THE NEED FOR PLANNING THE FUTURE OF PLANETARY CARTOGRAPHY. B. A. Archinal[1], R. L. Kirk[1], L. R. Gaddis[1], T. N. Titus[1], K. E. Herkenhoff[1], L. P. Keszthelyi[1], S. J. Lawrence[2], R. Beyer[3,4], and A. Nefian[4], [1]U. S. Geological Survey, Astrogeology Science Center, (2255 N. Gemini Drive, Flagstaff, AZ 86001, USA, barchinal@usgs.gov), [2]School of Earth and Space Exploration, Arizona State University (Tempe, AZ 85287-3603, USA), [3]Carl Sagan Center, SETI Institute (Mountain View, CA, 94043, USA), [4]NASA Ames Research Center, Moffett Field, CA, 94035, USA).

Introduction: Cartography is the science and art of placing information in a community-recognized spatial framework. It is essential for comparing or combining data taken at different times or by different instruments. As such, it is foundational to most planetary science, especially as more involved data analysis is required to solve more mature questions.

A lack of planning in constructing this foundation can have and has had serious and expensive consequences to the scientific return from planetary missions. In this abstract we highlight the unprecedented lack of formal cartographic planning for the U.S. space program and suggest a straightforward community-driven solution.

Background: While the USGS has been heavily involved in planetary cartography for over 50 years, this work has always been a broad community effort. During the late 1960s and 1970s multiple organizations helped plan and carry out this work, including NASA JSC, the National Geodetic Survey, the Defense Mapping Agency, RAND, various universities, and others. The table below lists the various groups chartered to coordinate these efforts, effectively disseminate information to the broader community, and/or advise NASA leadership on cartographic matters [1].

Start Date	Name
1974	Lunar Photography and Cartography Committee
1977	Lunar and Planetary Photography and Cartography Committee
1979	Planetary Cartography Working Group
1994	Planetary Cartography & Geologic Mapping Working Group (PCGMWG)

The last of these, the PCGMWG, includes the chair of the NASA Geologic Mapping Subcommittee (GeMS). Other groups have been active in making recommendations on mapping standards (e.g., IAU WGCCRE, 1976-present; MGCWG, mid-'90's-present; LGCWG, 2007~2009) but not general cartography planning [2-4].

From 1994 to 2012, the PCGMWG made cartography recommendations to NASA, including submitting a white paper on cartography [5] to the NRC Decadal Survey. The PCGMWG ceased making cartography recommendations in 2012. The group continues its other responsibilities.

Unaddressed Issues: The cessation of cartographic planning leaves many issues unresolved, which has direct and indirect impact on many strategic decisions facing the leadership of the U.S. planetary exploration efforts (i.e., NASA). We highlight a few key issues to give a sense of the magnitude of the issues created by the current situation.

High priority examples. How should the current massive planetary data sets be geodetically controlled and integrated to best enable science and operation of current and future missions? How should global, regional, and local topographic models be created from multiple available data sets? What are the requirements on missions? How can research and analysis funding better support development of mapping procedures for large scale and complex products? What are the strategic knowledge gaps (SKGs) [6] related to mapping and how should such guidance be used? How should standards groups (LGCWG, MGCWG, and others) operate? When and how should mapping tools be developed and tested for accuracy?

Need for geodetic control. Controlling data sets (with photo- or radar-grammetric, or altimetric solutions) is the only way to register data in a common frame at known levels of accuracy. Such knowledge is critical for science (e.g., analysis of body orientation variations, photometric correction for spectral/mineral studies, geologic mapping, change detection, and multi-instrument comparisons) and mission operations (e.g., landing site selection, targeting images from orbit, and landed surface operations). These activities can sometimes be conducted without controlled data, but the confidence in the results can be significantly, or even totally, degraded. Uncontrolled data not only have poorer spatial accuracy, but also the level of uncertainty is usually unquantified.

The current special concern is related to the volume (order PBs) of uncontrolled data that has been collected, especially from Mars and the Moon. There is an urgent and growing need to devise a realistic and affordable plan to refine this vast treasure trove. It is potentially very economical to systematically control at least a few of the most widely used data sets, but the cost-benefit ratio can only be quantified after a rough prioritized implementation plan is developed.

Need for accepted cartographic standards. Controlling each data set to a different cartographic standard only minimally improves the scientific value of the data. In an operational environment, confusion regarding coordinate systems could have catastrophic consequences. The effect is comparable to that of not standardizing measurement units. While the development of standards can be a truly arcane subject, the real key is to have universal acceptance of a standard – even when there is no one best choice based on technical considerations.

As such, the current special concern is to find the most effective inducements to obtain the widest ac-

ceptance of planetary cartographic standards, especially by active missions. A recent example of concern is the Dawn mission's confusing use of multiple coordinate systems for Vesta [7], only one of which has been recognized as following existing international conventions and standards [8]. While the issue of standards is an international problem, the U.S. (i.e., NASA) has the opportunity to lead by example. However, such leadership will not take place without at least a general plan developed by key stakeholders.

Prioritizing cartographic tool development. Many needs exist for new or improved tools to handle the increasingly complex instruments and vast data volumes of current and planned missions. Examples include (1) faster and more robust matching between disparate data types, enabling new types of data fusion; (2) ability to simultaneously adjust data from different platforms (e.g., orbital, descent, lander, and rover) and data types (e.g., images, radar, and altimetry); (3) new tools to combine different methods for generating topographic information, especially combining LIDAR and image-based techniques.

In the current budget environment it is impossible to develop all the desired tools concurrently. At the same time, in the absence of such a plan, the community has duplicated efforts related to many widely used data sets. Such uncoordinated efforts are especially painful when resources are scarce. A prioritized list of tools to be developed for the community as a whole, with adequate community input, will stretch limited research and analysis funding significantly.

Multi-mission data analysis. Individual missions and instruments usually have an understanding of their own cartographic needs and effectively address them. However, without a broader planning group, multimission cartography is, unsurprisingly, sometimes neglected. Specific concerns span the entire Solar System. For Mercury, the eventual combination of Mariner 10, MESSENGER, and Bepi-Columbo data will be necessary, but current work largely focuses on MESSENGER data only. For Venus, complete processing of the Magellan stereo data has not been attempted. For the Moon, hundreds of terrabytes of data now exist from multiple nations, missions, and instruments, posing many challenges (and opportunities) for co-analysis [9]. For Mars, similar problems exist, with many complex data sets that have not been completely processed or well-registered to each other, or are not of sufficient resolution for future needs. For example, recent MEPAG planning documents [10] require 2 m, high-resolution knowledge of the mineralogy of Mars, and yet there are no current requirements to obtain the necessary topographic base for photometric correction of such data beyond the current >50 m (HRSC) to 1,500 m (MOLA) level. For Jupiter, further joint processing of Voyager, Galileo, and perhaps New Horizons data is needed in order to provide improved mosaics and initial topography (in areas where possible) of the Galilean satellites. Such solutions will also place constraints in their internal structure and possible oceans. Similar arguments can be made for Titan and the other Saturnian satellites. Reprocessing of the Voyager data from the satellites of Uranus and Neptune with current techniques would likely yield improved quality products. And while new cartographic data will be collected of Pluto and Charon by New Horizons there is no NASA requirement for the production of globally controlled cartographic products, although the team may create them. The "state of the art" for mapping small, irregular bodies is uncertain and currently poorly developed. There are numerous needs for the development of proper analysis algorithms and software, as well as the further development and use of proper standards. We are unaware of any planning for the accuracy verification of current small-body mapping methods. These issues should be of significant concern to current and future missions to small bodies, including (as we have described [11]) for any asteroid hazard mitigation or return mission). See [12] for a summary of such problems.

Recommendation: In principle, ending the unprecedented interruption in planetary cartography planning should be straightforward – a new working group would be chartered to resume this essential work. However, there are some specific community actions that will expedite this process and ensure that the new group is effective:

1) Members of the planetary science community, especially those considering leading future planetary missions, should advocate that the NASA Advisory Group closest to their interests "find" that a new cartographic planning group should be chartered. The USGS has made some presentations to this effect to SBAG and LEAG, but broader community action is desirable.

2) A clear charter for the new group is needed, addressing the scope of their purview, avenues of communication to the science community and NASA leadership, and metrics to assess the success of the planning efforts.

3) Key stakeholders, and not just professional cartographers, should plan to be involved in the new group. Advocates for a variety of basic research, future robotic missions, future human missions, data archiving, tool development, international cooperation, and advocates for training a new generation of planetary cartographers, need to be heard.

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