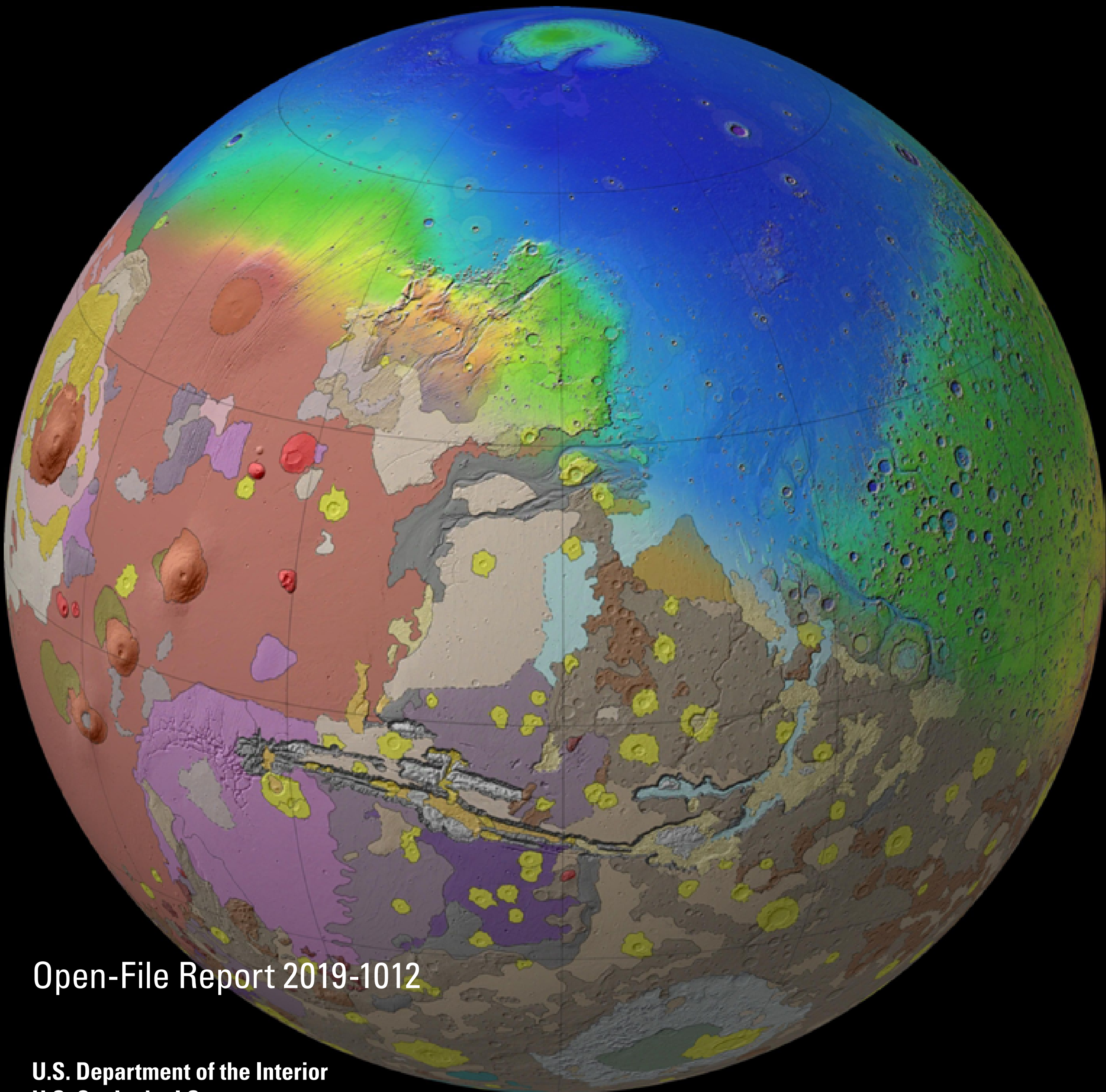
Planetary Geologic Mapping—Program Status and Future Needs



Open-File Report 2019-1012

U.S. Department of the Interior
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Cover. The global-scale geologic units of Mars, as shown by draping USGS SIM 3292 (Tanaka and others, 2014) over a Mars Orbiter Laser Altimeter (MOLA) color-shaded relief map in orthographic projection.

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By James A. Skinner, Jr., Alexandra E. Huff, Corey M. Fortezzo, Tenielle Gaither, Trent M. Hare, Marc A. Hunter, and Holly Buban

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DAVID BERNHARDT, Acting Secretary

U.S. Geological Survey
James F. Reilly II, Director

U.S. Geological Survey, Reston, Virginia: 2019

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Suggested citation:
Skinner, J.A. Jr., Huff, A.E., Fortezzo, C.M., Gaither, T., Hare, T.M., Hunter, M.A., Buban, H., 2019, Planetary geologic mapping—program status and future needs: U.S. Geological Survey Open-File Report 2019–1012, 40 p., https://doi.org/10.3133/ofr20191012

ISSN 2331-1258 (online)

USGS Astrogeology Science Center—Planetary Geologic Map Coordination Group

James A. Skinner, Jr.

Alexandra E. Huff

Corey M. Fortezzo

Tenielle A. Gaither

Trent M. Hare

Marc A. Hunter

Holly C. Buban

with review input from

Mike Bland, (USGS Astrogeology)

Devon Burr, (University of Tennessee)

Colin Dundas, (USGS Astrogeology)

Lisa Gaddis, (USGS Astrogeology)

Laz Kestay, (USGS Astrogeology)

Jay Laura, (USGS Astrogeology)

Pete Mouginis-Mark, (University of Hawaii Manoa)

Sharon Purdy-Wilson, (Smithsonian Institution)

Chris Okubo, (USGS Astrogeology)

Dave Williams, (Arizona State University)

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Planetary Geologic Mapping—Program Status and Future Needs

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Executive Summary

The United States Geological Survey's (USGS) Planetary Geologic Map Coordination Group (Flagstaff, Ariz.) surveyed planetary geoscience map makers and users to determine the importance, relevance, and usability of such products to their planetary science research and to current and future needs of the planetary science community. This survey was prepared because the planetary science community lacks a modern assessment of the value invested in geoscience map products and processes (including the diverse scientific and technical personnel who add to and maintain this infrastructure) and a strategy that ensures these efforts appropriately prioritize mapping efforts across all solid surface bodies in the Solar System. A 30-question survey was conducted through an online questionnaire and was designed to (1) take <10 minutes, (2) instill a sense that responses would be acted upon, and (3) encourage community participation through a user-friendly interface. There was no intention to identify and then require responses from named members within the planetary science community nor was there an attempt to target a specific set of discipline scientists. As a result, we understand and fully acknowledge that the cumulative responses represent a "self-selected" set of perceptions about planetary geoscience maps.

The survey made a distinction between "standardized" geoscience maps (those published by the USGS that require adherence to specific cartographic standards, conventions, and principles) and "non-standardized" geoscience maps (those published by other venues such as peer-reviewed journals that are not required to, but might, adhere to some cartographic standards, conventions, and principles). The survey was opened on Sunday, March 18, 2017 (to coincide with the annual Lunar and Planetary Science Conference in The Woodlands, Tex.) and was closed on Thursday, May 25, 2017. There was a total of 265 unique responses.

Responses were formulated into 17 unique findings that are matched with one or more recommendations to be addressed by the planetary science community. In general, both standardized and non-standardized planetary geoscience maps are broadly valued as a community resource and both appear to fill a critical role in research and exploration. Standard approaches to planetary geoscience mapping, regardless of publication venue, are deemed important and efforts should be made within the community to not only continue support for these products but also to capture and transfer the knowledge associated with map-making to sustain the endeavor in the long-term through university classes and training of post-graduate students. Global to hemispheric-scale standardized geologic maps should be made for all solid surface bodies within the Solar System for which they do not already exist (and for which adequate data are available). For those bodies or planetary systems that already have such maps, efforts should focus, at least in part, on campaigning at set scales (or a narrow range of scales) and for particular types of terrains. Geomorphological, surficial, and compositional maps are deemed legitimate and useful geoscience maps and efforts should be made to adapt existing approaches to accommodate their creation as standardized products. Control to standard reference frame, objectivity of unit description, and use of standard symbol sets are highly valued in geoscience maps and increased efforts should be made to assist a larger part of the community in meeting these standards in the geoscience map-making process. The community is strongly encouraged to discuss minimum cartographic standards for all geoscience map products, both standardized and non-standardized. Once established, the community should provide open database schemas, symbol sets, tools, and tutorials needed to enable the broadest part of the community to make maps that meet those minimum standards. Digital maps, especially GIS format maps, are the most valued, though there appears to be difficulty in the community on finding and using the maps, particularly in digital format. As such, the community is encouraged to explore the technical, managerial, and financial means by which all planetary geoscience maps, regardless of publication venue, could be searched for and accessed in a single location.

Introduction

Geoscience maps, regardless of target body, are spatial and temporal representations of materials and processes recorded on planetary surfaces (Varnes, 1973; Spencer, 2000). The information and context provided by these maps promote basic and applied research within and across various geoscience disciplines. They also provide an important basis for programmatic and policy decisions (for example, H.R. 2763 – 102nd Congress, National Geologic Mapping Act of 1992). Since 1961, planetary geoscience maps (maps that summarize the geology of all solid surface bodies in the Solar System beyond Earth) have been used in nearly every facet of planetary exploration, from landing site characterization for human (for example, Grolier, 1970) and robotic (for example, Anderson and Bell, 2010) missions to mineralogical analyses of water-alteration on Mars (for example, Loizeau and others, 2007). Modern planetary geoscience maps are either standardized (those published by the United States Geological Survey (USGS) that require adherence to cartographic standards, conventions, and principles) or non-standardized (those published by other organizations that are not required to, but might, adhere to some cartographic standards, conventions, and principles). Geoscience mapping and its resultant map product, whether standardized or non-standardized, is widely considered a routine reconnaissance and contextual investigation that should be performed in advance of and (or) in tandem with surface science investigations. Geoscience mapping campaigns are systematically included in mission proposals as anticipated derivative products (for example, Williams and others, 2014), along with other high-order cartographic data products such as controlled-image mosaics and digital terrain models. Additionally, planning documents from multiple planetary-science focused programs, organizations, and institutions identify geoscience maps as key scientific and technical results from and contributors to planetary exploration strategies (Planetary Decadal Survey, 2011; MEPAG, 2015; Hendrix and others, 2018). In line with these community uses and priorities, the National Aeronautics and Space Administration (NASA), in cooperation with the USGS Astrogeology Science Center (Flagstaff, Ariz.), has built and maintained a significant infrastructure dedicated not only to producing geoscience maps but also to building and releasing mapping-based resources to the planetary science community.

USGS-NASA Planetary Geologic Mapping Program

The USGS-NASA Planetary Geologic Mapping Program is a multi-decades-long cooperative program between the USGS and NASA whose objective is to define the geology of all solid surface bodies (other than Earth) in the Solar System by making, distributing, and supporting the use of geoscience maps. This Program is managed by the USGS Planetary Geologic Map Coordination Group (hereafter USGS Planetary Mapping Group) that is tasked with building, supporting, and maintaining planetary geoscience maps as reliable scientific context for conducting research and supporting a long-lived, robust planetary exploration strategy. In ongoing efforts to fulfill this task, the USGS Planetary Mapping Group works to generate, distribute, and maintain policies and resources for the construction and use of planetary geoscience maps, both standardized and non-standardized, by the planetary science community. We note that NASA planetary geoscience maps supported and eventually published by the USGS Planetary Mapping Group are based on the explicit direction of NASA program officers.

The USGS is effectively the default publication venue for NASA-funded research projects that generate a standardized product because of its long history with establishing and using mapping standards. These projects are currently published as USGS Scientific Investigation Maps (SIM) series products. As such, the USGS Planetary Mapping Group not only develops the requirements involved in making standardized products (with community input) but also manages the progression, production, and formal standards review of NASA-funded maps to ensure a baseline level of objectivity and adherence to cartographic standards, conventions, and principles through peer review. Most of the resources provided by the USGS Planetary Mapping Group are directly related to the generation of SIM series maps that meet USGS mapping standards. The USGS publishes formal map products that result from NASA-funded projects that have been through such a review.

The Program has significant interest in the production of all planetary geoscience maps and provides varying levels of assistance to all researchers who produce planetary geoscience maps, regardless of publication venue, institutional affiliation, or nationality. All resources (for example, mapping-based process documents, tutorials, guidelines, and standards) are intended to be used to produce geoscience maps, standardized or non-standardized, and there are certainly other publication venues under which planetary geoscience maps have been—and should continue to be—published, including peer-reviewed journal articles. Even though planetary geoscience maps are recognized as important products that both document and drive exploration of worlds beyond Earth, currently there is no other institution, organization, or program that provides an equivalent service to the national and international community. However, the planetary science community lacks a modern assessment of the value of NASA's significant investment in geoscience map products and processes (including the diverse scientific and technical personnel who add to and maintain this infrastructure) and a strategy that ensures these efforts appropriately balance and prioritize mapping efforts across all solid surface bodies in the Solar System.

Survey Rationale

As part of its charge to maintain and advocate for the construction and use of reliable planetary geoscience map products, and to assess the scientific value placed by the community in geoscience map products and processes, the USGS Planetary Mapping Group compiled and released a survey of planetary geoscience map makers and users (summarized in the "Distribution" section below). The survey was intended to assess the importance, relevance, and usability of planetary geoscience maps within the science community. More explicitly, survey responses were designed to help determine current and future needs related to production and use of geoscience maps for multiple bodies within the Solar System and to ensure that geoscience maps adequately meet the scientific and technical needs of the broadest part of the planetary science community possible in the short- and long-term. This survey, the summary responses, and recommendations provided herein are intended to contribute to a larger, more focused effort to recognize and promote data processes and products as key to a successful planetary exploration strategy by improving the community's recognition that raw data alone is insufficient to satisfy short- and long-term exploration goals.

The recommendations herein address four audiences: (1) the strategic and programmatic decision makers (NASA and international administrators of space exploration), (2) scientific and technical coordinators and facilitators (USGS Planetary Mapping Group, community advisory and working groups), (3) planetary geoscience map makers (planetary geoscience mappers), and (4) planetary geoscience map users (planetary science community, engineers, program managers, policy-makers, and the public). However, specific audiences are not identified per recommendation to avoid limiting community-wide improvement and to encourage multiple audiences to contribute to and benefit from any recommendation herein. Recommendations are purposefully non-thematic to allow for innovative responses and action by various audiences. Further discussions and interpretations of the survey results, as well as the range of interpretations and resultant recommendations, are strongly encouraged.

Survey Questionnaire

Preparation

The survey questionnaire was designed to capture input from respondents who represent the broadest part of the planetary science community that have a self-described interest in the production and (or) use of planetary geoscience maps. The questionnaire leveraged the approaches taken by past surveys and questionnaires that assessed similar use and need statistics for terrestrial geologic maps. To obtain a high level of response, the questionnaire was designed to (1) take <10 minutes, (2) instill a sense that responses would be acted upon, and (3) encourage participation through easy interfacing. The survey questionnaire was developed through multiple rounds of input and review. External review came from community members, including the Mapping and Planetary Spatial Data Infrastructure Team (MAPSIT) steering committee, and discipline scientists who complete geoscience mapping as part of their work, as well as those who do not.

Gathering input from the general planetary science community presents a challenge by making it difficult to ensure that all survey respondents, regardless of scientific discipline, understand the definition and use cases of mapping-specific terms included within the survey questionnaire. To mitigate possible misunderstandings, a section of the front page of the survey defined the following terms:

- **Geoscience maps**—Maps that discretely delineate and describe units or terrains using base maps (for example, geologic, structural, geomorphological, stratigraphic maps).

- **Base maps**—Derived data products upon which units or terrains may be identified (for example, controlled mosaics, digital terrain models, elemental composition).

- **Standardized maps**—Geoscience maps published by USGS that require adherence to cartographic standards, conventions, and principles.

- **Non-standardized maps**—Geoscience maps published by other venues (for example, peer review journal, thesis/dissertation, special issue, book chapter) that are not required to, but might, adhere to some cartographic standards, conventions, and principles.

- When not specified, assume that 'geoscience maps' indicate both standard and non-standardized products.

This document applies the same definition and use cases as summarized above. 'Geoscience maps' is pointedly used in this document because, though 'geologic' is used in the Program and Group name, the USGS Planetary Mapping Group acknowledges that geologic maps are a subset or group of map types under the umbrella of all geoscience maps relevant to planetary science investigations.

The questionnaire was organized into five sections with a total of 30 questions: (1) a "Respondent Details" section consisting of 12 questions, (2) a "Map Scales and Topics" section consisting of 3 questions, (3) a "Map Use" section consisting of 5 questions, (4) a "Map Access" section consisting of 3 questions, and (5) a "Future Needs" section consisting of 4 questions. Only the 12 questions in the first section in the survey questionnaire were required. The "Respondent Details" section asked for non-sensitive, wholly anonymous details about each respondents' self-identified educational/research background and work efforts, specifically type of organization, career stage, scientific and (or) technical discipline, funding source, mission involvement, bodies of interest, relevant data sets, software services used, and the frequency with which maps are made and used. No questions inquired about respondent's personally identifiable information, race, ethnicity, gender, age, or sexual orientation. The "Map Scales and Topics" section asked respondents for information regarding the range of relative map scales and topics as well as terrain types, processes, and environments that are relevant to their work, irrespective of the target body of interest. The "Map Use" section asked for information about how respondents use geoscience maps, what geoscience map elements respondents deem important, and how the respondents perceive the role of geoscience maps in establishing context on various planetary bodies. The "Map Access" section asked for information about how respondents locate and access geoscience maps and what formats they perceive as most important. The "Future Needs" was designed to ascertain how respondents perceive geoscience maps can and (or) should be used to establish and refine scientific context, how mapping processes can be improved upon, and how geoscience maps can and (or) should support exploration goals, including surface science conducted by current and future landed assets. In addition to these five sections, the questionnaire allowed respondents to post optional comments to expand on any topic deemed relevant. To preserve anonymity, these responses are not included herein but are described and categorized in a subsequent section. The questionnaire, as distributed, is provided in appendix 1. Responses per question are provided in appendix 2. Cross-correlated questions, as discussed in the following sections, are provided purely as reference information in appendix 3 through appendix 7 to support the statistics reported herein (Skinner and others, 2018).

Distribution

The finalized survey questionnaire contained 30 questions displayed over 8 web pages (appendix 1). The questionnaire was prepared using SurveyMonkey, Inc., an online survey development company that specializes in cloud-based survey services. This mode of release was selected because it allowed users to access the survey anonymously using a variety of web-enabled devices. The survey questionnaire was opened on Sunday March 19, 2017, to coincide with the Lunar and Planetary Science Conference (LPSC), which convenes annually in The Woodlands, Tex. The survey was responded to 26 times during the week of the LPSC (10% of total responses). The survey was then posted to various listserv and social media groups on March 27, 2017. It was responded to 199 times (75% of total) during the following three days, with the remaining 40 responses (15%) submitted within the subsequent two weeks. The survey was closed on Thursday May 25, 2017. The questionnaire was advertised to community members via a weblink and QR code printed on business cards (distributed at LPSC), as a link in an email to community listservs, and through social media platforms (table 1).

There was neither an intent to identify and then require responses from a statistically selected set of members within the planetary science community, nor was there an attempt to target a specific set of discipline scientists. As a result, it is understood and fully acknowledged that the cumulative responses represent a “self-selected” set of perceptions about planetary geoscience maps by only those people who wanted to respond. It cannot be assumed that responses can be applied to the entirety of the planetary science community. However, reasonable judgements can be made about the importance of planetary geoscience maps based on survey responses generally and respondents who self-identify as frequent or occasional map users specifically. This survey was intended to capture a range of information about planetary map use and future needs where there was previously no such information.

Summary Responses

A total of 265 responses to the questionnaire were received. The following is a summary of responses per section as well as results from selected cross-correlated questions. Readers are encouraged to review the detailed responses to the survey questionnaire (appendix 2) as well as results of cross-correlating selected questions (appendix 3 through appendix 7). Cross-correlations are indicated with the symbol “×”. For example, “Q7 × Q17” means Question 7 cross-correlated with Question 17. We identify notable “findings” as first-order implications from question responses and cross-correlations. In subsequent sections, these findings are matched with one or more “recommendations” that can be addressed by the planetary science community.

Respondent Details

The first section of the questionnaire requested details about the anonymous respondents and was completed by all 265 respondents (in short, no survey-taker quit the questionnaire prior to finishing this section). This section was designed to accumulate specific details about respondent background (for example, organization, career stage, funding source) as a point of correlation and cross-comparison to later questions.

Responses to question 1 indicate that university/college and federal institutions constitute by far the largest organizational groups (75%) whereas the second largest category was non-teaching, non-governmental research institutions (20%). The stages of career in which respondents reside are diverse (question 2) but focus on early, middle, or late career

Table 1. Email listserv and social media details for releasing the survey questionnaire. The survey was posted to listserv and social media groups on March 27, 2017.

Group	Platform	Members/Subscribers (at time of posting)
Planetary Geologic Mapping Community	Listserv	118
NextGen Lunar Scientists and Engineers	Listserv	146
Lunar-L	Listserv	690
Mercury-planet	Listserv	105
Young Scientists for Planetary Exploration	Facebook	1,795
NextGen Lunar Scientists and Engineers	Facebook	120

professionals (69%). Scientific discipline per respondent was assessed in question 3 using a “select up to three” question that included 11 potential choices (including “other”) that have varying use for geoscience maps. This question was designed to acknowledge that many scientists self-affiliate with both a primary discipline and sub-discipline. There were 488 total selections to this question, implying that most respondents self-identify with at least two scientific disciplines. Respondents predominately identify geology/geomorphology as their primary discipline (71%), with geophysics, GIS, and geochemistry/cosmochemistry/petrology as secondary disciplines. The type of work conducted by respondents was assessed through a “select up to three” question (question 4), wherein the overwhelming work type was “research” (93%), followed by “image processing/archiving/dissemination” (24%) and “education (university of college)” (21%). The “other” category was selected by <5 percent of respondents. There were 541 total selections to this question, implying that not only do most respondents self-identify with at least two types of work but that respondents often perceive their research to be critically coupled with educational (university or college) or technical expertise (image processing/archiving/planning, mission planning, or instrument/payload concept development). NASA is the dominant funding source (72%) for respondent work activities (question 5) and 56 percent of respondents are specifically involved in missions (planning, operations, and (or) research) (question 6). Mars, the Moon, and Earth are the most relevant planetary bodies/systems for respondent work (question 7), with broad consistency for Mercury, asteroids, and outer planet satellite systems at lower levels, based on “very relevant” responses. The relevance of data type to respondent work efforts was assessed in question 8, with the following data types identified as “very relevant”: “topography/DTM” (81%), “orthoimages and image mosaics” (78%), and “controlled image mosaics” (70%). Every data type category (except “other”) garnered >80 percent “very relevant” or “somewhat relevant” cumulative response, implying that respondents favor certain data sets but clearly find value in the full range of data. Similarly, respondents find GIS and image processing software/services the most relevant (question 9), but they value a broader range of services including Planetary Data System (PDS) and web-map services. A majority of respondents (75%) have a hardcopy USGS map in their office or workspace (question 10). Respondents often use geoscience maps (62 percent of respondents to question 11) but were less likely to have made geoscience maps as by-products or final products of their work (35 percent of respondents to question 12). However, of the 35 percent of respondents who answered “often” when queried about creating geoscience maps in their work effort (question 11), 94 percent answered “often” when queried about using geoscience maps in their work effort (question 12). Of the 23 percent of respondents who answered “never” when queried about creating geoscience maps in their work effort (question11), 25 percent answered “often” and 60 percent answered “occasionally” when queried about using geoscience maps in their work effort (question 12).

FINDING 1: Planetary geoscience maps are used more frequently by map makers, though respondents who never make maps still use them as a resource for their work and value them as critical contextual products.

Three percent of total respondents reported never using geoscience maps in question 12 and were provided an exit page to the survey questionnaire (question 13). Therein, respondents stated that limiting factors for geoscience map use included maps are generally inapplicable to their line of work, lack of existing maps relevant to their research background, poor access, lack of objectivity, and incompatible formats. No respondent, when given an exit page to the survey, used the opportunity to provide additional comments (question 14).

Map Scale and Topics

The second section of the survey requested information regarding geoscience map scales and topics as well as the types of terrains that are relevant to respondents’ work efforts. Respondents indicated in this section that all map scales—from local to global—are very relevant to their work. However, cross-correlating question 7 (body relevance) and question 15 (map scale relevance) (appendix 3), indicates that respondents prefer local to regional scales only when hemispheric to global scales already exist. For example, respondents who identify outer planet systems as “very important” also identify “hemispheric and global scales” as the most relevant whereas respondents who identify the Martian system as “very important” identify “local to regional scales” as the most relevant. We interpret these responses as indicating that local to regional scale geoscience maps become more relevant only after geologic and stratigraphic context has been established at hemispheric and global scales. These responses may imply that effective and long-lived geoscience mapping efforts are those that establish geologic and stratigraphic context at smaller scales (larger areas) before progressing to larger scales (smaller areas) rather than vice versa or at an arbitrary or self-selected variety of scales. Alternatively, or perhaps in addition to the above implication, respondents who study outer planets and icy satellites recognize that, in general, there is insufficient data for many of those bodies to support local to regional mapping. As such, respondents understand that global products are the only viable option.

FINDING 2: Local to regional scale maps are valued more highly when hemispheric to global scale geoscience maps have already identified broadly occurring units and established their spatial and temporal context.

Every map type (except hydrogeologic maps and “other”) garnered >75 percent very relevant and somewhat relevant cumulative responses, with geologic maps, geomorphologic maps, surficial geology maps, and compositional maps having 90 percent “very relevant” and “somewhat relevant” cumulative response (question 16). Geologic maps had the highest "very relevant" response at 68 percent. There were slight differences in the relevance of map types based on the planetary body or system that respondents deemed "very relevant" to their work (question 16 × question 7) (appendix 4), particularly regarding an increased relevance of compositional maps for asteroids, Mercury, and the Moon.

FINDING 3: Geologic maps are perceived as the most relevant planetary geoscience map type, though geomorphologic, surficial, and compositional maps are also relevant map types.

The relevance of different unit, terrain, and (or) feature types were assessed in question 17. Respondents identified volcanic, impact-related, stratified, ancient crustal, and fluvial/alluvial as very relevant to their work. The relevance of these units, terrains, and (or) features is consistent, even when cross-correlated with body relevance (question 17 × question 7) (appendix 5). With few exceptions, volcanic and impact-related terrains were deemed the most relevant for all solid surface bodies in the Solar System, though there were other units, terrains, and features that were deemed relevant depending on the body (table 2).

FINDING 4: Volcanic and impact-related units, features, and terrains are the most widely relevant for solid surface bodies throughout the Solar System, though there are other units, features, and terrains that are perceived as relevant on bodies that have more diverse geologic histories.

Map Use

The third section of the survey requested information about how respondents use maps, what elements or characteristics they deem important, and how they perceive the role of geoscience maps in establishing context for the exploration of planetary bodies. Respondents indicated that both USGS-published and peer-reviewed journal maps are more important to their work than maps presented in theses, dissertations, and book chapters (question 18). When queried about the importance of various map elements to their work (question 19), respondents indicated that maps that are controlled to a standard coordinate system, have objectivity in unit descriptions, and apply consistent use of symbols were "very important" whereas comparability in map scale and in look and feel were "somewhat important".

FINDING 5: Control to standard reference frame, objectivity in unit description, and consistent use of symbols are the three most important elements of planetary geoscience maps.

Question 20 asked respondents whether non-standardized geoscience maps (that is, those not published by the USGS) that implement standard cartographic symbol sets and formats are "more useful", "equally useful", or "less useful" than those that do not. Respondents indicated that non-USGS published planetary geoscience maps that implement standardized cartographic symbols and formats are more useful or equally useful than those that do not in equivalent proportions (43%). Only 14 percent of respondents indicated that the implementation of standard symbols and formats makes a non-standardized map less useful. Respondents overwhelmingly indicated that standardized maps are very important to establishing context for the scientific community compared to non-standardized maps (question 21).

FINDING 6: Standardized and non-standardized geoscience maps are equally valued, though maps that follow cartographic standards are more effective at establishing context for the scientific community.

Table 2. Units, terrains, and (or) features per body that respondents indicated were "very relevant" in proportions greater than "somewhat relevant" or "not relevant". Determined by cross-comparing question 7 (body relevance) with question 17 (unit/terrain/feature relevance).

Body	Units, terrains, features (% very relevant)
Mercury	Impact-related (74), Volcanic (68)
Venus	Volcanic (76), Impact-related (49)
Moon	Volcanic (71), Impact-related (69), Ancient-crustal (41)
Mars (including Deimos and Phobos)	Volcanic (62), Impact-related (54), Fluvial/Alluvial (50), Stratified (47), Ancient-Crustal (43), Aqueously-altered (42), Aeolian (39)
Main belt asteroids	Impact-related (65), volcanic (54)
Jovian system	Impact-related (68), Volcanic (52), Mass-wasting (44), Ancient-crustal (41), Fluvial/Alluvial (38)
Saturnian system	Impact-related (69), Densely-faulted (43), Mass-wasting (43), Ancient Crustal (38), Fluvial/Alluvial (37), Aqueously-altered (33)
Uranian/Neptunian system	Impact-related (57), Mass-wasting (45), Stratified (35), Glacial/Periglacial (30)
Pluto (including Charon)	Impact-related (61), Mass-wasting (42), Stratified (38), Aeolian (35), Glacial/Periglacial (35)

Question 22 asked respondents whether they agree or disagree, along a continuum of 5 choices, that they are knowledgeable of and can confidently apply standard geologic mapping process. Respondents indicated that they “strongly agree” (28%) or “somewhat agree” (37%). “Somewhat disagree” and “strongly disagree” garnered 17 percent of cumulative responses. Those respondents who frequently make and use geoscience maps self-report as more knowledgeable and confident appliers of standard mapping processes compared to those who infrequently make and use such products (question11 × question 22 and question 12 × question 22) (appendix 6).

FINDING 7: Frequent geoscience map users and (or) makers are more knowledgeable of standard geologic mapping processes, though there appears to be a lack of strong community knowledge related to application of standard geologic mapping processes.

Map Access

The fourth section of the questionnaire requested information about how respondents locate and access geoscience maps and queried what map formats and resources they deem most important. Respondents indicated that standardized (USGS-published) planetary geoscience maps are generally easier to locate, access, and use than non-standardized (peer-reviewed journal maps) (question 23). The high proportion of moderate to negative responses regarding the ease of locating, accessing, and using both standardized and non-standardized maps is notable.

FINDING 8: Even though standardized geoscience maps are easier to locate, access, and use than non-standardized geoscience maps, neither are considered suitably easy to accommodate widespread use.

Respondents heavily favor geoscience maps in digital rather than hardcopy format (question 24). Therein, responses indicate GIS formats are preferred over PDF formats, though both are valued. Only 7 percent of respondents considered GIS and PDF map formats to be “not important.” In contrast, hardcopy maps were deemed “very important” by only 18 percent, “somewhat important” by 49 percent, and “not important” by 33 percent of the respondents.

FINDING 9: The community overwhelmingly favor geoscience maps in digital rather than hardcopy format. Therein, the community prefers GIS formats over PDF formats, though both are valued.

Question 25 asked respondents whether they would find a single online location in which to search for and access geoscience maps beneficial to their work. Respondents “strongly agree” (77%) that they would find such an online location useful, with another 20 percent of respondents indicating they “somewhat agree” with this statement. “Neither agree nor disagree,” “somewhat disagree,” and “strongly disagree” cumulatively garnered 3 percent of the responses.

FINDING 10: A single online repository that enables map makers and (or) map users to search for and access geoscience maps would be an extremely useful resource.

Future Needs

The fifth, and final, section of the survey questionnaire requested information about future needs of the broader scientific community as supported by the planetary geoscience mapping community and the needs of the geoscience mapping community as supported by the USGS-NASA Planetary Geologic Mapping Program. Respondents overwhelmingly agree (96 percent strongly and somewhat agree responses) that surface science investigations fundamentally rely on the spatial and temporal context established and refined by geoscience maps (question 26).

FINDING 11: Planetary geoscience investigations fundamentally rely on the spatial and temporal context established and refined by geoscience maps.

They also overwhelmingly agree (90% strongly and somewhat agree responses) that expedited production of standardized geoscience maps for areas of high interest and (or) relevance would benefit both scientific investigations and potential future exploratory mission planning (question 27).

FINDING 12: Expedited production of standardized planetary geoscience maps for areas of high interest and (or) relevance would benefit both scientific investigations and potential future exploratory mission planning.

Respondents agreed that multi-year geologic mapping campaigns that focus on making a series of maps for a particular body at a set map scale would be useful to the scientific community (question 28). Responses did not vary depending on respondent’s planetary body of interest (question 28 × question 7) (appendix 7).

FINDING 13: Multi-year geologic mapping campaigns that focus on making a series of maps for high priority bodies and terrains at relevant map scales are perceived as valuable future contributions to the scientific community.

Question 29 asked for input on respondent’s likelihood of using topical mapping guidance on nine topics. Respondents generally indicated they were cumulatively “likely” over “not likely” to use mapping guidance for all topics: GIS tutorials (65% vs. 13%), GIS templates (58% vs 14%), description of map unit templates (54% vs. 13%), method summaries (53% vs. 10%), short course in GIS mapping techniques (52% vs. 16%), map layout templates (52% vs. 14%), correlation of map unit templates (51% vs. 15%), online mapping help boards (49% vs. 11%), and short course in photogeologic mapping (45% vs. 23%). If "somewhat likely" is added to "likely" responses, there is strong preference for the full range of mapping guidance.

FINDING 14: Planetary geoscience map makers and (or) users want more assistance with making geoscience maps, including tutorials, templates, and process documents.

Optional Comments

Question 30 asked respondents to provide any additional comments regarding planetary geoscience mapping efforts. These responses were optional and, to preserve the anonymity of respondents, were not included herein. 60 respondents opted to provide additional comments (23%) with responses ranging in length and topic. However, responses broadly fell into one or more of four categories:

1. General support of the planetary geoscience mapping process and product, particularly for mission support.
2. Testaments on the need for web-based access to GIS-formatted geoscience maps.
3. Concerns about the difficulty in making standardized geoscience map products, especially as related to the perceived and perhaps actual high entry bar for new mappers.
4. Requests for easily accessible guidance on the preparation of standardized geoscience maps.

FINDING 15: The technical nuances of GIS are limiting factors in making standardized and non-standardized geoscience maps for broad-distribution and use by the planetary science community.

FINDING 16: The lengthy technical review process for standardized geoscience maps inhibits broader participation by interested community mappers.

FINDING 17: Planetary missions can benefit from strong support by appropriately scaled and themed planetary geoscience maps that implement standards but are also rapidly produced.

Key Findings and Recommendations

Seventeen key findings and their associated recommendations are listed below. These recommendations are a direct response to interpreted respondent data gathered by the questionnaire and represent various paths forward for the planetary science community. They can be addressed by multiple entities and initiatives in the community, either in series or parallel.

FINDING 1: Planetary geoscience maps are used more frequently by map makers, though respondents who never make maps still use them as a resource for their work and value them as critical contextual products.

RECOMMENDATION 1—Resources and support should continue to be provided to the planetary geoscience mapping community by both USGS and NASA to sustain and advance the production of these critical contextual products.

FINDING 2: Local to regional scale maps are valued more highly when hemispheric to global scale geoscience maps have already identified broadly-occurring units and established their spatial and temporal context.

RECOMMENDATION 2A—The planetary science community should prioritize making standardized global to hemisphere scale geoscience maps for all Solar System bodies for which they do not already exist. Specifically, the community should prioritize making standardized geoscience maps at global to hemispheric scales of Mercury, Venus, Deimos, Phobos, Vesta, Ceres, Europa, all mid-sized Saturnian satellites, Pluto, and Charon.

RECOMMENDATION 2B—The planetary science community should prioritize making local to regional scale geoscience maps of the Moon and Mars at consistent scales or within a narrow range of scales (between approximately 1:50,000 and 1:500,000) to refine existing context and promote comparability.

FINDING 3: Geologic maps are perceived as the most relevant planetary geoscience map type, though geomorphologic, surficial, and compositional maps are also relevant map types.

RECOMMENDATION 3A—The planetary geoscience mapping community should either effectively and consistently integrate geomorphologic, surficial, and compositional details into the preparation of both standardized and non-standardized geologic maps or consider, where appropriate, the production of separately focused (and titled) geomorphologic, surficial, or compositional maps.

RECCOMENDATION 3B—The USGS-NASA Planetary Geologic Mapping Program should, where appropriate, consider the technical means by which a wider variety of standardized geoscience maps could be published, including those that focus exclusively on geomorphology, surficial deposits, and compositional units across various bodies.

FINDING 4: Volcanic and impact-related units, features, and terrains are the most widely relevant for solid surface bodies throughout the Solar System, though there are units, features, and terrains that are perceived as relevant on bodies that have more diverse geologic histories.

RECOMMENDATION 4A—In addition to volcanic and impact-related terrains, Moon mapping efforts should target ancient crustal terrains.

RECOMMENDATION 4B—In addition to volcanic and impact-related terrains, Mars mapping efforts should target fluvial/alluvial, stratified, ancient crustal, aqueously-altered, and aeolian terrains.

FINDING 5: Control to standard reference frame and objectivity in unit description are the two most important elements of planetary geoscience maps.

RECOMMENDATION 5A—The planetary science community should prioritize generation of standard reference frames for solid surface bodies in the Solar System that do not currently have them and should prioritize generation of and documentation for controlled local to global scale data sets for use in making geoscience map products.

RECOMMENDATION 5B—The planetary science community should strive for objectivity in the delineation and description of units presented in both standardized and non-standardized geoscience maps. Interpretations should be clearly separated and be directly supported by unit characteristics and contact relationships.

RECOMMENDATION 5C—Data acquired by new missions should adopt and adhere to coordinate systems and standard reference frames as defined by the International Astronomical Union (IAU). Such adoption and adherence critically facilitate the creation, co-location, and widespread use of derivative higher-order data products, including geoscience maps.

FINDING 6: Standardized and non-standardized geoscience maps are equally valued, though maps that follow cartographic standards are determined to be more effective at establishing context for the scientific community.

RECOMMENDATION 6A—The planetary science community should agree upon and make geoscience maps that adhere as closely as possible to a minimum set of cartographic standards for non-standardized geologic maps.

RECOMMENDATION 6B—The community is strongly encouraged to use existing advisory and working groups as a forum to discuss and determine minimum cartographic standards for all geoscience map products, both standardized and non-standardized. Once established, the community, in concert with the USGS, should offer open database schemas, symbol sets, tools, and tutorials needed to make a map that meets those minimum cartographic standards.

FINDING 7: Frequent geoscience map users and (or) makers are more knowledgeable of standard geoscience mapping processes, though in general there appears to be a lack of strong community knowledge related to application of standard geoscience mapping processes.

RECOMMENDATION 7A—The process of making, reviewing, and publishing the components of a standardized planetary geoscience map should be clearly documented and made available to the broadest part of the planetary science community possible.

RECOMMENDATION 7B—When constructing a planetary geoscience map, regardless of publication venue, the planetary geoscience mapping community should search out resources related to the mapping process. The planetary geoscience community should implement the recommendations of these resources whenever possible and should use published products as guidance for map compilation.

RECOMMENDATION 7C—The planetary science community should ensure that current knowledge regarding the construction of planetary geoscience maps is not only thoroughly captured but specifically transferred to the broader scientific community and to the next generation of scientists and explorers.

RECOMMENDATION 7D—University and colleges should more broadly consider how to specifically include a rubric that captures the historic, scientific, and technical concepts and processes related to photogeologic mapping and the creation of planetary geoscience maps at undergraduate and graduate levels.

FINDING 8: Even though standardized geoscience maps are easier to locate, access, and use than non-standardized geoscience maps, neither are considered suitably easy to accommodate widespread use.

RECOMMENDATION 8—The community is strongly encouraged to explore the technical methods by which all planetary geoscience maps should be prepared and packaged to increase online discoverability and is strongly encouraged to enforce implementation of such methods once identified.

FINDING 9: The community overwhelmingly favors geoscience maps in digital rather than hardcopy format. Therein, the community prefers GIS formats are over PDF formats, though both are valued.

RECOMMENDATION 9A—Planetary geoscience maps, regardless of publication venue, should be made available in GIS and PDF formats.

RECOMMENDATION 9B—Hardcopy prints of planetary geoscience maps should be curtailed, perhaps by limiting initial print runs, re-printing maps only when high demand makes it necessary, and (or) emphasizing "print-on-demand".

FINDING 10: A single online repository that enables map makers and (or) map users to search for and access geoscience maps would be an extremely useful resource.

RECOMMENDATION 10—The community is strongly encouraged to explore the technical, managerial, and financial means by which all planetary geoscience maps regardless of publication venue could be searched for and accessed in a single location.

FINDING 11: Planetary geoscience investigations fundamentally rely on the spatial and temporal context established and refined by geoscience maps.

RECOMMENDATION 11A—The planetary geoscience mapping community should continue targeted investments in making and releasing planetary geoscience maps; including, in part, by addressing the recommendations presented herein.

RECOMMENDATION 11B—The planetary geoscience mapping community should continue to make both standardized and non-standardized geoscience maps and acknowledge that each fulfill important, complementary roles in defining and refining the geologic and stratigraphic context of solid surface bodies in the Solar System.

RECOMMENDATION 11C—The planetary science community is encouraged to use and cite the relevant range of geoscience maps in peer-reviewed literature, including USGS-published maps, when establishing context and rationale for investigation and (or) presenting scientific results.

FINDING 12: Expedited production of standardized planetary geoscience maps for areas of high interest and (or) relevance would benefit both scientific investigations and potential future exploratory mission planning.

RECOMMENDATION 12—NASA programs and current and upcoming missions are encouraged to work with the USGS-NASA Planetary Geologic Mapping Program to fully leverage available geoscience mapping resources in making mission-supportive and (or) mission-derivative geoscience maps and expediting the production of standardized geoscience maps that directly support the planning of future missions.

FINDING 13: Multi-year geologic mapping campaigns that focus on making a series of maps for high priority bodies and terrains at relevant map scales are perceived as valuable future contributions to the scientific community.

RECOMMENDATION 13—The community should consider what high priority bodies, regions, and map scales would be most beneficial and should investigate proposal and funding avenues with NASA program officers to execute these campaigns.

FINDING 14: Planetary geoscience map makers and (or) users want more assistance with making geoscience maps, including tutorials, templates, and process documents.

RECOMMENDATION 14A—The planetary geoscience mapping community should continue to build and make available tutorials, templates, and process documents to assist those members of the community who want to make planetary geoscience maps as part of their research.

RECOMMENDATIN 14B—The planetary geoscience mapping community should make available relevant templates and process documents that improve the transparency of the generation and production processes of planetary geoscience maps for those members of the community who use planetary geoscience maps as part of their research.

FINDING 15: The technical nuances of GIS are limiting factors in making standardized and non-standardized geoscience maps that are intended to be broadly-distributed and used by the planetary science community.

RECOMMENDATION 15A—The planetary geoscience mapping community should not only continue to make and release standardized and non-standardized map product in GIS format but also build and make available GIS tutorials, best practices, and process documents to aid the development of those products and reduce barriers to using GIS methods.

RECOMMENDATION 15B—The planetary geoscience mapping community should prioritize the inclusion, on an as needed basis, of GIS specialists on mapping projects to help make GIS-based geoscience maps in a timely and effective manner.

FINDING 16: The lengthy technical review process for standardized geoscience maps inhibits broader participation by interested community mappers.

RECOMMENDATION 16A—The USGS-NASA Planetary Geologic Mapping Program is encouraged to assess ways in which the technical review process can be streamlined without sacrificing product quality.

RECOMMENDATION 16B—Map makers and technical reviewers are encouraged to be intimately aware of the standardized geoscience mapping process and to complete review obligations in a thorough and timely manner.

RECOMMENDATION 16C—The process for making standardized geoscience maps, particularly the process of technical review and edit, needs to be thoroughly documented, broadly advertised, and made easily available for implementation.

FINDING 17: Planetary missions can benefit from strong support by appropriately scaled and themed planetary geoscience maps that implement standards but are also rapidly produced.

RECOMMENDATION 18—The USGS-NASA Planetary Geologic Mapping Program and missions should work more closely to ensure that planetary geoscience map products are created with specifications that strongly support and enhance mission goals in the short- and long-term.

Next Steps

Until now, there has been no modern assessment of the planetary geoscience mapping community for the following: (1) the investment value of geoscience map products and processes, (2) a future strategy that ensures appropriate prioritization of mapping efforts across all solid surface bodies in the Solar System, and (3) an evaluation of whether geoscience maps adequately meet the scientific and technical needs of the broadest part of the planetary science community possible. The findings and recommendations listed in this document begin an important community discussion regarding priorities for the creation and use of planetary geoscience maps. These results, and subsequent, separate discussions, mark an important effort toward filling a void in the aforementioned lack of modern assessment of the status and future needs of planetary geoscience mapping community. The findings revealed by this survey validate the need and usefulness of planetary geoscience map products and highlight areas where the planetary geoscience mapping community and the USGS-NASA Planetary Geologic Mapping Program can improve and streamline processes and products. The resultant recommendations can help to strengthen the planetary geoscience community and to compel modernization in the creation, access, and use of geoscience map products.

The survey results convey a positive return on the investment made by NASA into the USGS-NASA Planetary Geologic Mapping Program by confirming planetary geoscience map products as critical contextual products for the planetary science community. The results also identify a set of high-priority data, services, and online searching and accessing requirements to inform crucial planning for the future of planetary geoscience mapping. The audiences of this document, who are the strategic and programmatic decision makers, scientific and technical coordinators and facilitators, planetary geoscience map makers, and planetary geoscience map users, should all assess both the needs of their individual audiences and the actions they can provide in response to the recommendations herein. Each audience is encouraged, individually and collectively, to seek opportunities to communicate the value, needs, and methodology of planetary geoscience mapping and to explore methods of engaging other audiences in response to one or more recommendations stated in this document. Innovative and sustained actions are integral to the improvement and future trajectory of a geoscience mapping community to ensure reliable, relevant, and robust map products are available for use in planetary sciences and exploration efforts.

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Appendixes

The survey questionnaire and summary responses are contained in appendix 1 and 2 respectively. Data pertaining to the cross correlation of survey questions (appendixes 3 through 7) are contained in a separate data release. This data release can be found online at https://doi.org/10.5066/P9PQCENT

Appendix 1. Survey Questionaire

Intent and Guidance

Please take a few minutes to give us your opinion of planetary geoscience maps!

We are working hard to ensure that planetary geoscience maps meet the needs of the broadest part of the scientific community possible. Your responses will help identify areas of improvement.

Maximum of 30 questions
<10 minutes
Responses are anonymous

Prepared by the Mapping and Planetary Spatial Infrastructure Team (MAPSIT). Collated responses will be posted on the MAPSIT website (http://www.lpi.usra.edu/mapsit) by August 31, 2017.

Terms used herein:

Geoscience maps—Maps that discretely delineate and describe units or terrains using base maps (for example, geologic, structural, geomorphological, stratigraphic maps).

Base maps— Derived data products upon which units or terrains may be identified (for example, controlled mosaics, degital terrain models, elemental composition).

Standardized maps—Geoscience maps published by USGS that require adherence to cartographic standards, conventions, and principles.

Non-standardized maps—Geoscience maps published by other venues (for example, peer review journal, thesis/dissertation, special issue, book chapter) that are not required to, but might, adhere to cartographic standards, conventions, and principles.

When not specified, assume that "geoscience maps" indicate both standard and non-standard products.

Figure 1.1. Cover and instructions to survey questionnaire.

Respondent Details [required]

1. Your **organization**?

- ◯ University or College
- ◯ Federal institution
- ◯ Non-teaching, non-governmental research institution
- ◯ Private industry
- ◯ Other

2. Your **stage of career**?

- ◯ Undergraduate student
- ◯ Graduate student
- ◯ Post-doc
- ◯ Early career professional
- ◯ Middle career professional
- ◯ Late career professional
- ◯ Other

3. Your **discipline**? [select up to three]

- ☐ Atmospheric science
- ☐ Biology/Astrobiology/Exobiology
- ☐ Education
- ☐ Engineering
- ☐ Geodesy/Photogrammetry
- ☐ Geochemistry/Cosmochemistry/Petrology
- ☐ Geographic Information Sciences
- ☐ Geology/Geomorphology
- ☐ Geophysics
- ☐ Information technology
- ☐ Other

Figure 1.2. Questions 1 through 3 on the topic of respondent career and organizational affiliation.

4. Your **type of work**? [select up to three]

- ☐ Research
- ☐ Computer science
- ☐ Education (primary or secondary instruction)
- ☐ Education (university or college)
- ☐ Image processing/archiving/dissemination
- ☐ Mission planning
- ☐ Mission, instrument, or payload concept development
- ☐ Public outreach
- ☐ Programmatic and/or institutional management
- ☐ Other

5. Your major **funding source(s)**? [select up to two]

- ☐ NASA programs
- ☐ Non-NASA U.S. Federal Programs European Space Agency (ESA)
- ☐ programs
- ☐ Non-ESA EU Programs
- ☐ College/University
- ☐ National Science Foundation (NSF)
- ☐ Other

6. Are you involved in active mission planning, mission operations, and/or specific mission-affiliated research?

- ◯ Yes
- ◯ No

Figure 1.3. Questions 4 through 6 on the nature of respondent work and funding.

7. Relevance of the following **planetary bodies/systems** to your work?

	Very relevant	Somewhat relevant	Not relevant
Mercury	○	○	○
Venus	○	○	○
Earth	○	○	○
Moon	○	○	○
Mars (including Deimos and Phobos)	○	○	○
Main belt asteroids	○	○	○
Jovian system	○	○	○
Saturnian system	○	○	○
Uranian/Neptunian systems	○	○	○
Pluto (including Charon)	○	○	○
Other	○	○	○

8. Relevance of the following **data types** to your work?

	Very relevant	Somewhat relevant	Not relevant
Topography/DTM	○	○	○
Orthoimages and image mosaics	○	○	○
Controlled image mosaics	○	○	○
Elemental composition/Mineral maps	○	○	○
Thermophysical property map	○	○	○
RADAR	○	○	○
Other	○	○	○

Figure 1.4. Questions 7 and 8 on the topic of relevant planetary bodies or systems and data types.

9. Importance of the following software/services to your work?

	Very important	Somewhat important	Not important
Geographic Information Systems (e.g., ArcGIS, QGIS)	○	○	○
PDS servers	○	○	○
Web-map services	○	○	○
Image processing (e.g., ISIS, ENVI)	○	○	○

10. Do you have a hard-copy USGS-publishing planetary geologic map in your office or workspace?

- ○ Yes
- No

11. Frequency that you **create geoscience maps** as by-product or final product for your work?

- ○ Often
- ○ Occasionally
- ○ Never

12. Frequency that you **use geoscience maps** for your work?

- ○ Often
- ○ Occasionally
- ○ Never

Figure 1.5. Question 9 through 12 on the topics of software services and respondent role in use or creation of geoscience maps.

Exit Page

13. I do not use geoscience maps for my work because:

	Check all that apply
Maps do not have scales that support my work	☐
Maps are not located in regions that support my work	☐
Maps are difficult to obtain	☐
Maps are not objective enough to support my work	☐
Maps are not in a format that is useful to my work	☐
Maps are just not applicable to my work	☐

14. Additional comments?

Figure 1.6. Questions 13 and 14 on why respondents do not use geoscience maps, prompted by a “never” response to Question 12 (frequency of geoscience map use).

Map Scale and Topics

15. Relevance of the following **map scales** to your work?

	Very relevant	Somewhat relevant	Not relevant
Very local scales			
Local to regional scales			
Regional to hemispheric scales			
Hemispheric to global scales			

16. Relevance of the following planetary **geoscience map types** to your work?

	Very relevant	Somewhat relevant	Not relevant
Geologic maps			
Geomorphologic and landform maps			
Surficial geology maps			
Geophysical maps			
Compositional maps			
Structural maps			
Hydrogeologic maps			
Landing site and/or traverse maps			
Other			

Figure 1.7. Questions 15 and 16 on the topics of map scale and geoscience map types used.

17. Relevance of the following **unit, terrian, and /or feature types** to your work?

	Very relevant	Somewhat relevant	Not relevant
Stratified			
Ancient crustal			
Aeolian			
Aqueously-altered			
Mass-wasting			
Fluvial/alluvial			
Volcanic			
Impact-related			
Densely-faulted			
Glacial/periglacial			
Other			

Figure 1.8. Question 17 on the relevance of geologic process to respondent work.

Map Use

Reminder:

- Standardized maps—Geoscience maps published by the U.S. Geological Survey (USGS) that require adherence to cartographic standards, conventions, and principles.
- Non-standardized maps—Geoscience maps published by other venues (for example, peer review journal, thesis/dissertation, special issue, book chapter) that are not required to, but might, adhere to cartographic standards, conventions, and principles.

18. Importance of the following **geoscience map publications** to your work?

	Very important	Somewhat important	Not important
USGS-published maps			
Peer reviewed journal maps			
Thesis/dissertation maps			
Book chapter maps			
Conference abstract maps			

Figure 1.9. Questions 18 through 20 on the importance of map publication source, elements, and the use of non-standardized maps that contain standard symbol sets and formats.

19. Importance of the following **geoscience map elements** to your work?

	Very important	Somewhat important	Not important
Consistent use of symbols	◯	◯	◯
Consistent preparatory methods	◯	◯	◯
Objectivity of unit description	◯	◯	◯
Comparability in look and feel	◯	◯	◯
Comparability in map scale	◯	◯	◯
Control to standard coordinate system	◯	◯	◯

20. **Non-standardized** geoscience maps that implement standard cartographic symbols sets and formats are ____________ useful than those that do not.

◯ More

◯ Equally

◯ Less

Figure 1.9. —continued.

21. Relevance of geoscience maps to **establishing context** for the scientific community?

	Very relevant	Somewhat relevant	Not relevant
Standardized maps	◯	◯	◯
Non-standardized maps	◯	◯	◯

22. You are knowledgeable of and can confidently apply standard geologic mapping processes.

Strongly agree	Somewhat agree	Neither agree nor disagree	Somewhat disagree	Strongly disagree
◯	◯	◯	◯	◯

Figure 1.10. Question 21 on the use of geoscience maps to establish context and question 22 on respondent knowledge of map standard mapping methods.

Map Access

Reminder:

- Standardized maps—Geoscience maps published by the U.S. Geological Survey (USGS) that require adherence to cartographic standards, conventions, and principles.
- Non-standardized maps—Geoscience maps published by other venues (for example, peer review journal, thesis/dissertation, special issue, book chapter) that are not required to, but might, adhere to cartographic standards, conventions, and principles.

23. Ease of **locating, accessing and using** planetary geoscience maps.

	Easy	Somewhat easy	Not easy
Standardized maps	○	○	○
Non-standardized maps	○	○	○

24.Importance of the following **geoscience map formats** to your work?

	Very important	Somewhat important	Not important
GIS (vector) format	○	○	○
PDF format	○	○	○
Hard-copy format	○	○	○

25. You would find it useful to **search for the access** geoscience maps **in online locations**.

Srongly agree	Somewhat agree	Neither agree nor disagree	Somewhat disagree	Strongly disagree
○	○	○	○	○

Figure 1.11. Questions 23 through 24 on respondent access to geoscience maps, importance of maps to respondent work and the importance of a single, online geoscience map repository.

Future Needs

26. Surface science investigations fundamentally rely on spatial and temporal context established and refined by geoscience maps.

Strongly agree	Somewhat agree	Neither agree nor disagree	Somewhat disagree	Strongly disagree
○	○	○	○	○

27. Expedited production of standardized geoscience maps for areas of high interest and/or relevance would benefit both scientific investigations and potential future exploratory mission planning.

Strongly agree	Somewhat agree	Neither agree nor disagree	Somewhat disagree	Strongly disagree
○	○	○	○	○

Figure 1.12. Questions 26 through 29 on topics concerning the future needs of the geoscience map community.

28. Multi-year geologic mapping campaigns that focus on creating a series of maps for a particular body at a set map scale would be useful for the scientific community.

Strongly agree	Somewhat agree	Neither agree nor disagree	Somewhat disagree	Strongly disagree
○	○	○	○	○

29. Likelihood of using **topical mapping guidance**.

	Likely	Somewhat likely	Not likely
GIS tutorials	○	○	○
Method summaries	○	○	○
GIS templates	○	○	○
Description of map unit templates	○	○	○
Correlation of map unit templates	○	○	○
Map layout templates	○	○	○
Short course in photogeologic mapping	○	○	○
Short course in GIS mapping techniques	○	○	○
Online mapping help boards	○	○	○

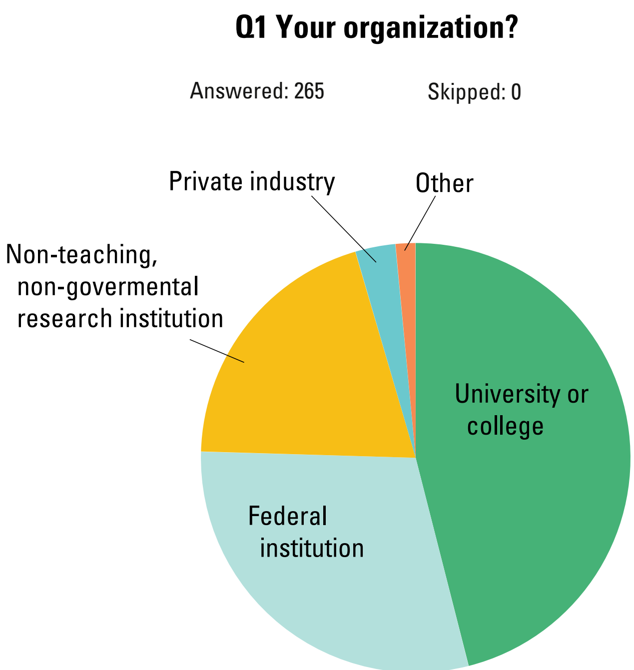
Figure 1.12.—continued.

Parting words

30. Please provide any additional comments regarding planetary geoscience mapping efforts.

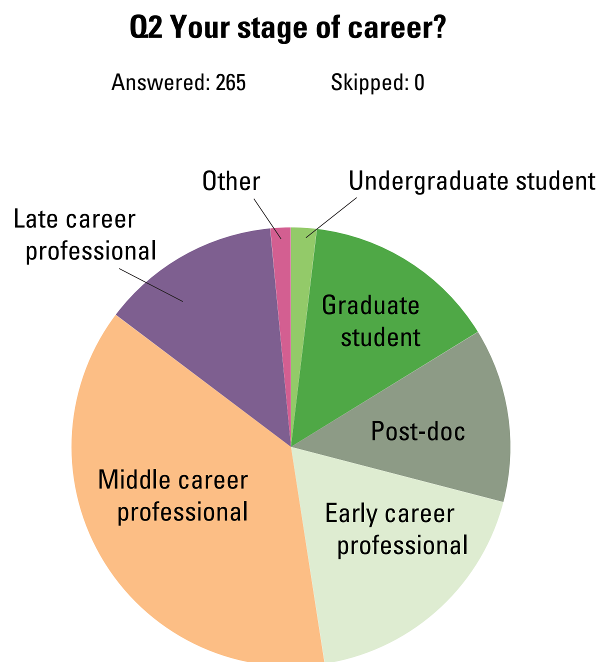
Figure 1.13. Question 30 providing respondents the ability to comment regarding planetary geoscience mapping efforts.

Appendix 2. Summary Responses



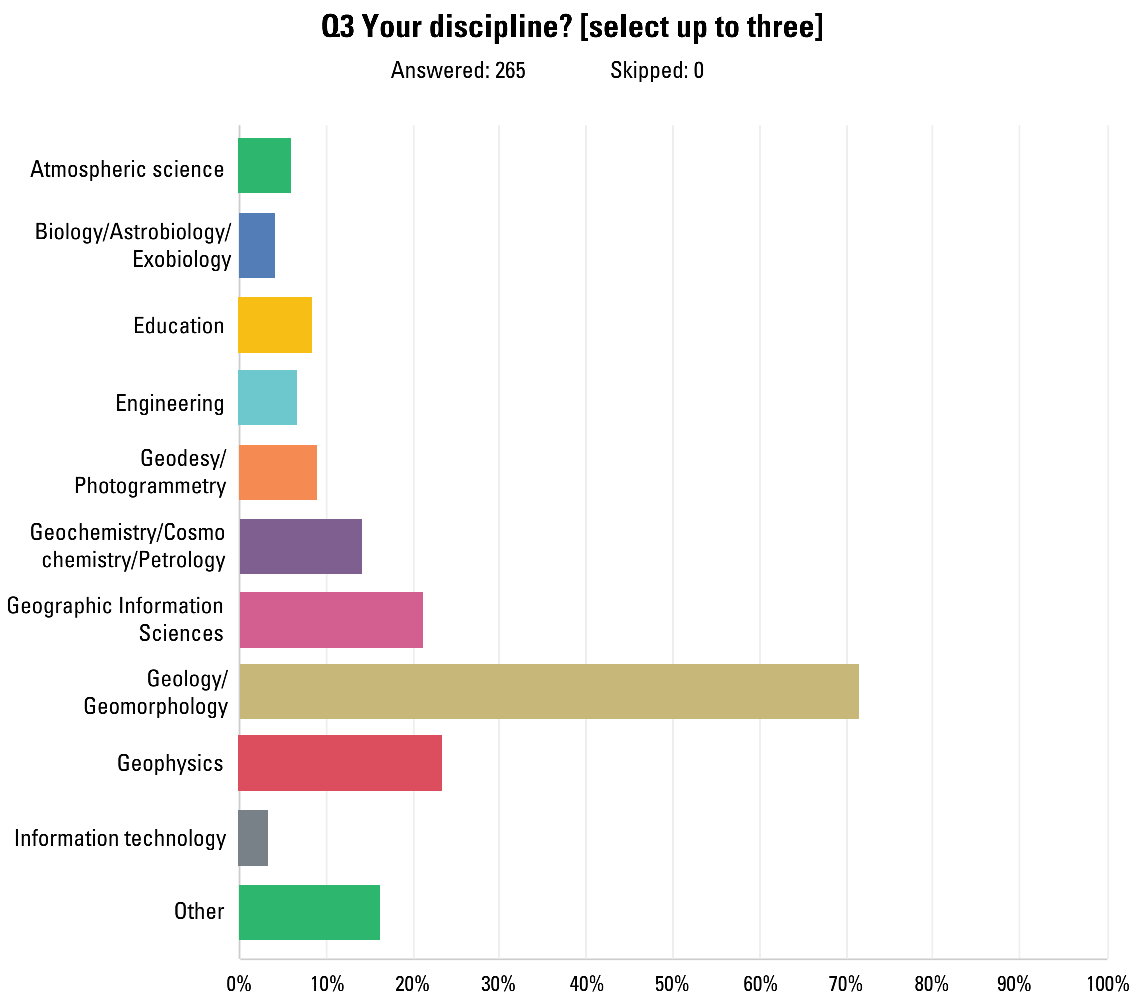
ANSWER CHOICES	RESPONSES	
University or college	46%	122
Federal institution	29%	78
Non-teaching, non-govermental research institution	20%	53
Private industry	3%	8
Other	2%	4
TOTAL		265

Figure 2.1. Responses showing a majority of respondent work based in university, college, or federal institutions (question 1).



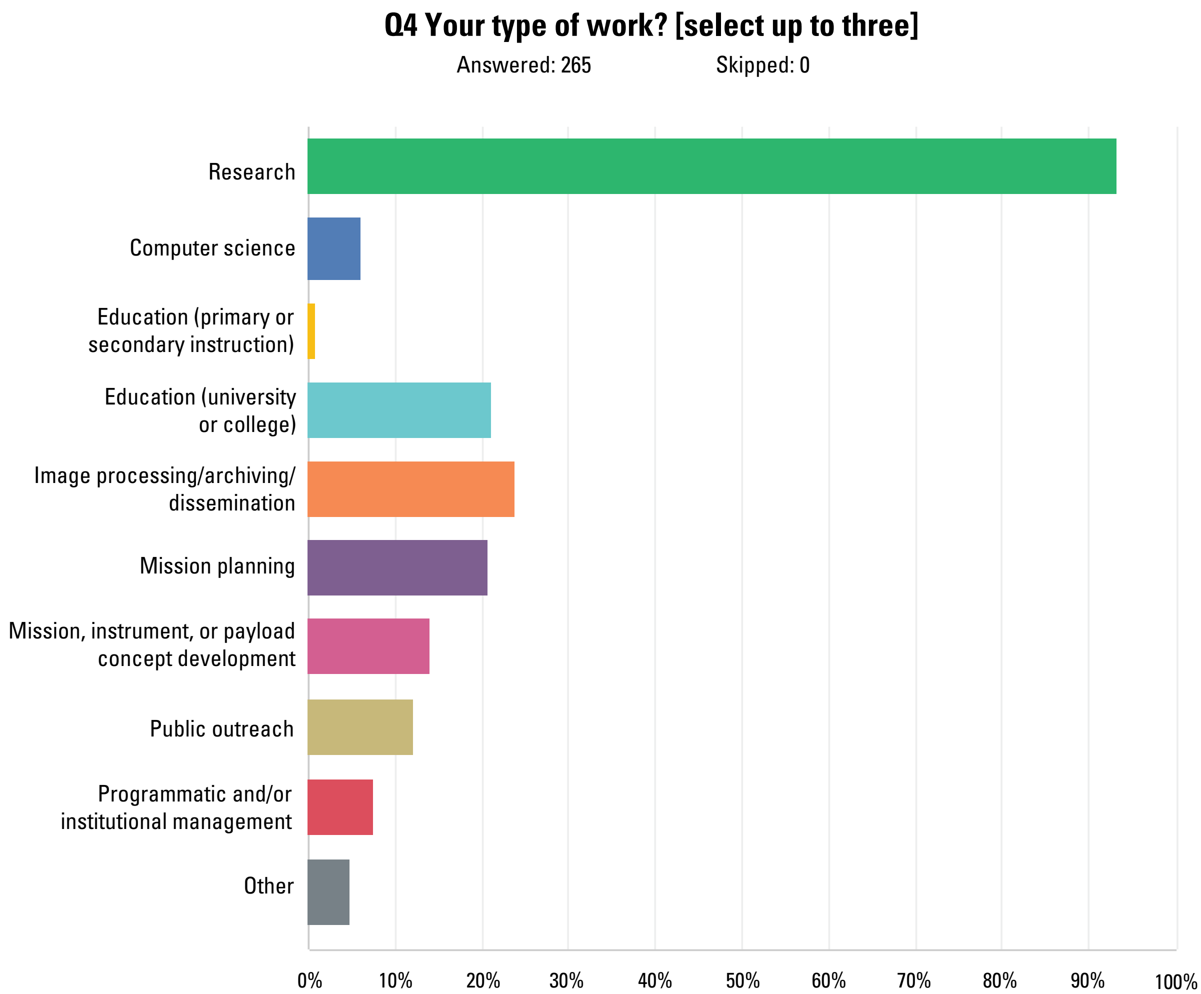
ANSWER CHOICES	RESPONSES	
Undergraduate student	2%	5
Graduate student	14%	38
Post-doc	13%	34
Early career professional	18%	49
Middle career professional	38%	100
Late career professional	13%	35
Other	2%	4
TOTAL		265

Figure 2.2. Responses indicating stages of career in which respondents reside (question 2).



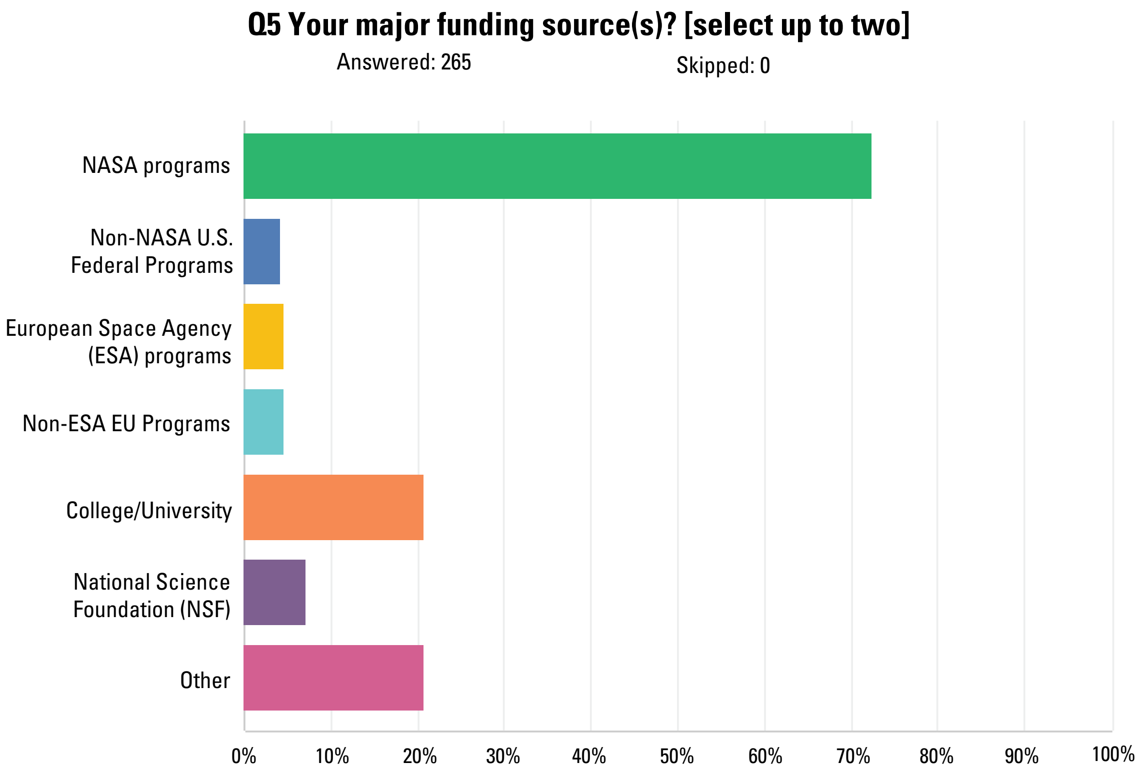
ANSWER CHOICES	RESPONSES	
Atmospheric science	6%	16
Biology/Astrobiology/Exobiology	4%	11
Education	9%	23
Engineering	7%	18
Geodesy/Photogrammetry	9%	24
Geochemistry/Cosmochemistry/Petrology	14%	37
Geographic Information Sciences	21%	56
Geology/Geomorphology	71%	189
Geophysics	23%	62
Information technology	3%	9
Other	16%	43
Total Respondents: 265		

Figure 2.3. Respondents area of discipline as chosen through a selection of up to three choices (question 3).



ANSWER CHOICES	RESPONSES	
Research	93%	247
Computer science	6%	16
Education (primary or secondary instruction)	1%	2
Education (university or college)	21%	56
Image processing/archiving/dissemination	24%	63
Mission planning	21%	55
Mission, instrument, or payload concept development	14%	37
Public outreach	12%	32
Programmatic and/or institutional management	8%	20
Other	5%	13
Total Respondents: 265		

Figure 2.4. Respondents type of work as selected through three options (question 4).

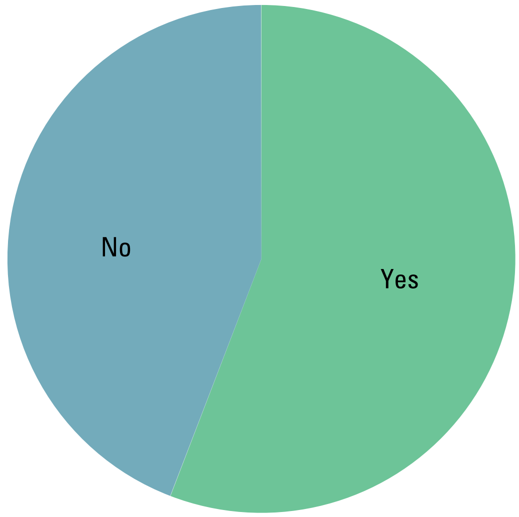


ANSWER CHOICES	RESPONSES	
NASA programs	72%	192
Non-NASA U.S. Federal Programs	4%	11
ESA programs	5%	12
Non-ESA EU Programs	5%	12
College/University	21%	55
NSF	7%	19
Other	21%	55
Total Respondents: 265		

Figure 2.5. Respondents source of funding (question 5).

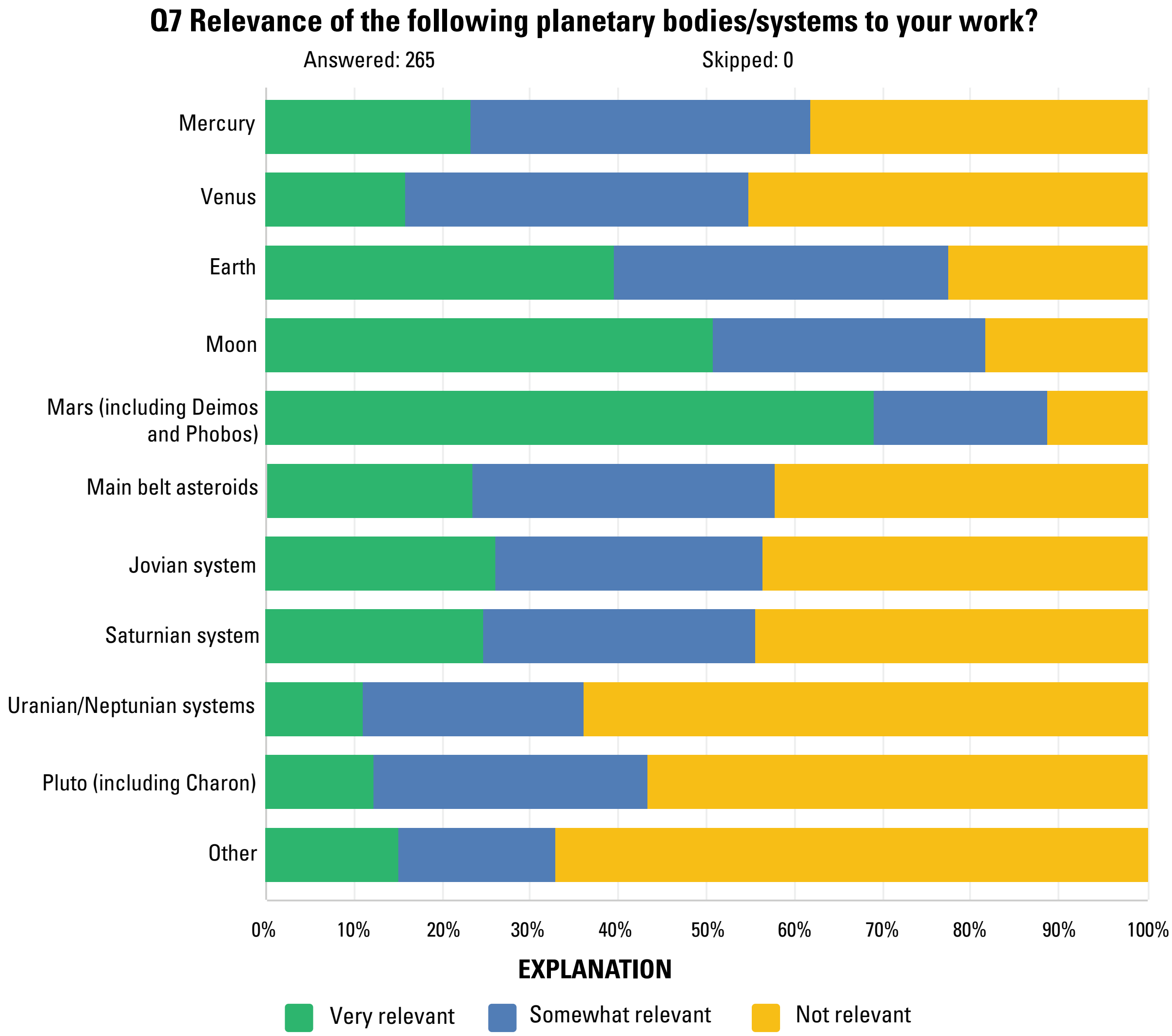
Q6 Are you involved in active mission planning, mission operations, and/or specific mission-affiliated research?

Answered: 265 Skipped: 0



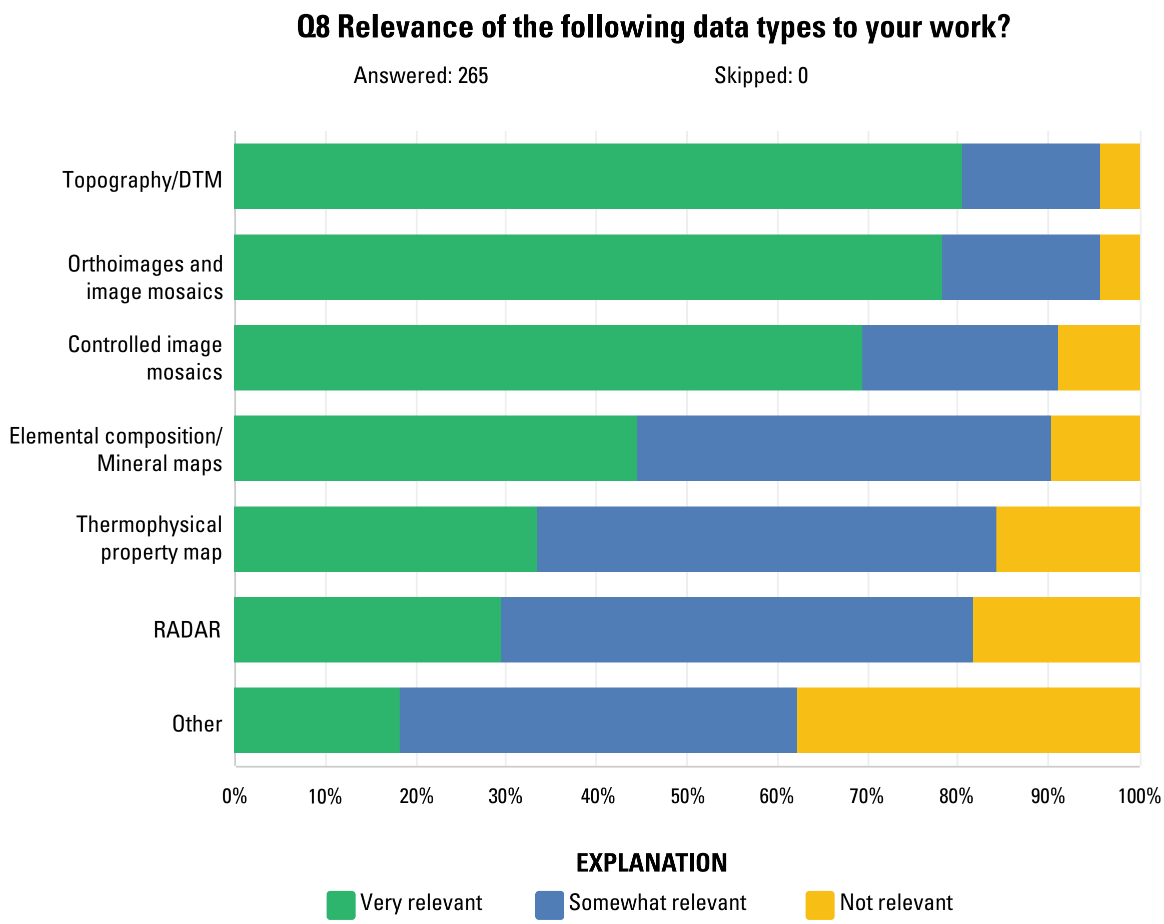
ANSWER CHOICES	RESPONSES	
Yes	56%	148
No	44%	117
TOTAL		265

Figure 2.6. Respondent involvement in active mission planning, operations, or affiliated research (question 6).



PLANETARY BODIES/SYSTEMS	VERY RELEVANT	SOMEWHAT RELEVANT	NOT RELEVANT	TOTAL
Mercury	23%	39%	38%	
Responses	57	94	93	244
Venus	16%	39%	45%	
Responses	38	93	108	239
Earth	40%	38%	23%	
Responses	98	94	56	248
Moon	51%	31%	18%	
Responses	130	79	47	256
Mars (including Deimos and Phobos)	69%	20%	11%	
Responses	178	51	29	258
Main belt asteroids	23%	34%	42%	
Responses	57	84	104	245
Jovian system	26%	30%	44%	
Responses	63	73	105	241
Saturnian system	25%	31%	44%	
Responses	59	74	106	239
Uranian/Neptunian systems	11%	25%	64%	
Responses	26	59	150	235
Pluto (including Charon)	12%	31%	57%	
Responses	29	74	134	237
Other	15%	18%	67%	
Responses	26	31	116	173

Figure 2.7. Relevance of planetary bodies or systems to respondent work (question 7).

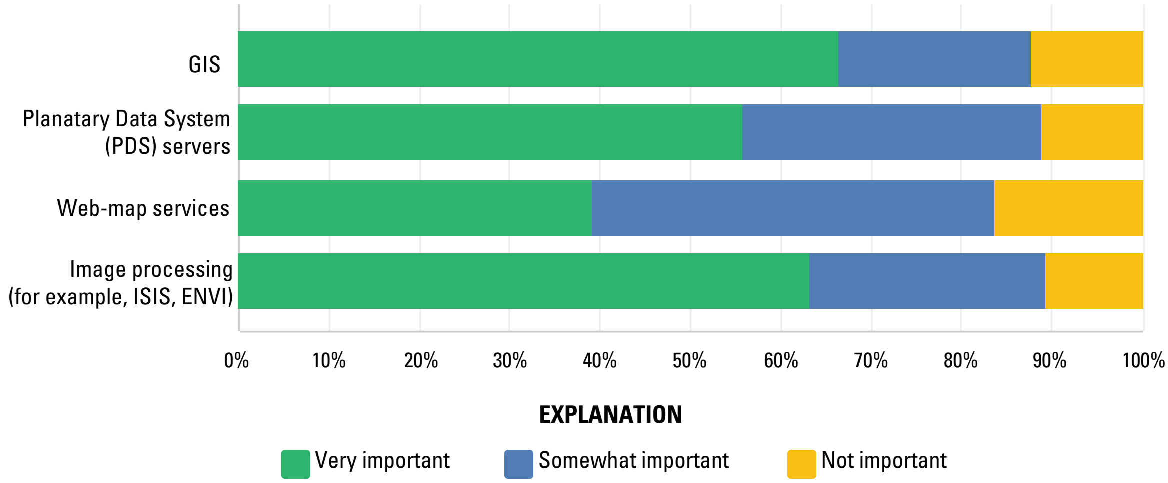


DATA TYPES	VERY RELEVANT	SOMEWHAT RELEVANT	NOT RELEVANT	TOTAL
Topography/DTM	81%	15%	4%	
Responses	211	40	11	262
Orthoimages and image mosaics	78%	18%	4%	
Responses	205	46	11	262
Controlled image mosaics	69%	22%	9%	
Responses	180	56	23	259
Elemental composition/Mineral maps	45%	46%	10%	
Responses	115	118	25	258
Thermophysical property map	33%	51%	16%	
Responses	83	126	39	248
RADAR	29%	52%	18%	
Responses	74	131	46	251
Other	18%	44%	38%	
Responses	29	70	60	159

Figure 2.8. Relevance of data type to respondent work (question 8).

Q9 Importance of the following software/services to your work?

Answered: 265 Skipped: 0

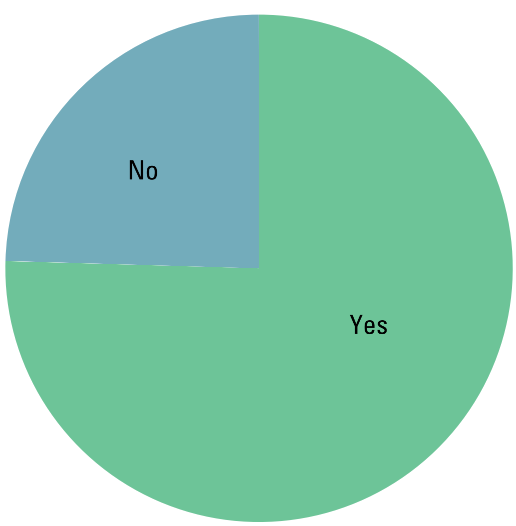


SOFTWARE/SERVICES	VERY IMPORTANT	SOMEWHAT IMPORTANT	NOT IMPORTANT	TOTAL
GIS	67%	21%	12%	
Responses	173	55	32	260
PDS servers	56%	33%	11%	
Responses	146	87	29	262
Web-map services	39%	45%	16%	
Responses	101	115	42	258
Image processing (for example, ISIS, ENVI)	63%	26%	11%	
Responses	167	69	28	264

Figure 2.9. Importance of software and services to respondent work (question 9).

Q10 Do you have a hard-copy U.S. Geological Survey (USGS)-published planetary geologic map in your office or workspace?

Answered: 265 Skipped: 0

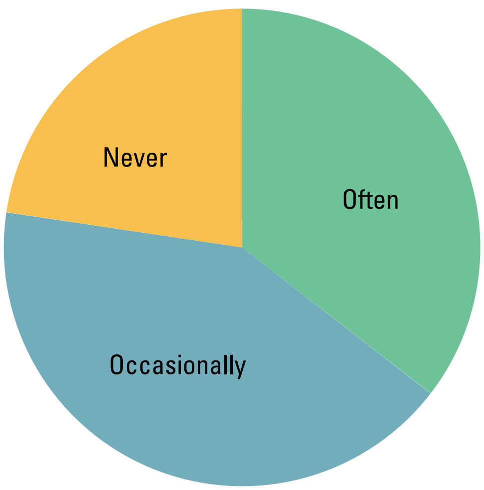


ANSWER CHOICES	RESPONSES	
Yes	75%	200
No	25%	65
TOTAL		265

Figure 2.10. Presence of hard-copy USGS-published planetary geologic map in respondent workspace (question 10).

Q11 Frequency that you create geoscience maps as by-product or final product for your work?

Answered: 265 Skipped: 0

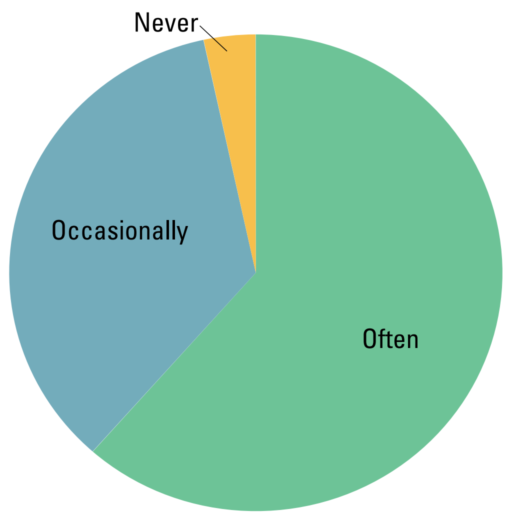


ANSWER CHOICES	RESPONSES	
Often	35%	94
Occasionally	42%	111
Never	23%	60
TOTAL		265

Figure 2.11. Frequency of geoscience map creation by respondents (question 11).

Q12 Frequency that you use geoscience maps for your work?

Answered: 265 Skipped: 0



ANSWER CHOICES	RESPONSES	
Often	62%	163
Occasionally	35%	93
Never	3%	9
TOTAL		265

Figure 2.12. Frequency of geoscience map use by respondents (question 12)

Q13 I do not use geoscience maps for my work because:

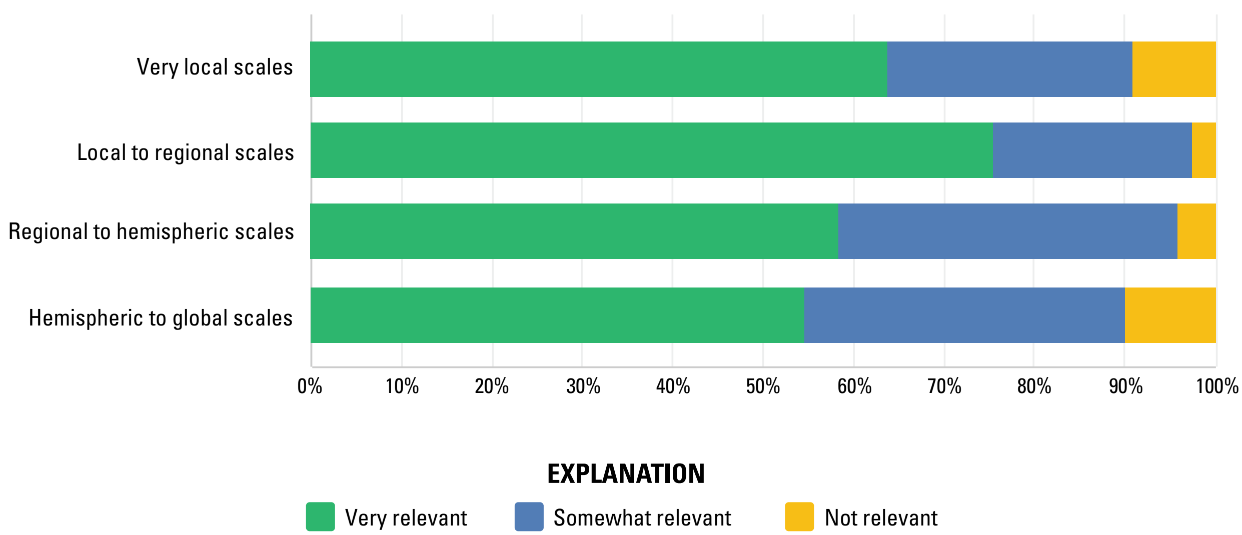
Answered: 9 Skipped: 256

REASON	CHECK ALL THAT APPLY	TOTAL RESPONDENTS
Maps do not have scales that support my work Responses	0% 0	0
Maps are not located in regions that support my work Responses	100% 2	2
Maps are difficult to obtain Responses	100% 1	1
Maps are not objective enough to support my work Responses	100% 2	2
Maps are not in a format that is useful to my work Responses	100% 1	1
Maps are just not applicable to my work Responses	100% 7	7

Figure 2.13. Respondent response and reason for lack of geoscience map use (question 13)

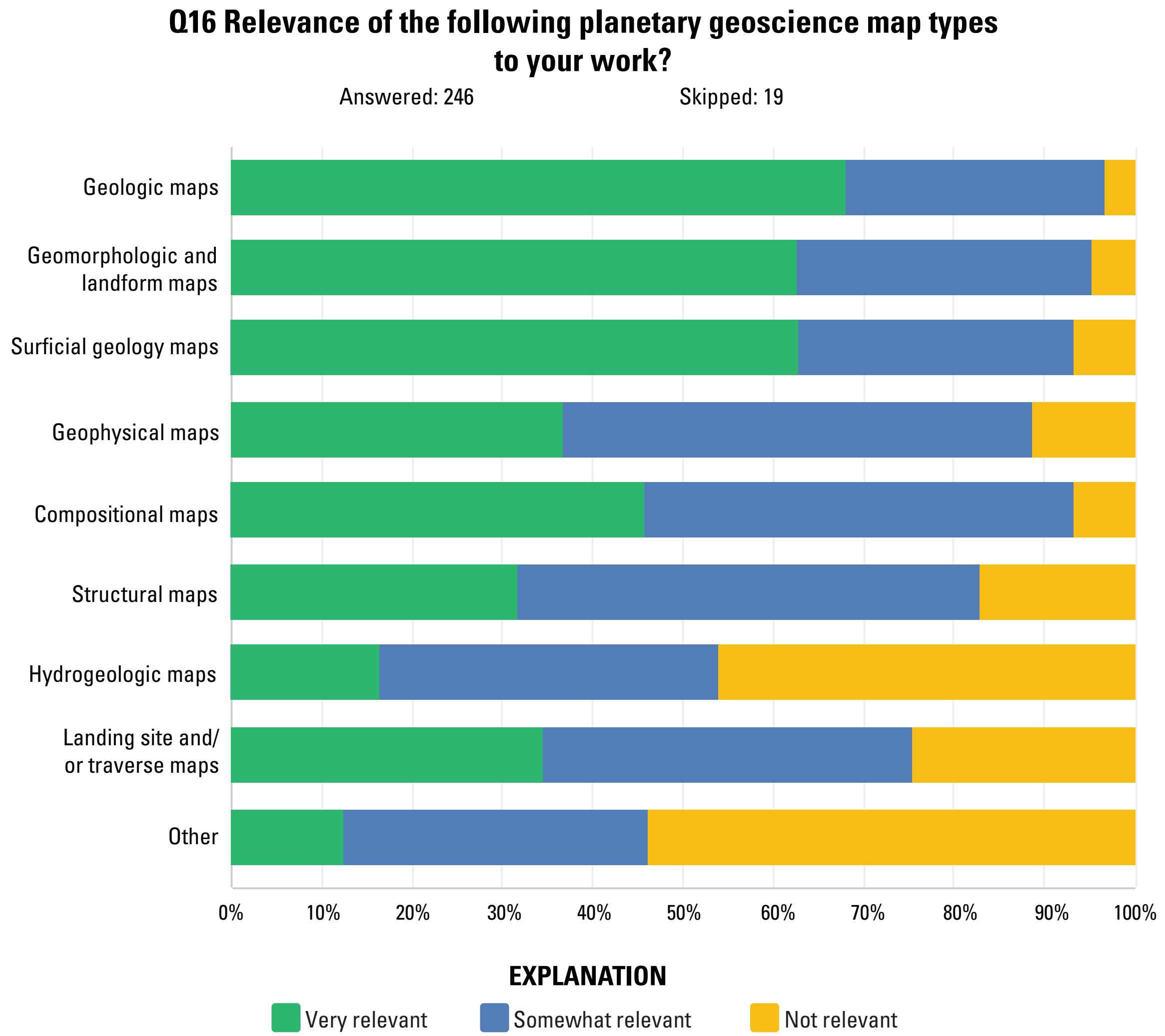
Q15 Relevance of the following map scales to your work?

Answered: 246 Skipped: 19



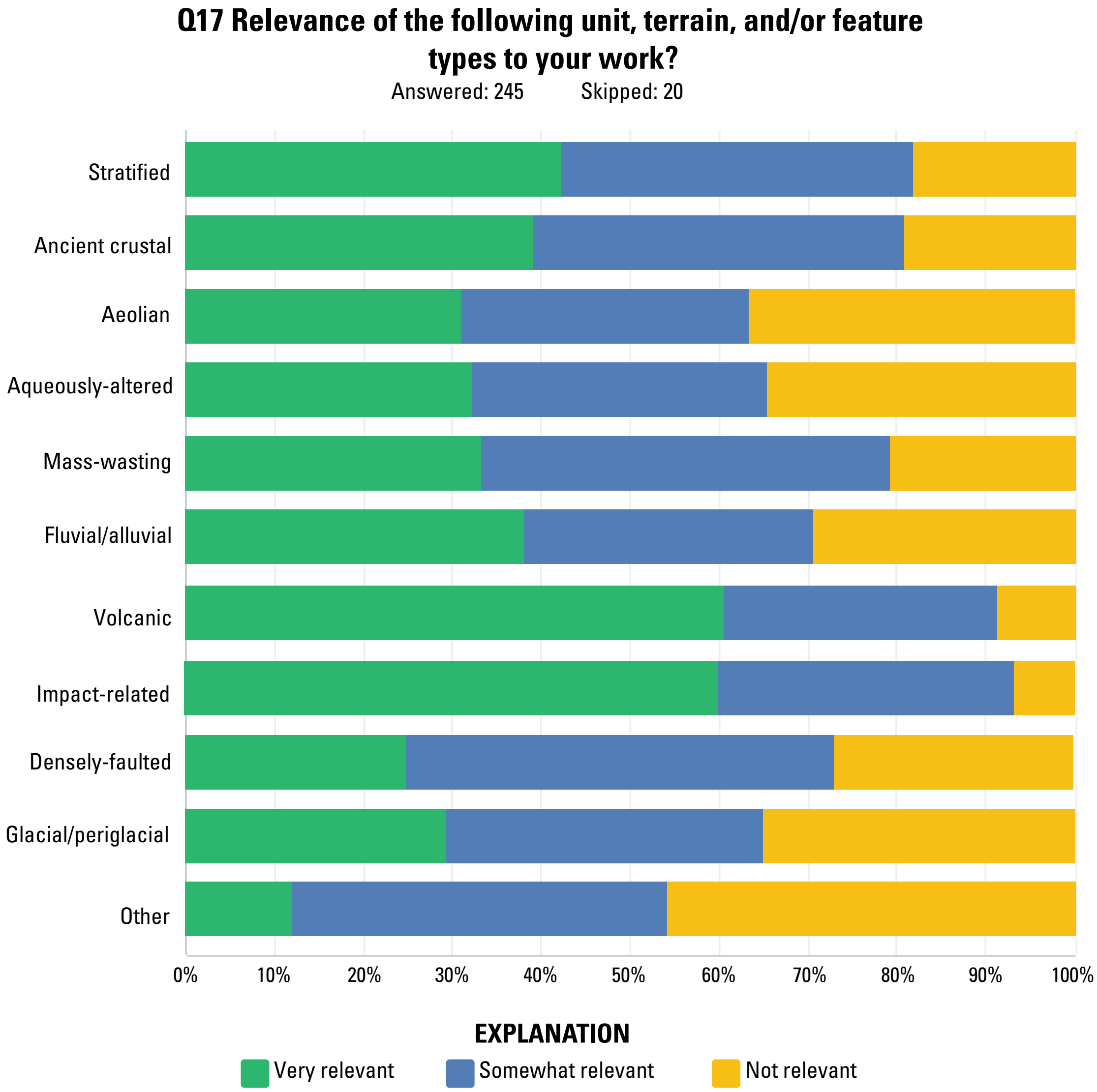
MAP SCALE	VERY RELEVANT	SOMEWHAT RELEVANT	NOT RELEVANT	TOTAL
Very local scales Responses	64% 156	27% 66	9% 22	244
Local to regional scales Responses	75% 184	22% 54	2% 6	244
Regional to hemispheric scales Responses	58% 142	37% 91	4% 10	243
Hemispheric to global scales Responses	55% 132	36% 86	10% 24	242

Figure 2.14. Relevance of map scale to respondent work (question 15).



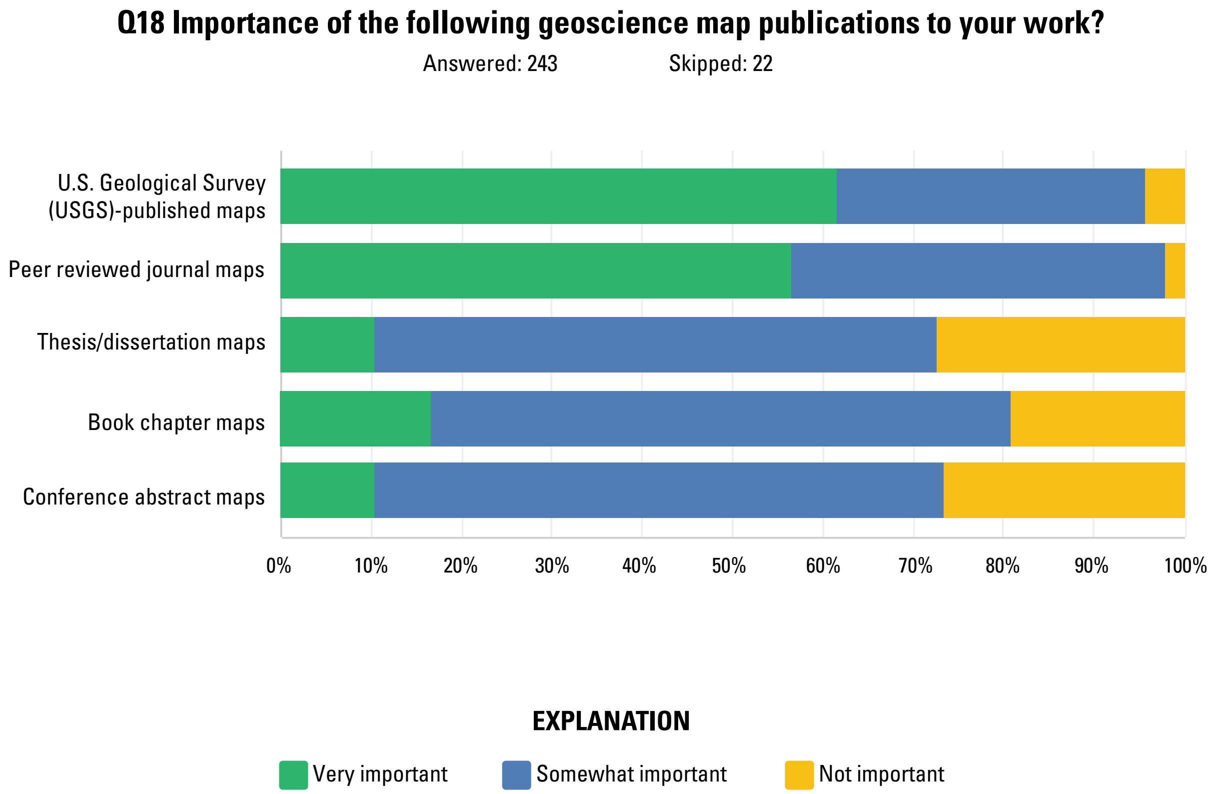
MAP TYPES	VERY RELEVANT	SOMEWHAT RELEVANT	NOT RELEVANT	TOTAL
Geologic maps	68%	29%	3%	
Responses	166	70	8	244
Geomorphologic and landform maps	63%	33%	5%	
Responses	152	80	11	243
Surficial geology maps	63%	31%	7%	
Responses	152	74	16	242
Geophysical maps	37%	52%	11%	
Responses	89	126	27	242
Compositional maps	46%	48%	7%	
Responses	110	114	16	240
Structural maps	32%	51%	17%	
Responses	76	123	41	240
Hydrogeologic maps	16%	38%	46%	
Responses	39	89	109	237
Landing site and/or traverse maps	35%	41%	25%	
Responses	83	98	59	240
Other	12%	34%	54%	
Responses	18	49	78	145

Figure 2.15. Relevance of geoscience map type to respondent work (question 16).



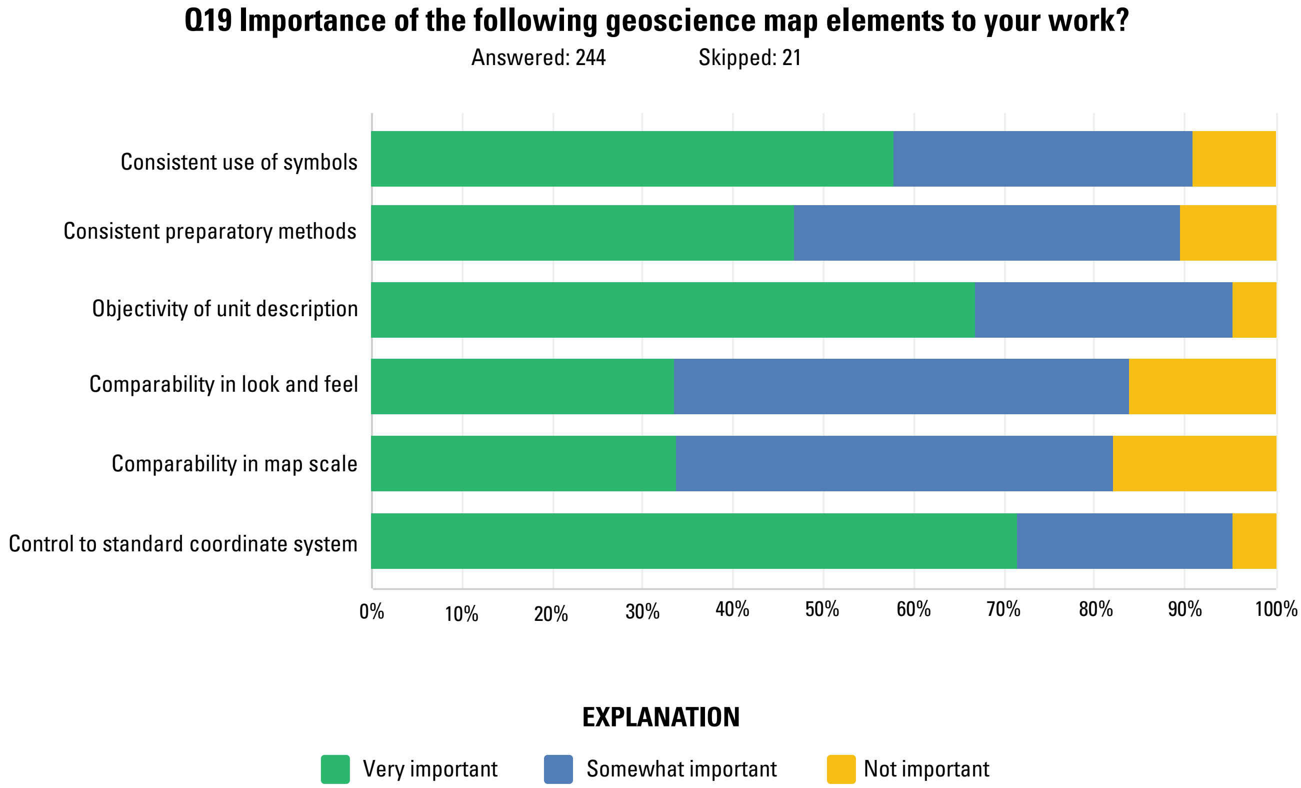
UNIT, TERRAIN, AND/OR FEATURE	VERY RELEVANT	SOMEWHAT RELEVANT	NOT RELEVANT	TOTAL
Stratified	42%	39%	18%	
Responses	101	94	43	238
Ancient crustal	39%	42%	19%	
Responses	94	100	46	240
Aeolian	31%	32%	37%	
Responses	74	77	87	238
Aqueously-altered	32%	33%	34%	
Responses	77	79	82	238
Mass-wasting	33%	46%	21%	
Responses	79	109	49	237
Fluvial/alluvial	38%	32%	29%	
Responses	91	77	70	238
Volcanic	61%	31%	9%	
Responses	146	74	21	241
Impact-related	60%	33%	7%	
Responses	146	81	16	243
Densely-faulted	25%	48%	27%	
Responses	59	114	63	236
Glacial/periglacial	29%	36%	35%	
Responses	70	85	83	238
Other	12%	42%	46%	
Responses	17	59	64	140

Figure 2.16. Relevance of unit, terrain and (or) feature type to respondent work (question 17).



GEOSCIENCE MAP PUBLICATIONS	VERY IMPORTANT	SOMEWHAT IMPORTANT	NOT IMPORTANT	TOTAL
USGS-published maps	62%	34%	4%	
Responses	149	83	10	242
Peer reviewed journal maps	57%	41%	2%	
Responses	137	100	5	242
Thesis/dissertation maps	11%	62%	27%	
Responses	25	148	65	238
Book chapter maps	17%	64%	19%	
Responses	40	154	46	240
Conference abstract maps	11%	63%	26%	
Responses	25	150	63	238

Figure 2.17. Importance of geoscience map publication type to respondent work (question 18).

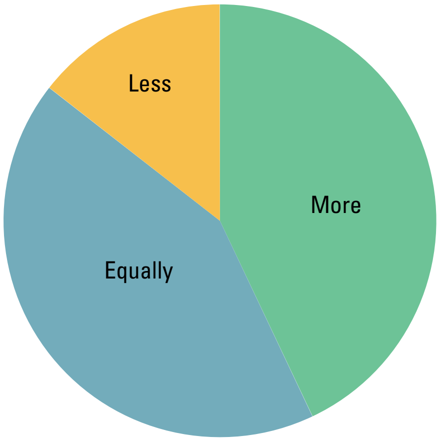


GEOSCIENCE MAP ELEMENTS	VERY IMPORTANT	SOMEWHAT IMPORTANT	NOT IMPORTANT	TOTAL
Consistent use of symbols	58%	33%	9%	
Responses	140	80	22	242
Consistent preparatory methods	47%	43%	10%	
Responses	112	102	25	239
Objectivity of unit description	67%	29%	5%	
Responses	161	69	11	241
Comparability in look and feel	34%	50%	16%	
Responses	80	120	38	238
Comparability in map scale	34%	48%	18%	
Responses	81	116	43	240
Control to standard coordinate system	71%	24%	5%	
Responses	173	58	11	242

Figure 2.18. Importance of map elements to respondent work (question 19).

Q20 Non-standardized geoscience maps that implement standard cartographic symbols sets and formats are ____________ useful than those that do not.

Answered: 242 Skipped: 23

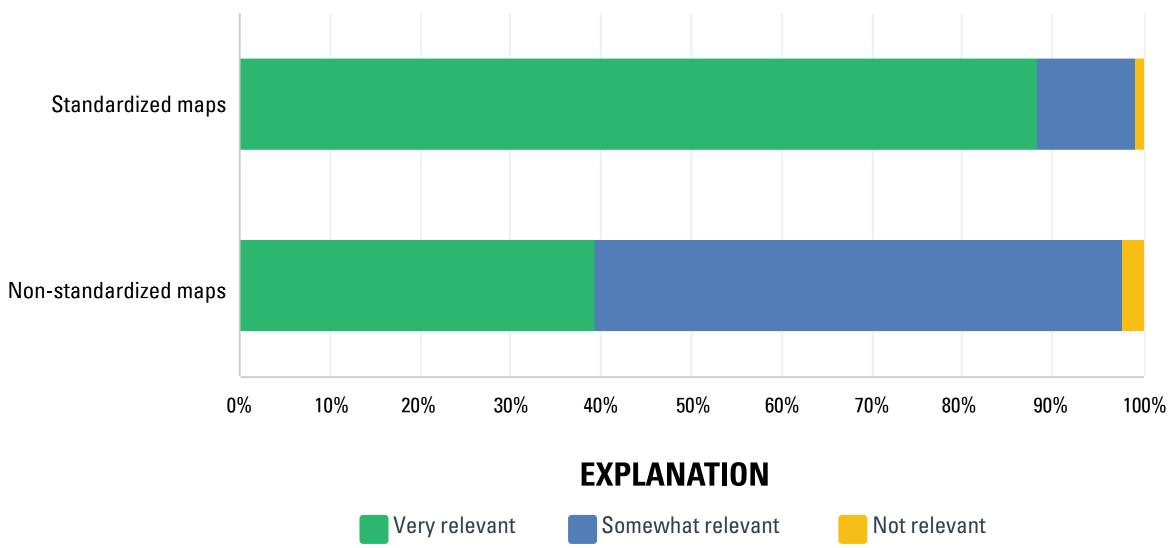


ANSWER CHOICES	RESPONSES	
More	43%	104
Equally	43%	103
Less	14%	35
TOTAL		242

Figure 2.19. Respondent evaluation of standard cartographic symbols in non-standardized geoscience maps (question 20).

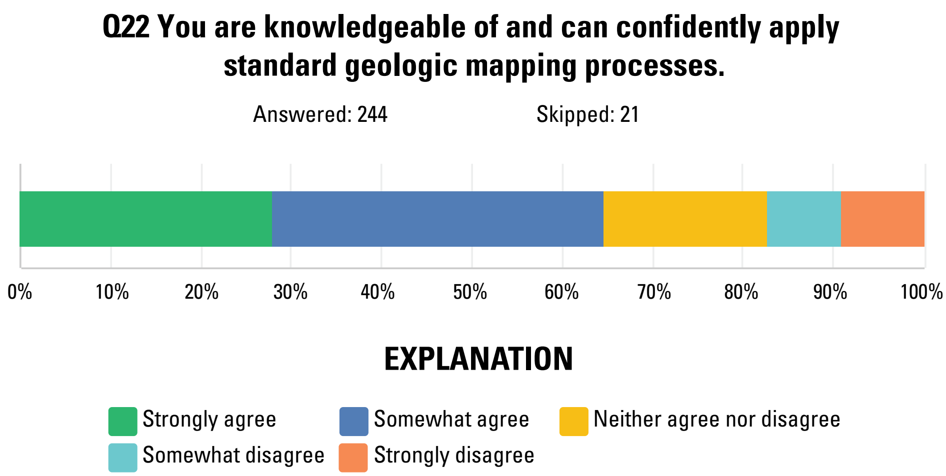
Q21 Relevance of geoscience maps to establishing context for the scientific community?

Answered: 240 Skipped: 25



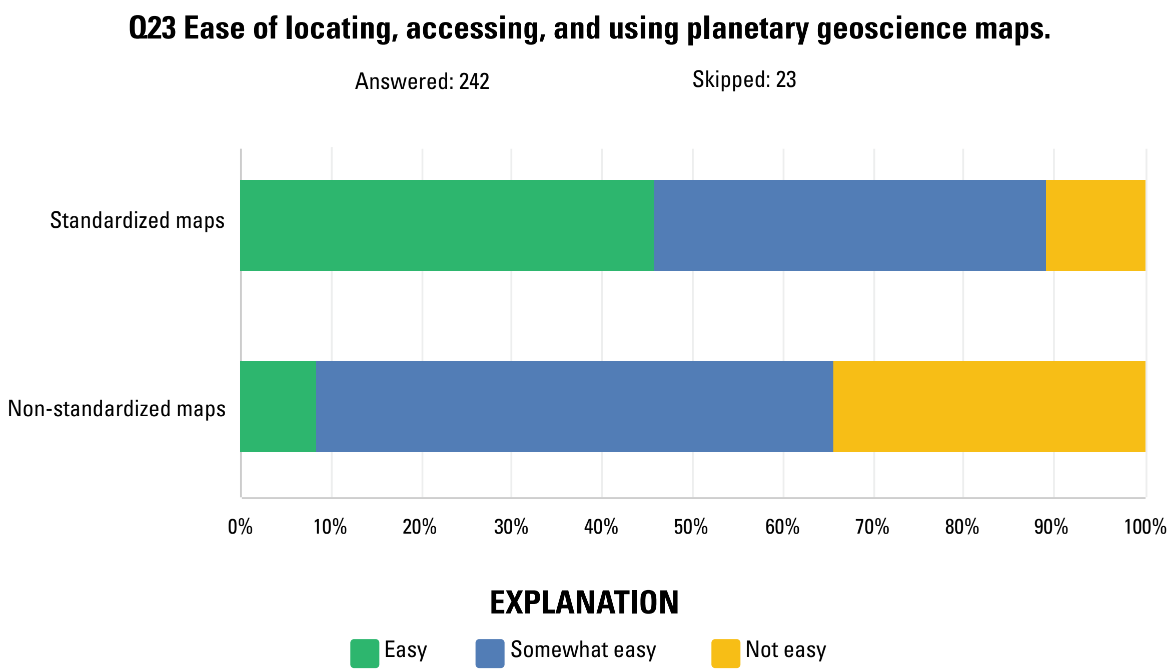
MAPS	VERY RELEVANT	SOMEWHAT RELEVANT	NOT RELEVANT	TOTAL	WEIGHTED AVERAGE
Standardized maps Responses	88% 211	11% 26	1% 2	 239	 1.13
Non-standardized maps Responses	39% 92	59% 137	2% 5	 234	 1.63

Figure 2.20. Relevance of geoscience maps to respondents in establishing context for scientific community (question 21).



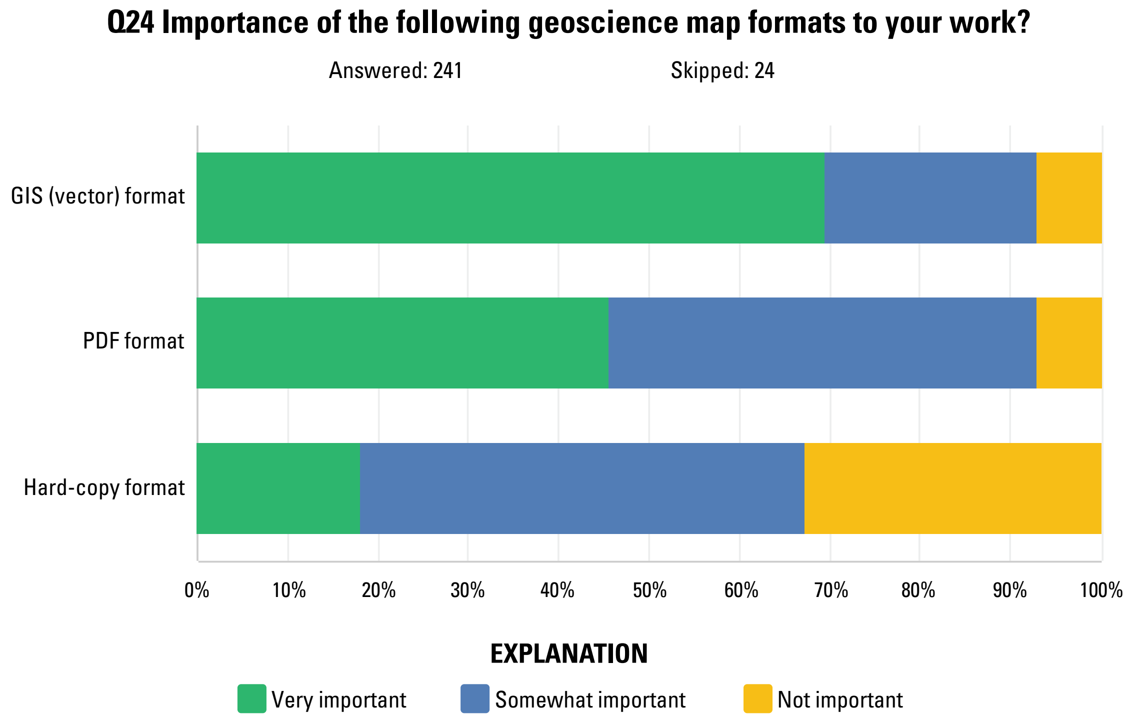
	STRONGLY AGREE	SOMEWHAT AGREE	NEITHER AGREE NOR DISAGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	TOTAL	WEIGHTED AVERAGE
	28%	37%	18%	8%	9%		
Responses	68	90	44	20	22	244	2.34

Figure 2.21. Evaluation of respondent confidence in applying standard mapping processes (question 22).



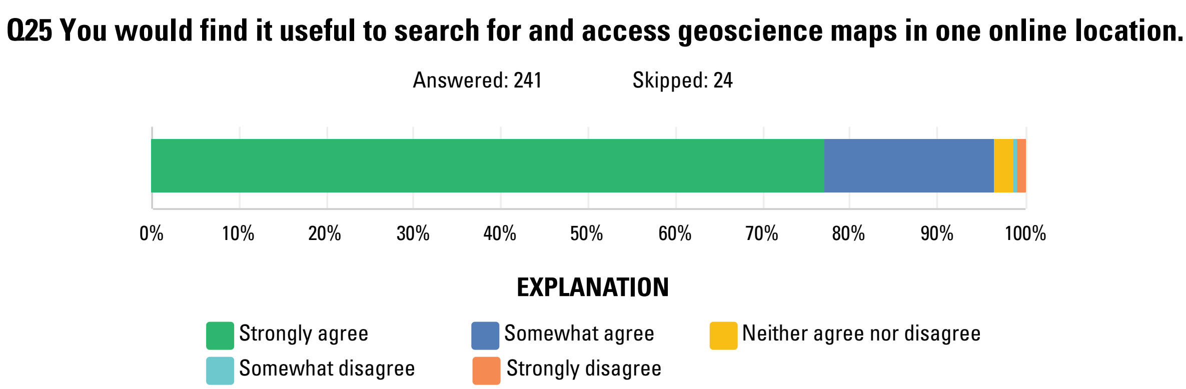
MAPS	EASY	SOMEWHAT EASY	NOT EASY	TOTAL	WEIGHTED AVERAGE
Standardized maps	46%	43%	11%		
Responses	111	105	26	242	1.65
Non-standardized maps	8%	57%	34%		
Responses	20	137	82	239	2.26

Figure 2.22. Respondent evaluation of geoscience map accessibility (question 23).



MAP FORMAT	VERY IMPORTANT	SOMEWHAT IMPORTANT	NOT IMPORTANT	TOTAL
GIS (vector) format	69%	23%	7%	
Responses	166	56	17	239
PDF format	46%	47%	7%	
Responses	109	113	17	239
Hard-copy format	18%	49%	33%	
Responses	43	118	78	239

Figure 2.23. Importance of map formats to respondent work (question 24).

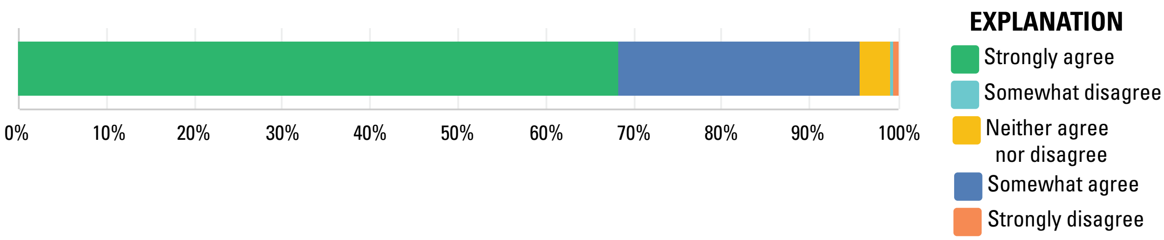


	STRONGLY AGREE	SOMEWHAT AGREE	NEITHER AGREE NOR DISAGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	TOTAL	WEIGHTED AVERAGE
	77%	20%	2%	0%	1%		
Responses	186	47	5	1	2	241	1.28

Figure 2.24. Respondent preference towards a single online repository of geoscience maps (question 25).

Q26 Surface science investigations fundamentally rely on spatial and temporal context established and refined by geoscience maps.

Answered: 236 Skipped: 29

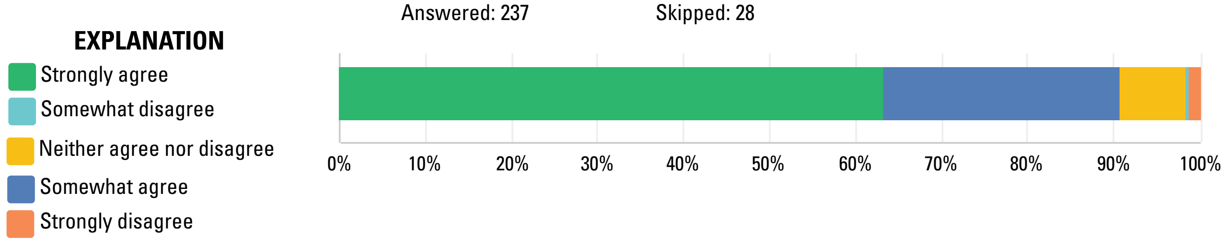


	STRONGLY AGREE	SOMEWHAT AGREE	NEITHER AGREE NOR DISAGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	TOTAL	WEIGHTED AVERAGE
Responses	68% 161	28% 65	3% 8	0% 1	0% 1	236	1.37

Figure 2.25. Respondent evaluation of geoscience maps as fundamental to surface science investigations (question 26).

Q27 Expedited production of standardized geoscience maps for areas of high interest and/or relevance would benefit both scientific investigations and potential future exploratory mission planning.

Answered: 237 Skipped: 28

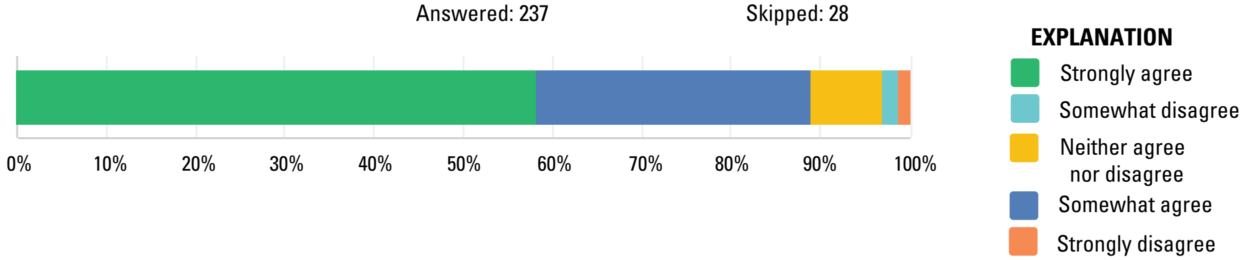


	STRONGLY AGREE	SOMEWHAT AGREE	NEITHER AGREE NOR DISAGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	TOTAL	WEIGHTED AVERAGE
Responses	63% 150	27% 65	8% 18	0% 1	1% 3	237	1.49

Figure 2.26. Respondent evaluation of expedited production of standardized geoscience maps (question 27).

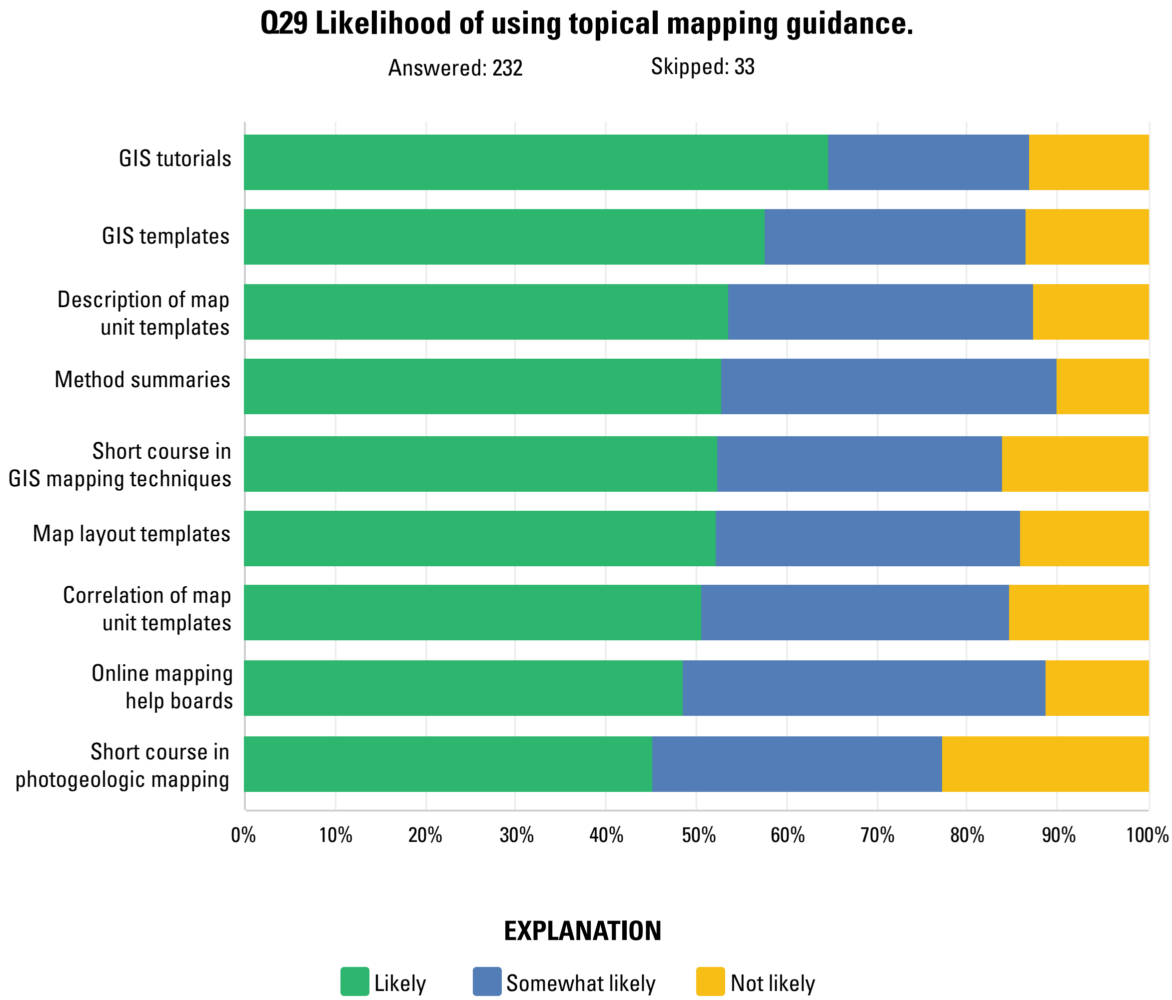
Q28 Multi-year geologic mapping campaigns that focus on creating a series of maps for a particular body at a set map scale would be useful for the scientific community.

Answered: 237 Skipped: 28



	STRONGLY AGREE	SOMEWHAT AGREE	NEITHER AGREE NOR DISAGREE	SOMEWHAT DISAGREE	STRONGLY DISAGREE	TOTAL	WEIGHTED AVERAGE
Responses	58% 138	31% 73	8% 19	2% 4	1% 3	237	1.57

Figure 2.27. Respondent evaluation of multi-year mapping campaigns for particular planetary bodies and map scales (question 28).



USE OF TOPICAL MAP GUIDANCE	LIKELY	SOMEWHAT LIKELY	NOT LIKELY	TOTAL
GIS tutorials Responses	65% 148	22% 51	13% 30	229
GIS templates Responses	58% 132	29% 66	14% 31	229
Description of map unit templates Responses	54% 123	34% 77	13% 29	229
Method summaries Responses	53% 121	37% 85	10% 23	229
Short course in GIS mapping techniques Responses	52% 120	31% 72	16% 37	229
Map layout templates Responses	52% 119	34% 77	14% 32	228
Correlation of map unit templates Responses	51% 116	34% 78	15% 35	229
Online mapping help boards Responses	49% 109	40% 90	11% 25	224
Short course in photogeologic mapping Responses	45% 104	32% 74	23% 52	230

Figure 2.28. Likelihood of respondent use of topical mapping guidance (question 29).

Menlo Park Publishing Service Center, California
Manuscript approved February 12, 2019
Edited by Phil Frederick
Layout by Kimber Petersen

USGS

Skinner and others—**Planetary Geologic Mapping—Program Status and Future Needs —Open-File Report 2019-1012**

ISSN 2331-1258 (online)
https://doi.org/10.3133/ofr20191012