The Global Geologic Map Package based on 15 individual maps of Ceres: Review of a Compilation Process.

A. Nass[1], and the Dawn Science Team,
DLR, Institute for Planetary Research, Rutherfordstrasse 2, 12489 Berlin, Germany (andrea.nass@dlr.de).

Introduction: One aim of the NASA Dawn mission was to generate global geologic maps of the asteroid Vesta and the dwarf planet Ceres. The geological mapping campaign of Vesta was completed and results have been published in e.g. [1]. Recently also geologic mapping of Ceres has been completed. The tiling used in this mapping project is based on recommendations by [2], and is divided into two parts (for Ceres described in [3,4]): four overview quadrangles (Survey Orbit, 415 m/pixel) and 15 more detailed quadrangles (High Altitude Mapping HAMO, 140 m/pixel). The atlases are available to the public through the Dawn webpage (dawngis.dlr.de/atlas) and the NASA Planetary Data System (PDS) (pdssbn.astro.umd.edu).
The first global geologic map at a scale of 1:2.5 M is based on survey and HAMO images. This served as basis for generating a more detailed view of the geologic history and also for defining the chronostratigraphy and time scale of Ceres [5]. A more detailed view could be expected within the 15 quadrangles (HAMO tiles) which was completed by the Low Altitude Mapping (LAMO) data (35 m/pixel). For the interpretative mapping one responsible mapper was assigned for each quadrangle. Once individual tile mapping has been finished, datasets are expected to be "combinable" within ESRI's ArcGIS platform.
To handle this task, a map template is needed to generate a geometrically and visually homogeneous map project representing a thematically consistent global map. Therefore, the mapping process was supported by a mapping template which was developed within the ArcGIS environment. Once set up using a set of specifications, templates can be distributed and facilitate the mapping process through pre-defined symbols, object attributes, geometric properties and map sheet elements. Templates like this are very established in multi-user projects, and were also used by and within the Geological Mapping Program conducted and guided by the USGS Astrogeology Science Center.

The template presented here contains different layers (termed feature classes) for different object/geometry types including predefined attribute values as well as cartographic symbol specifications. The cartographic symbols follow guides set up in [6] as far as possible, and colors for geological units were defined according to individual needs and requests within the mapping team. The color choice was based on established color values used in geologic maps, e.g., defined and used within standardized planetary maps generated by USGS. Previous statuses of the mapping compilation process are described in [7, 8].

Background for the mapping: The global geological map was created by merging the 15 individual quadrangle maps, which were mapped at a scale of 1:100K-125K, and published at a scale of 1:1M in the special volume on "The geological mapping of Ceres" [9]. The quadrangle map boundaries based on the HAMO atlas published by [4]. The basemap mosaic of Ceres was created using camera data from LAMO (Low Altitude Mapping Orbiter) orbit phase (over 31,300 clear filter images with a resolution of about 35 m/pxl during the eleven cycles). This global mosaic is also the basis for a high-resolution Ceres atlas that consists of 62 tiles mapped at a scale of 1:250K. The LAMO atlas was published by [10] and is available through the Dawn GIS web page and the NASA PDS (linked above).

Final map package: The entire mapping project will be available to the community via the PDS annex. All mapping data is saved in an ArcGIS File Geodatabase, FGDB: this FGDB contains two feature data sets: the map sheet layer with boundary data and graticule, and mapping layers divided into contacts, units, linear, point, and surface features. The needed metainformation is also defined within the ArcGIS environment. Furthermore, additional data are included:

- *layer files* contain the cartographic visualization stored for every individual thematic layer (*.*lyr*). Especially helpful for comparable cartographic visualization if *.*shp* are being used instead of feature classes.
- *shapes* are extracted from the filegeodatabase using in other GIS environments (*.*shp*).
- *projection files* described the four primary projections are stored for visualizing the global data set in different views.
- *project files* are created as *.*mxd* which this shows the whole mapping project within a proprietary map document using ArcGIS. *.*mpk* and *.*lpk,* which stored the map project within a compressed proprietary map document using ArcGIS.
- *image files* as *.*png* which show 1. the cartographic legend of the global map, and 2. the global geologic dataset conducted by the merged quadrangle maps is visualized as separate map sheet (in plate carree and stereographic projection, as *.*pdf*).

It should be noted that the merged project still contains some excess objects in overlap areas along the boundary between the quadrangles. This is primarily due to different scientific interpretations of mappers. In order to homogenize this, follow-up discussions among mappers are required. A detailed description of all those interpretations is published in the papers listed in [9]. Due to this, the map dataset could currently not have a clean topology.

Critical Review: The current template has served as a necessary basis for mappers to generate their individual – but still comparable – maps, and thus gives the possibility to merge the 15 quads in the future to one global map. The final status and general information of the mapping project are summarized in [11]. Because the creation of the mapping template was an iterative process, there are still some topics (focus on GIS and cartographic visualization) to discuss on the way to a homogeneous and comparable map layout. These are:

1) *Boundary regions*: Within the review process the mappers again should engage in a discussion with all quad neighbors to allow for a clean and consistent description of Ceres.

2) *Map scale and minimum object dimension*: Mapping scale and minimum dimension of planetary objects have to be fixed during the mapping process and double-checked during the review process. Otherwise the impression may arise that some regions show more features than others, where the differences are only a result of the different mapping techniques and lack of mapping constraints.

3) *Boundaries of the quad maps as supplemental material*: The map boundaries defined by the HAMO atlas schema should be consistent for the supplemental material map sheets, independently of whether or not important objects are fully included. Otherwise it would reject the character of the schema which is established for giving a first fully covered and consistent description of the geologic/geomorphologic of Ceres – visually similar to the HAMO atlas [3].

4) *Additional units and colors*: The color scheme was generated by defining one color for each of the units expected by the mappers. These colors should be distinguishable on the map sheet but should still allow a visual affiliation or distinction of the units. Thus, it has to decide very carefully if additional colors for individual and regional phenomena should be used. The global color scheme will be updated if all geological units are clearly and consistently interpreted.

5) *Additional information on the map sheet*: to support the general understanding of the map content it will be useful to provide additional information (like DTM sources, quad schema, or CoMU) on the map sheet. If so, this information should be included uniformly and consistently for all map sheets.

6) G*lobal relevant feature catalogue*: to describe the different units and features generically and visually it would be useful to combine an updated version of the already existing feature catalog and the generated map legend (applicable to all map quads). This will provide a first global overview of the objects and units identified on Ceres and could be used for a final discussion on individual interpretations and serves as base for a more detailed investigation in the future.

7) *Transferable template*: Beside the proprietary usage within ArcGIS the GIS-based template was also used in the open source software *QGIS* [12]. The template for the final graphical work was transferred into an open format **.svg*, so it could be used in a wide range of graphic software tools, e.g., in *Inkscape*, and web-based environments. In the future the *FGDB* schema will also be made transferable to open-source database systems (e.g., *PostgreSQL*).

Conclusion: The final map product presented here represents the first global map showing the geology of Ceres on LAMO resolution data at a mapping scale of 1:100-125K within an GIS-based map package, and is published digitally at a scale of 1:2.5M in A0 (as combination of 15 1:1M quadrangle maps [in 9]). Thus, the global map serves as an accessible basis for upcoming investigations, and is available via the PDS annex with all relevant information. The template developed specifically for Ceres mapping serves as a basis to enable consistent and homogeneous compilation of a global map from 15 individual quadrangle maps.

However, while a map template provides the technical framework and allows for consistency, human interaction, iteration and a certain degree of flexibility, a homogenization of the global interpretation is still indispensable in order to arrive at common approach and understanding of mapping boundaries. Thus, only through a final scientific review of the global map dataset and subsequent adjustment of remaining cartographic issues would allow the creating of the homogenous and unified global map product.

References: [1] Williams D.A. et al., 2014, Icarus, 244, 1-12, [2] Greeley, R. & Batson, G., Planetary Mapping, Cambridge University Press, 1990, [3] Roatsch et al 2016, PSS 121, 115-120, doi:10.1016/j.pss.2015.12.005, [4] Roatsch et al, 2016, PSS 126, p 103-107, doi:10.1016/j.pss.2016.05.011, [5] Mest, S. et al., 2017, LPSC, #2512, [6] FGDC, Digital Cartographic Standard for Geologic Map Symbolization, FGDC-STD-013-2006, 2006, [7] Nass, A. and the Dawn Mapping Team, 2017, LPSC #1892, [8] Nass, A. and the Dawn Mapping Team, 2017, EPSC #147-2, [9] Williams D.A. et al. (ed.), 2018, Icarus, 316, 1-204, [10] Roatsch et al., 2017, PSS 140, 74-79, doi:10.1016/j.pss.2017.04.008, [11] Williams, D.A. et al., 2018, Icarus 316, 1-13, doi:10.1016/j.icarus.2017.05.004, [12] Frigeri, A. et et al., 2018 Icarus 316, 114-127.