the USGS MC will act as liaison between the Author and Technical Reviewers to ensure that all comments are fully addressed and required changes are integrated into the Map Package. The USGS MC is solely responsible for adjudicating issues that arise during the review process. The Map Package can only go through three rounds of Technical Review–one initial submission and (if needed) two additional rounds of resubmission.

6.6.1 Technical Review Guidelines

The USGS Planetary Mapping Group has provided these Technical Review Guidelines for formal Technical Review of Map Packages submitted for publication under the USGS Scientific Investigations Map (SIM) series:

- Technical Reviewers are required to assess the accuracy of all components of the assigned Map Package, both individually and in total. 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, which allows 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 to authors that they should consult with the USGS MC for clarification.
- Technical Reviewers need to substantiate their technical and scientific comments with the same care as which they report their own work, including–but not limited to–the following:
    - 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. Technical Reviewers are encouraged to itemize general and specific comments through hand annotation of the map sheet, using leader lines to identify areas/features of commentary. Alternatively, reviewers can digitally annotate the included Geologic Map PDF using comment markers.

- Geologic contacts need to be clearly and consistently portrayed on the Geologic Map, and 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 reference and (or) example problems made on the map sheet.
- The use of different contact types needs to make cartographic and scientific sense. The contact symbology needs to 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 deviation is meaningful and well-applied.
- Triple junctions should be assessed throughout the map in order 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 cannot be overly dense so 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. These should be thorough (for the scale of the map). Placement should be accurate.
- Unit colors should be consistently applied and visually appealing. Cross-sections, if they exist, need to 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.

o Geologic Map Text: This text component provides 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 are encouraged to itemize general and specific comments in MS Word (or similar) using section, page, and (or) line numbers rather than digital editing capabilities. Technical Reviewers can include suggested edits and commentary within a TrackChanges version of the Geologic Map Text MS Word document, but only in support of the itemized, comment-response listing.

- Writing should be clear and comprehensive, yet succinct. Objectivity should pervade the map document to the extent possible. The Geologic Map Text should avoid excessive topical science results unless these 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.

- 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).
- Primary Map Base and Supplemental Data should be described.
- Mapping Methods 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 mapped was compiled.
- Age Determinations should be clearly described.
- A Geologic History must be included and 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 reference list (and vice versa).

o Description of Map Units (DOMU): The Description of Map Units component provides the basis for graphically conveying the spatial and temporal relationships of the mapped geologic units. Technical Reviewers are encouraged to provide general and specific review comments regarding the DOMU in itemized text format.

- Descriptions should be tabulated, separating out Unit Label, Name, Definition, Additional Characteristics, and Interpretations.
- All components 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, spatially consistent characteristics of geologic units as identified on the Primary Map Base. Definitions can include a type locality. Characteristics per 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 needs to 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 are sufficiently integrated into the Unit Definition and Interpretation.

o Correlation of Map Units (COMU): Technical Reviewers are encouraged to provide general and specific review comments regarding the COMU in itemized text format. These comments can be augmented, as necessary, through hand annotation of the COMU.

- Unit Names, Labels, and colors are complete and consistent with what is presented in other Map Package Components.
- Any unit groupings (and sub groupings) are 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) depicts all facets of the COMU.
- An "Event Column" (if included) depicts all facets of and accurately corresponds to the Geologic History, DOMU, and other Map Package Components.

o Explanation of Map Symbols (EOMS)
- All symbols applied on the map are listed and described.
- Symbols are rooted in FGDC geographic standards.
- Symbols are clearly described, justified, and consistently applied.
- Symbols are used to delineate discrete features.

o Figures and Captions: Geologic Map sheets can include Figures, both 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 absolutely necessary to clearly convey aspects of the geologic mapping and interpretation that is not apparent in the scaled Geologic Map and associated Map Package Components. An annotated, page-sized (maximum) color-shaded relief map of the map region is an acceptable figure to convey physiographic and topographic context.
- 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 will be used, when possible. Color figures should be minimized.
- Figure locations (extents and identifiers) will be included on the map sheet.
- Scale bars will be included.
- North is toward the top, unless otherwise denoted.
- Figures are clearly and thoroughly annotated.
- Captions need to be comprehensive yet succinct and include grid/graticule or center lat/lon and reference to data source (including image number, as necessary).
- Figures are referenced in order of their occurrence in the Geologic Map Text.

o Tables
- Tables will have a title or brief summary above the table.
- Tables will be referenced in order of their initial occurrence in the Geologic Map Text.
- Time-stratigraphic relationships table (if included) should accurately reflect the temporal occurrence of units as depicted in the COMU.
- Notations (if present) are succinctly described underneath the table.

6.6.2 MC Review

During the Technical Review Process, the USGS MC, with assistance from other USGS Planetary Mapping Group specialists as needed, performs an **MC Review** to ensure that: (1) the Map Package conforms to the specified scale and projection; (2) Technical Reviewer comments are adequately addressed; (3) map information conforms to specified USGS Planetary Mapping Group

conventions; (4) Nomenclature is sufficient, given what the Geologic Map Text discusses; and (5) stratigraphic inferences are accurately conveyed and supported by observations. During this review, a Nomenclature specialist will evaluate the Map Package to ensure all relevant and cited Nomenclature are present and accurate; formatting and placement will be finalized during USGS PSC production. The MC Review will list comments (similar to Technical Reviews), and the Author will respond to the MC Review with additional Author Responses and resubmit the Map Package. The MC Review occurs in tandem with or after the peer reviews, depending on the depth of edits required.

6.6.3 Technical Review Recommendations and Timelines

The USGS MC will determine if a Map Package will be **Accepted** for publication based on the Review Recommendations the Technical Reviewers provide. The **Review Recommendations** are based on map accuracy, conciseness, representation, and scientific substantiality. These factors are defined as:

- Accuracy: The Author has provided an accurate summary of the mapping methods and the discrete geologic units and features that result from these methods, as well as how mapped units and features exist within a temporal 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 generally reside outside of the scope of the map product.
- Representation: The Author uses appropriate classifications, spatial densities, and cartographic symbols to represent geologic elements (e.g., point- and line-features, contacts, units, etc.) discernable at the publication scale.
- Scientific substantiality: The Author has generated a map product that provides a significant 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.

The two Review Recommendations that are titled “Accept” are considered by the USGS MC as positive recommendations for Acceptance. Minor revisions encompass changes that require low-level revision of the Map Package such as merging two units, altering a portion of the Geologic Map Text, annotating a Figure, or changing the symbology of a geologic element. Major revisions encompass higher-level revision of the Map Package that must be integrated across multiple Map Package Components, or significant changes to the GIS files. The Review Recommendations are defined as follows:

- Accept and publish as is: The Author has presented an accurate, concise, and representative geologic map product that is scientifically substantial and is therefore recommended to be Accepted for USGS publication.
- Accept and publish with minor revision: The Author has presented a *mostly* accurate, concise, and (or) representative geologic map product that is scientifically substantial and is therefore recommended to be Accepted for USGS publication with minor revisions.
- Resubmit with major revision: The Author has presented a geologic map product that is (1) not an accurate, concise, and (or) representative geologic map product, and (or) (2) not clearly scientifically substantial, but which has the potential for USGS publication with major revisions and re-review.
- Reject: The Author has either (1) presented a geologic map product that is not scientifically substantial, or (2) has failed to incorporate feedback from Technical Reviews and (or) MC Reviews at a level that is acceptable by the Technical Reviewer and (or) USGS MC and is therefore not recommended for USGS publication. *Note this recommendation is only allowed after two or more rounds of Technical Review.*

The USGS MC will evaluate the technical review recommendations as a whole and determine an overall Review Recommendation, which will dictate the subsequent steps in the Technical Review Process. Map Packages that receive an "Accept and publish as is" recommendation may still need minor revisions based upon the MC Review elements. For Map Packages that receive an "Accept and publish with minor revision" recommendation, the Author will incorporate all Technical and MC Review feedback and the updated Map Package may be approved by the USGS MC without additional Technical Review. When a Map Package receives an "Accept and publish with minor revision" recommendation or an "Accept and publish as is" that needs minor MC Review revisions, the Author must provide the updated Map Package to the USGS MC within two months.

For Map Packages that receive a "Resubmit with major revision" recommendation, the Author will incorporate all Technical and MC Review feedback and the updated and re-submitted Map Package will be re-examined by the Technical Reviewers. The Map Package resubmission will be assigned a second Review Recommendation. At this point, the USGS MC may identify a third Technical Reviewer to help resolve reviewer conflicts, and (or) to help reconcile discrepant reviews. If a Map Package receives a "Resubmit with major revision" recommendation after the first Technical Review round, Authors must provide their updated Map Package for resubmission within four months. For second, and if needed, third Reviews, Technical Reviewers must provide their review within one month of receipt of resubmitted Map Package and the Author must provide their updated Map Package within two months of receipt of Review.

The "Reject" recommendation will only be used after two or more rounds of Technical Reviews have been completed for a Map Package. This recommendation will be used in instances when the Author has not revised the Map Package sufficiently enough to (1) demonstrate that a map submitted for USGS review and publication is scientifically substantial, or (2) address comments made by peer reviewers that carry-over across multiple Technical and MC Reviews. If Technical Reviewers provide a "Reject" recommendation, or if the USGS MC deems the Map Package has not reached USGS publication standards after multiple rounds of Technical Review, then the Map Package has the potential to be rejected for USGS publication by the USGS MC on grounds of failure to complete Technical Review.

6.6.4 Sunset Date and Target Dates

With the consent of NASA program officers, a Sunset Date and Target Date are being initiated with the release of this Protocol in order to prevent funded geologic maps from stalling during the mapping and (or) Technical Review Process. The **Sunset Date** is 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 defined as the end of the final year of funding plus two years, and will be documented at the beginning of the mapping project in the Selection Document. This 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 (Section 6.6.3, Technical Review Recommendations and Timelines). These timelines are facilitated by setting **Target Dates**. Technical Reviewers who do not meet the Target Date agreed upon with the USGS MC will not cause the Author's Map Package to become Delinquent; this provides assurance to the Author that their timeline is not impacted by events outside their control. 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**.

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

6.6.5 Acceptance and Rejection

In order 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 Technical Reviewers and updated by the Author. At that point, the USGS MC will consider the Review Recommendations and assess if the Map Package is an accurate, concise, and representative geologic map product that is scientifically substantial, in which case 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** 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 Target Date, the Map Package has the potential to be rejected for USGS publication on grounds of Delinquency.
- Technical Review: If Technical Reviewers provide a "Reject" recommendation which is conferred by the USGS MC, or if the USGS MC deems the Map Package has not reached USGS publication standards after three rounds of Technical Review, then the Map Package is rejected for USGS publication by the USGS MC on grounds of failure to complete Technical Review.

If an Author has been notified of Rejection by the USGS MC, they have the opportunity to 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, along with the USGS Planetary Mapping Group as necessary, will 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.

6.7 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 at Menlo Park, CA, for editing and production. When the USGS Planetary Mapping Group has Accepted the Map Package for publication, the project is considered complete with respect to NASA's timeline. Any correspondence needed from Author after Map Package submission to USGS PSC is minimal and intermittent. In order 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 non-scientific aspects of the Geologic Map (e.g., grid and graticules, scale bars, symbols, Nomenclature, and Unit Label placement). If there are content-specific and (or) scientific aspects of the map that arise during production that 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 (e.g., label completeness and placement). No significant content changes are allowed after the Map Package has been Accepted and delivered to USGS PSC.

6.8 Printing and Web Posting

Once the map proof has been approved by USGS Planetary Geologic Mapping Group and the Author, USGS PSC submits the completed map to the General Printing Office (GPO) for bid and printing. Copies of the map are produced according to anticipated demand (directed by the USGS MC) with a portion sent directly to the Author and the rest received by both the USGS RPIF in Flagstaff, Arizona, and the USGS Publication Warehouse in Denver, CO. The USGS RPIF will distribute the map to other RPIF nodes and additional copies can be requested by both the scientific community and the general public through the RPIF Manager. Digital files of map materials are posted to the USGS Publication Warehouse for download (which, importantly, is a PDS-equivalent archive due to the long-term, archival nature of the USGS Publication Warehouse) including PDFs of all printed materials produced by the USGS PSC as well as the GIS database, metadata, readme, and Supplemental Data files.

7. References

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Tanaka, K.L., Skinner, J.A., Jr., and Hare, T.M., 2005, Geologic map of the northern plains of Mars: USGS Map SIM 2088, 1:15,000,000.

Varnes, D.J., 1974, The logic of geological maps, with reference to their interpretation and use for engineering purposes: USGS Prof. Paper 837, 48 pp.

Wilhelms, D.E., 1987, The geologic history of the Moon: USGS Prof. Paper 1348, 302 pp.

Wilhelms, D.E., 1990, Geologic mapping, *in* Greeley, R., and Batson, R.M., eds., Planetary Mapping: New York, Cambridge University Press, p. 208-260.

Young, D.A., and Hansen, V.L., 2003, Geologic map of the Rusalka Planitia Quadrangle (V-25), Venus: USGS Map I-2783, 1:5,000,000.

8. Useful Web Pages

FGDC Digital Cartographic Standard for Geologic Map Symbolization:
http://ngmdb.usgs.gov/fgdc_gds/geolsymstd.php
FGDC Metadata Content Standards:
http://www.fgdc.gov/csdgmgraphical/index.html
IAU Gazetteer of Planetary Nomenclature Homepage:

http://planetarynames.wr.usgs.gov/
IAU Gazetteer of Planetary Nomenclature Descriptor Terms:
http://planetarynames.wr.usgs.gov/jsp/append5.jsp
IAU Gazetteer of Planetary Nomenclature Feature Name Request Form:
http://planetarynames.wr.usgs.gov/jsp/request.jsp
IAU Naming of Astronomical Objects:
https://www.iau.org/public/themes/naming/#spelling
LPI Planetary Sciences Community Meetings Calendar
https://www.hou.usra.edu/meetings/calendar/
NASA Research Opportunities:
http://nspires.nasaprs.com
PEN Meeting Calendar:
http://planetarynews.org/meetings.html
USGS Planetary Geologic Mapping:
http://astrogeology.usgs.gov/Projects/PlanetaryMapping/
USGS Mapping, Remote-sensing, Cartography, Technology, and Research (MRCTR) GIS Lab:
https://astrogeology.usgs.gov/facilities/mrctr-gis-lab
USGS Map-a-Planet 2:
https://astrogeology.usgs.gov/tools/map-a-planet-2
USGS Astropedia Search Portal:
http://astrogeology.usgs.gov/maps
USGS Style Guide
https://pubs.usgs.gov/msb/7000088/report.pdf

9. Support Personnel and Facilities

USGS Mapping Coordinator:
Jim Skinner
jskinner@usgs.gov; (928) 556-7043
USGS Planetary Mapping Group
Contact for Mapping Process help
pgm_help@usgs.gov
Regional Planetary Image Facility Coordinator
Justin Hagerty
jhagerty@usgs.gov; (928) 556-7173
MRCTR GIS Lab

The Mapping, Remote-sensing, Cartography, Technology and Research (MRCTR, pronounced "Mercator") GIS Lab at the USGS Astrogeology Science Center, which is available for funded mappers and provides both in-person and web-based resources aimed at 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. 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. Please note that workstations in the lab and availabilities of USGS Planetary Mapping Group personnel are limited. Additionally, 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.