THE GLOBAL LAMO-BASED GEOLOGIC MAP OF CERES. S.C. Mest[1], D.C. Berman[1], D.L. Buczkowski[2], D.A. Crown[1], J.E.C. Scully[3], D.A. Williams[4], R.A. Yingst[1], A. Frigeri[5], A. Nass[6], A Neesemann[7], T.H. Prettyman[1], and H.G. Sizemore[1], [1]Planetary Science Institute, 1700 E. Ft. Lowell Rd., Suite 106, Tucson, AZ 85719 USA, mest@psi.edu. [2]Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20723 USA, [3]NASA Jet Propulsion Laboratory, Pasadena, CA 91109 USA, [4]School of Earth & Space Exploration, Arizona State University, Tempe, AZ 85287 USA, [5]Istituto Nazionale di Astrofisica e Planetologia Inaf, Rome, Italy, [6]German Aerospace Center, DLR, Berlin, Germany, [7]Freie, Universität, Berlin, Germany.

Introduction: The Dawn mission to Ceres began in 2014 after its successful mission to Vesta. Dawn acquired image, spectral, and topographic data from its approach to Ceres (late 2014) through two extended missions, until its conclusion in October 2018. Images acquired by Dawn during the LAMO phase of the mission provided global coverage at ~35 m/pixel. In addition, images acquired during the extended phases of the mission for several targeted locations, such as Occator crater, have resolutions as high as 2.8 m/pixel.

Background: Prior to the Dawn encounter at Ceres, no geologic map of the surface had ever been produced. Throughout the mission, iterative geologic mapping was conducted during Survey, HAMO, and LAMO phases. Survey mapping (Fig. 1a) yielded a large number of structures and 12 geologic units consisting primarily of cratered terrain, smooth material, and undivided crater material, although albedo differences permitted some unique crater materials, such as Haulani, to be identified [1-3].

Building on those results, the global HAMO-based geologic map (Fig. 1b) yielded a more distinct suite of structures and 21 geologic units [4,5] that constitute three major unit types – upland, plains, and impact materials. The improvement in image resolution allowed more detail to be observed, better characterizations of the surface to be made, and more distinct units to be mapped.

Finally, 15 quad-scale maps were produced [6] from images and mosaics acquired during the LAMO phase and compiled into a global map (Fig. 1c). LAMO resolutions allowed significantly more features and geologic units (45 units) to be identified and characterized. Although these maps were produced from the highest resolution data available, and provide local views of the surface, they were produced rapidly by multiple authors in a compressed span of time during the active mission. As a result there are inconsistencies in the level of detail, as well as interpretations, between maps.

We are utilizing LAMO-scale Dawn Framing Camera (FC), Visible and Infrared (VIR) Mapping Spectrometer, Gamma Ray and Neutron Detector (GRaND), and derived topographic data to construct a global geologic map of Ceres based on systematic analysis of the full suite of Dawn mission datasets. This geologic map of Ceres will be published as a U.S. Geological Survey (USGS) Special Investigation Map (SIM) at 1:3,000,000 scale for the equatorial region (+/- 60° latitude) and 1:1,500,000 scale for the polar regions (>60° N and S latitude). Our mapping effort will (a) constrain the lateral extent of the major geologic units observed on Ceres, (b) characterize the nature and composition of geologic units to understand the nature of internal layering, stratigraphy, and post-emplacement processes, and (c) evaluate the temporal relationships of geologic units and events and determine their position within the current Cerean chronostratigraphy [5,7].

Geologic Setting: Ceres exhibits ~17 km of relief with the highest elevation (~9.5 km) located at the peak of Yamor Mons near the north pole (85.5°N, 11.9°E), and the lowest elevation (~-7.3 km) located on the floor of crater Rongo (68 km in diameter; 3.2°N, 348.7°E). Images acquired during Approach and Survey showed that Ceres is dominated by broad expanses of low-lying terrains and small areas of elevated terrains [2]. The "lows" that form the low-lying terrains are shaped by large-diameter impact structures (e.g., Urvara, Yalode, Kerwan, and unnamed quasi-circular depressions [8]) that form large basins and broad low-lying plains (e.g., Vendimia Planitia), whereas the "highs" are composed of knobs and the rims of impact craters, such as within Hanami Planum and the north polar regions.

Cratered terrain forms the most widespread continuous unit on the surface of Ceres [4,5]. At HAMO mapping scale this unit is largely undifferentiated except for impact-related units. The unit consists of rugged and heavily cratered materials with moderate albedo that form most of Ceres' surface. The cratered terrain exhibits topography derived largely from impact features and includes the oldest surfaces exposed on Ceres, but the geologic materials likely consist of crustal materials that have been heavily mixed by impact processes.

Smooth material forms widespread flat-lying to hummocky plains of moderate albedo in the western equatorial hemisphere (Fig. 1) [4,5]. This unit embays the cratered terrain and is found on the floor of, and surrounding, crater Kerwan. At HAMO scale, with the exception of superposing primary and secondary impact structures the unit appears featureless. Closer inspection in LAMO images reveals underlying hummocky texture, a set of narrow parallel ridges and grooves in the western part of the deposit, and buried impact structures throughout. Although none of the features visible within the smooth material are suggestive of its source or an emplacement process, the distribution of this unit across high and low elevations suggests it is impact related [4,5].

Impact craters are the most prevalent geologic features on the surface of Ceres, and appear to have caused most of the visible modification of the surface (Fig. 1) [1-6,9]. Impact craters on Ceres exhibit sizes ranging from the limits of resolution to larger structures such as Urvara (170 km), Yalode (260 km), and Kerwan (284 km). Ceres' impact craters exhibit a range of morphologies and preservation styles. Craters of all sizes appear morphologically "fresh" to moderately degraded with rims that are raised above the surrounding terrain and continuous ejecta blankets. Most "fresh" to moderately degraded craters exhibit circular to nearly circular planform shapes, but some have rims that display polygonal planform shapes, reflecting either preexisting fractures in the subsurface and (or) modification of the rim by mass wasting [10].

Materials generated by impact processes cover large areas of Ceres' surface and form 19 distinct units in the HAMO-scale map (Fig. 1) [4,5]. For many craters, especially the larger and morphologically fresh-appearing craters, their associated deposits are able to be subdivided into distinct geologic facies that are common or recurring across the surface of Ceres. These craters generally show some combination of rim, central peak, floor, and ejecta deposits. In some cases, such as Urvara and Yalode, the largest impact structures on Ceres, the impact-related deposits cover a broad part of Ceres' surface and therefore their associated deposits (e.g, floor, rim, and (or) ejecta) are mapped as formations unique to those craters [4,5,11]. Impact craters represent distinct chronological markers in the stratigraphic record of Ceres. Geologic mapping at HAMO scale has identified deposits associated with craters clearly identifiable at HAMO resolutions.

Mapping Goals: Based on prior HAMO- and LAMO-based mapping studies, our LAMO-based geologic mapping effort has several goals. First, mapping the cratered terrain will enable us to investigate the unit for any previously unrecognized sub-units, and evaluate the precise areal extent of this unit. Second, mapping the smooth material will allow for further investigations of the nature of its relationships with other features (such as Kerwan), and the possible origin(s) of this deposit. Third, mapping impact craters (and other surfaces) at LAMO scale will enable more subtle differences in surface properties (e.g., texture, brightness) to be discerned, which will allow us to accurately define extents of crater materials, characterize types of crater materials, evaluate crater morphologies, and estimate ages of these important stratigraphic markers. Fourth, incorporation of spectral and mineralogical data into mapping all surfaces will enable compositional signatures to be identified and possible sub-units to be mapped. Lastly, accurately defining the extents of geologic units is critical in accurately estimating their ages and placing geologic units and events within the Cerean chronostratigraphy [4,5], and documenting Ceres' geologic history.

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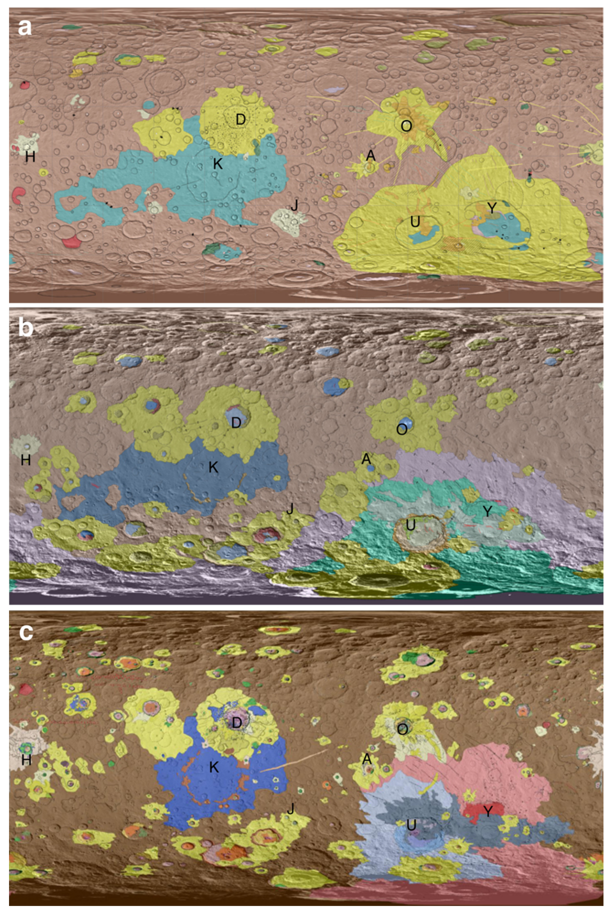

Figure 1. Three iterations of the global geologic map of Ceres from (a) Survey and Approach, (b) HAMO, and (c) LAMO (quad based). Craters labeled here include H=Haulani, D=Dantu, K=Kerwan, O=Occator, A=Azacca, J=Juling, U=Urvara, and Y=Yalode.