THE CHRONOSTRATIGRAPHY OF CERES. S.C. Mest[1], A Neesemann[2], D.A. Crown[1], D.C. Berman[1], J.H. Pasckert[3], N. Schmedemann[4], S. Marchi[5], H. Hiesinger[3], D.L. Buczkowski[6], J.E.C. Scully[7], D.A. Williams[8], R.A. Yingst[1], T. Platz[1], R. Jaumann[9], T. Roatsch[9], F. Preusker[9], A. Nathues[4], C.A. Raymond[7], and C.T. Russell[10], [1]Planetary Science Institute, 1700 E. Ft. Lowell Rd., Suite 106, Tucson, AZ 85719 (mest@psi.edu). [2]Freie Universität, Berlin, Germany. [3]Institut für Planetologie, WWU, Münster, Germany. [4]Max Planck Institute for Solar System Research, Göttingen, Germany. [5]SwRI, Boulder, CO. [6]Johns Hopkins University Applied Physics Laboratory, Laurel, MD. [7]NASA Jet Propulsion Laboratory, Pasadena, CA. [8]School of Earth & Space Exploration, Arizona State University, Tempe, AZ. [9]German Aerospace Center, DLR, Berlin, Germany. [10]Institute of Geophysics and Planetary Physics, University of California at Los Angeles, Los Angeles, CA.

Introduction: NASA's Dawn spacecraft [1] was inserted into orbit around Ceres on March 6, 2015, and observed the dwarf planet through a series of successively lower orbits, obtaining morphological, topographical, mineralogical, elemental, and gravity data [2]. From 2015 to 2018, while in orbit around Ceres, observations and measurements by the Dawn spacecraft provided significant advancements in our understanding of the internal structure, composition, and geology of the dwarf planet.

The Dawn Science Team conducted a geologic mapping campaign for Ceres that used clear and color filter mosaics and topographic data to produce a series of maps at successively lower orbits, similar to what was done for Vesta [3,4]. Geologic maps of Ceres include a preliminary geologic map (1:10M-scale) based on Approach- and Survey data [5], fifteen 1:500K-scale quadrangle geologic maps based on Low Altitude Mapping Orbit (LAMO) data subsequently combined into a global map product [6], and most recently the global High Altitude Mapping Orbit (HAMO) based geologic map (1:2.5M-scale) [7-9]. Using this HAMO-based global geologic mapping effort, we present the first proposed Cerean chronostratigraphic time scale. Based on the most prominent geologic features, with modeled age estimates from crater size-frequency distribution (CSFD) statistics, we propose a time scale that is subdivided into three geologic time periods – pre-Yalodean, Yalodean, and Azaccan [9].

Background: The surface of Ceres is heavily cratered. Impact cratering represents the most significant geologic process on Ceres with regards to creating local topography and resurfacing [5,6,9]. Craters range in size from the limits of respective Dawn Framing Camera (FC) resolution to hundreds of kilometers in diameter [10,11]. The oldest craters exhibit degraded rims, shallow depths, and no observable ejecta blankets, whereas the youngest craters display sharp rims, steep walls, flat floors, and well-preserved and extensive ejecta blankets.

Cerean Time-Stratigraphic System: The HAMO-based global geologic map of Ceres reveals the stratigraphic sequence of map units, which can be placed into a time-stratigraphic scheme to document the global geologic history of Ceres. Establishing a formal chronostratigraphic classification scheme (*Figure 1*) is important for correlation of distinct and widely separated geologic units on Ceres, as well as to provide a means to correlate Cerean geologic units and events to the geologic histories of other planetary bodies.

Development of the Cerean chronostratigraphy relied upon measuring impact crater diameters globally and determining absolute model ages (AMAs) of Ceres' major geologic units, identified through HAMO-based geologic mapping, and calculation of CSFD statistics for each unit. CSFDs were determined for several geologic units of interest using procedures established for Ceres [12]. CSFDs derived from subsets of unit areas, full units areas, and/or 1R ellipses around craters were compared in order to determine the optimal AMAs. The rigorous task of identifying and measuring all craters greater than 100 m in diameter was conducted using Dawn FC images and FC-based DTMs. Here we use the Poisson Timing Analysis (PTA) [13] to evaluate CSFDs. In order to use the measured CSFDs for deriving AMAs, two different chronology models, the Lunar Derived chronology Model (LDM) [10] and the Asteroid-flux Derived chronology Model (ADM) [11,14-16] were applied.

pre-Yalodean System: The two oldest Cerean chronostratigraphic systems are divided by the deposits resulting from the Yalode impact event. The pre-Yalodean Period includes all geologic events and deposits emplaced within the time span from the formation of Ceres up to the Yalode impact event, from 4.6 Ga to >1.029 Ga (using the lunar derived chronology model (LDM)) or 4.6 Ga to >403 Ma (using the asteroid flux-derived chronology model (ADM)). Similar to the geologic histories of other planetary bodies (e.g., the Moon, Vesta, Mercury, Mars), the pre-Yalodean was dominated by the formation of large impact structures, such as Kerwan (284 km) and Yalode (260 km), large quasi-circular depressions (e.g., Vendimia Planitia) [11], and heavily cratered terrains.

Yalodean System: The base of the Yalodean system is defined by the Yalode impact event and its related deposits, with an age of 1.029 Ga (LDM) or 403 Ma (ADM)). The Yalodean Period covers the time span between the Yalode and Azacca impact events, from 1.029 Ga to 223 Ma (LDM) or 403 Ma to 23 Ma (ADM) and represents a time of relative geologic quiescence (i.e., reduced cratering rate) on Ceres. Whereas the major impact basins and upland terrains formed during the pre-Yalodean, large impact events appear to have diminished in the Yalodean Period. A few notable impact craters formed during the Yalodean, including Ezinu, Omonga, Achita, Liber, Ninsar, and Gaue [17,18]. The formation of Urvara crater (170 km) and emplacement of its impact-related units occurs near the end of the Yalodean Period [19].

Azaccan System: The impact event that formed crater Azacca and its associated deposits defines the base of the youngest chronologic system on Ceres, the Azaccan system. The Azaccan Period covers the time span from the Azacca impact event to the present, beginning 223 Ma (LDM) / 23 Ma (ADM). However, it is likely that Azacca materials are highly contaminated by secondary craters from other impacts (e.g., Occator) and is younger than 223 Ma / 23 Ma.

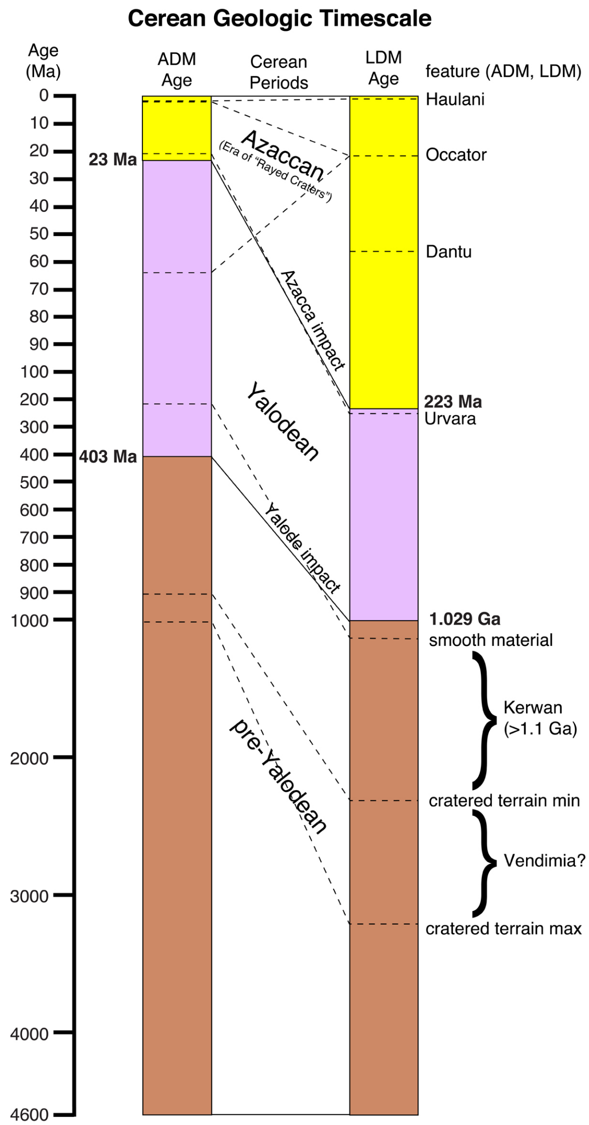

Figure 1. Proposed geologic time scale for Ceres, including the Cerean time units and AMAs of key geologic units and events. The ages are absolute model ages derived from both the lunar-derived chronology system (LDM) [10] and the asteroid flux-derived chronology function (ADM) [11,14-16]; note the different age scales for the respective chronology systems. The solid black lines separate the different periods.

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