CARTOGRAPHIC NEEDS FOR GEOLOGIC MAPPING DURING ACTIVE ORBITAL PLANETARY MISSIONS. D. A. Williams, School of Earth & Space Exploration, Arizona State University, Box 871404, Tempe, Arizona 85287 (David.Williams@asu.edu).

Introduction: NASA's Planetary Science Division supports the geologic mapping of planetary surfaces through a distinct organizational structure and a series of research and analysis (R&A) funding programs, in which maps are made traditionally using cartographic products (e.g., controlled image mosaics, digital terrain models) from completed planetary missions. However, active orbital and landed missions, such as NASA's Dawn and Mars Science Laboratory missions [1,2], have requested that science teams conduct geologic mapping either prior to or during the nominal mission as images are being acquired, to support mission operations and/or to provide geologic context for other instruments. Here, we discuss the nature of mission-supportive geologic mapping campaigns during active orbital missions using the Dawn at Vesta example, address lessons learned from that campaign, and identify the critical cartographic products and support required to ensure high-level mission support.

Why Geologic Mapping?: Geologic mapping is an investigative process used to understand the evolution of the terrestrial planets and solid-surface satellites [3,4]. The goal of geologic mapping is to identify spatially and temporally discrete material units and surface features and place these a stratigraphic context in order to resolve a sequence of events and timescales for the evolution of planetary surfaces. For non-terrestrial bodies, understanding geologic evolution requires multi-scale determination of relative ages between discrete units, often correlated with estimates of ages derived from impact crater populations. The advantage of geologic mapping relative to photogeologic analyses alone is that it reduces the complexity of heterogeneous planetary surfaces into comprehensible proportions wherein many facets of geologic evolution must be simultaneously addresed.

In-mission geologic mapping has historically been conducted in *ad hoc* fashion due to the unknown nature of the target body as well as prohibitive nature of mapping during period of high data flux. Standardized planetary geologic maps are completed for bodies with adequate image coverage , often using cartographic products produced after the missions are completed and the range of surface characteristics are better understood. Recently, mission science teams have asked team members to conduct geologic mapping to support active missions. For example, during the Vesta encounter, the Dawn Science Team asked for a geologic mapping campaign, in which iterative geologic mapping of increasingly higher spatial resolution Framing Camera (FC) images obtained during Dawn's orbital phases would be used 1) to provide geologic and stratigraphic context of surface features as they were being studied, and 2) to better support the analysis of compositional data from the Visible and Infrared Spectrometer (VIR) and the Gamma Ray and Neutron Detector (GRaND). Additional thematic mapping (e.g., crater catalogs, structural features) was also done in parallel as part of the standard initial image analyses of Vesta's surface.

Organization of Dawn-Vesta Mapping Campaign: The Dawn Science Team planned to produce cartographic products of Vesta from the FC images, including global mosaics as well as 15 regional quadrangles [5]. A global geologic map at scale 1:500,000 [6] and production of 15 quadrangle geologic maps at scale 1:250,000 were planned using the cartographic image quadrangles produced by DLR as basemaps. The goal of the quadrangle mapping effort was to improve upon the geologic history identified by the global map (made with lower resolution data) using Low Altitude Mapping Orbit (LAMO, FC resolution of 20-25 m/pixel) data, in which identification of the major types of surface features, geologic units, and stratigraphic relations at regional and local scales could be done at greater fidelity. The quadrangle mapping was to be driven by the science questions and hypotheses that arose during the global mapping.

Challenges: It was recognized early on that vestan geologic maps would be published in peer-reviewed journals and not by the USGS because of the length of time required to review and produce standardized products. However, community mapping guidelines disseminated through the USGS, particularly with regard to the use of GIS templates, were used to be as consistent as possible with standard processes and products.

Lessons Learned: Although not initially driven by specific science goals for each quad, the geologic mapping of the vestan quadrangles provided the team with initial descriptions and interpretations of regional geologic units, building on the work of the global mapping effort [6]. Mappers were able to revise their interpretations as higher-resolution images were returned to aid the analysis of data returned from other science instruments, e.g., identifying the geologic context of mineral or elemental signatures. However, map interpretation did not lend itself well to the compressed mission timeline. The needs of the team for rapidly-produced maps meant that coordination between global and regional efforts was non-trivial, and thus, broad-scale geologic map units were established earlier than was ideal. *For future missions, we recommend that mappers retain more generic descriptors and planet-centric symbology for as long as possible, until higher-resolution data is obtained and descriptions and interpretations can be refined. Early contact/coordination with the USGS mapping specialists when beginning the mapping process, as well as Mapping spliters at Team Meetings, is essential.*

For Vesta the quadrangle mapping began before a first draft global map was completed, where the global map would have enabled recognition of the most interesting regions to which higher resolution mapping was justified. Also, the quad boundaries were defined and mappers assigned prior to Dawn's arrival. The result of this was that, when the mapping process began, it was an impediment to contextual understanding, coordination of mapping effort, and consistency of maps.

The choice to produce 15 quadrangle geologic maps was based on utilization of the FC cartographic products [5], itself based on the approach in *Greeley & Batson* [7]. Although these maps were useful to display Vesta's unique surface to the scientific community as a series of posters at conferences during the nominal mission, attempting to use these same 15 maps as the basis for more detailed geologic mapping studies made the mapping process more difficult. Specifically, key geologic features often crossed quadrangle boundaries, which were rarely crossed during the mapping process, or during the follow-on analysis. Also, differences in expertise with ArcGIS™ software, mapping styles, and experience all were amplified by the large number of mappers (14) to cover 15 quadrangles.

Recommendation for Mapping & Cartography for Future Missions: Building on the Dawn at Vesta lessons learned, we recommend the following guidelines for conducting geologic mapping campaigns on future planetary missions:

1) Complete a first draft global geologic map first, identify the regions where more detailed mapping is justified, then assign regions to team members, and match surface features with mappers having the correct expertise, skills and interests to produce quality maps. These regions could use single quadrangles, multiple quadrangles, parts of quadrangles, or hemispheric quadrangles, where *science & mapping needs define the cartographic products required, not the other way around.* Note that this approach does not preclude work on other topical science studies, including local morphological, compositional, or thematic mapping. Additionally, it is important that individuals who are assigned quads are experienced mappers, or students with the time and desire to learn how to complete a geologic map.

2) The number of individual mappers assigned for detailed mapping should be based on the size of the regions mapped, the science rationale for mapping, and/or the amount of detail that is observable in the areas. In general, the more mappers, the more difficult it is to correlate map units and contacts, especially if the maps are to be combined/integrated.

3) Mission science teams should coordinate with community advisory panels to the extent possible on development of mapping templates, approaches, and cartographic products early in the Nominal Mission, in some cases prior to acquisition of first images. Their assistance with application of coordinate systems consistent w/IAU, with development of ArcGIS™ projects for mapping, and other deliverables is a key to success.

4) Abstracts and conference poster presentations are an ideal way to present preliminary maps for early community input, but should not necessarily drive later peer-reviewed publications.

5) Rather than requiring each mapper to write a peer-reviewed paper based on mapping of a cartographic quadrangle, geologic mapping should be based on regional features or process-related science drivers.

6) Ongoing research should be carefully coordinated within the broader science team, to assure that research facilitated by geologic mapping is fully supported, without placing undue pressure on team members to define a potential publication solely by a geologic map where such is not warranted.

Current Cartographic Support for Geologic Mapping: Cartography and geologic mapping issues for NASA's planetary science programs are overseen by the Mapping and Planetary Spatial Infrastructure Team (MAPSIT), which is a self-organized comnunity advisory team that addresses and prioritizes short- and long-term needs for planetary cartographic infrastructure. The Geologic Mapping Subcommittee (GEMS) is a group of community mappers that advises the USGS Planetary Mapping Coordinator & develops policy to aid the planetary geologic mapping community.

References: [1] Russell, C.T. and Raymond, C.A. (2011) *Space Sci. Rev., 163*, 3-23. [2] Russell, C.T., et al. (2012) *Science, 336*, 684-686. [3] Carr, M.H., et al. (1976) *NASA SP-417,* 13-32. [4] Wilhelms, D.E. (1990), in *Planetary Mapping,* Cambridge Un. Press, NY, 208-260. [5] Roatsch, T., et al. (2012) *PSS 73*, 283-286; Williams D.A. et al. (2014) *Icarus, 244,* 1-12. [6] Yingst R.A. et al. (2014) *PSS, 103,* 2-23. [7] Greeley, R. & Batson, R. (1990), *Planetary Mapping,* Cambridge Un. Press, NY.