STRATEGIES FOR THE GEOLOGIC MAPPING OF SMALL AIRLESS BODIES: THE VESTA EXAMPLE.
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Introduction: In July 2011 NASA's Dawn spacecraft entered orbit around the main belt asteroid (4)Vesta, beginning a lengthy orbital study of this unique protoplanet [1,2]. A geologic mapping campaign was developed as part of the Nominal Mission to provide a systematic, cartography-based initial characterization of the global and regional geology of Vesta. In this abstract we highlight major aspects of the geologic mapping campaign for Vesta, including discussion of the goals of the mapping effort, the methodologies used, the challenges that arose in the mapping of a small airless body like Vesta, and a list of lessons learned that future missions should review when designing a mapping program to aid in nominal mission data analyses of small airless bodies.

Purpose & Goals of Mapping: Geologic maps are tools to understand the evolution of the terrestrial planets. The goal of geologic maps is to place observations of surface features into their stratigraphic context to develop a sequence of events for the evolution of planetary surfaces [3,4]. The advantage of geologic mapping over photogeologic analyses alone is that it reduces the complexity of heterogeneous planetary surfaces into comprehensible portions, in which discrete material units are defined and characterized based upon specific physical attributes related to the geologic processes that produced them. The distributions of these units are then mapped, along with structural features, in order to identify the relative roles of various processes in shaping their surfaces.

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]. We were chosen to oversee the geologic mapping campaign during the Nominal Mission. We oversaw production of a global geologic map at scale 1:500,000 [6] and production of 15 quadrangle geologic maps at scale 1:250,000, using the cartographic image quadrangles produced by DLR as basemaps. The goal of the Vesta global mapping was to use iterative geologic mapping of increasingly higher spatial resolution FC images obtained during Dawn's orbital phases 1) to support the Geosciences Working Group by providing geologic and stratigraphic context of surface features, and 2) to better support the analysis of data from the Visible and Infrared Spectrometer (VIR) and the Gamma Ray and Neutron Detector (GRaND). 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.

Methodologies: For each quadrangle, mappers assembled the base map mosaics, DTMs, and other materials and imported them into ArcGIS™10 software by ESRI, Inc. to facilitate geologic mapping. Each quadrangle mapper was free to define and characterize subunits and structures derived from the global geologic map [6], with the expectation that units would be updated and modified to take advantage of the higher spatial resolution LAMO data. The quadrangle mappers were encouraged to collaborate with the mappers of neighboring quadrangles, to assure unit contacts matched across quadrangle boundaries, that similar units were used, and that a consistent level of detail in the mapping was maintained.

Challenges: One of the key early findings of the Dawn mission was that Vesta's ratio of surface relief to radius is ~15%, compared to ~1% for the Moon and Mars [7]. This means that extremely steep slopes are common on Vesta compared to other terrestrial planets. These steep slopes cause impact craters to be deformed into an asymmetric shape, or partly buried by subsequent mass movements triggered by later impacts. These crater-related processes often make clearly defined contact boundaries between map units very hard or impossible to identify, except for the youngest (freshest) units. This fact makes delineation and description of units more difficult and identification of the relations between units problematic compared to mapping on other bodies. Thus, Vesta mappers often use approximate, gradational, or inferred contacts when mapping Vesta's large-scale units at high resolution, except where in contact with young crater materials or at steep scarps.

Other challenges encountered with application of geologic mapping to asteroids include: 1) the lack of non-impact processes limits the variety of geological units that can be defined; and 2) many previously studied smaller asteroids are spectrally "bland" with no composition-related color differences. We were pleasantly surprised to see strong color and spectral variations on Vesta [8,9].

Lessons Learned: Although not initially driven by specific science goals for each quad, the geologic mapping of the 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 in real time to aid the analysis and interpretation 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, units were standardized 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 U.S. Geological Survey mapping specialists when beginning the mapping process 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]. Although 15 early geological "sketch" maps were useful to display Vesta's unique surface to the scientific community as a series of posters at conferences during the nominal mission, it is now the perspective of the Science Team that 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 (mappers ranged from graduate students to mid-career scientists) all were amplified by the large number of mappers (14) to cover 15 quadrangles. Because of these difficulties, we recommend the following for Dawn at Ceres or future missions to small airless bodies:

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, or parts of quadrangles as defined by the cartographic products. Note that this approach does not preclude work on other topical science studies, including local morphological, compositional, thematic, or geologic 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) Decrease the number of mappers. The number of 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.

3) To support coordination of effort, develop mapping templates early in the Nominal Mission, for the ArcGIS™ projects, for conference posters, for the format of mapping publications, and for presenting results.

4) Utilize abstracts and conference presentations as the best way to present preliminary maps that may be based more on cartography than pure geology, which should be separate from future geologic maps for peer-reviewed publications.

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

6) Geologic mapping is an excellent way for graduate students and younger team members to conduct useful mission-related scientific research and write first-author publications.

7) 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.

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