A PROPOSED TIME-STRATIGRAPHIC SYSTEM FOR PROTOPLANET VESTA. D. A. Williams[1], R. Jaumann[2], H.Y. McSween[3], Jr., C.A. Raymond[4], C.T. Russell[5], [1]School of Earth and Space Exploration, Arizona State University, Tempe, AZ (David.Williams@asu.edu), [2]German Aerospace Center (DLR), Berlin, Germany; [3]Department of Earth and Planetary Sciences, University of Tennessee, Knoxville, TN; [4]NASA Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA; [5]Department of Earth and Space Sciences, UCLA, Los Angeles, CA.

Introduction: The Dawn Science Team completed a geologic mapping campaign during its nominal mission at Vesta, including production of a 1:500,000 global geologic map derived from High-Altitude Mapping Orbit (HAMO) images (70 m/pixel) [1] and 15 1:250,000 quadrangle maps derived from Low-Altitude Mapping Orbit (LAMO) images (20-25 m/pixel) [2]. In this abstract we propose a time-stratigraphic system and geologic time scale for the protoplanet Vesta, based on global geologic mapping and other analyses of NASA Dawn spacecraft data, supplemented with insights gained from laboratory studies of howardite-eucrite-diogenite (HED) meteorites and geophysical modeling.

Why a time-stratigraphic system?: A time-stratigraphic or chronostratigraphic system is a listing of all of the major time-rock units emplaced on a planet over its geologic history, in chronological order from oldest to youngest. Time-rock units are generally correlated with the major rock units defined from a global geologic map, and serve to relate the map's rock units (i.e., 3D physical units that make up a planet's crust) to the planet's time units (i.e., the subdivisions of time during which the time-rock units were emplaced). For example, on the Moon, rock units related to the Imbrium basin impact (including crater materials and Imbrium impact ejecta, called the Fra Mauro Formation) are contained in the time-rock unit called the Lower Imbrian Series, which is correlated with time unit called the Early Imbrian Epoch [3,4]. On Mercury, rock units related to the Caloris basin impact (including crater materials and Caloris impact ejecta) are contained in the time-rock unit called the Calorian System, which is correlated with a time unit called the Calorian Period [5,4]. These distinctions between rock, time-rock, and time units not only facilitate geologic mapping, but also enable better understanding of the geologic history of a planet, and comparison to the histories of the planets.

Results: We propose the following time-stratigraphic system for Vesta (**Table 1**) that relates the geologic map (rock) units identified from geologic mapping to a series of time-rock units and corresponding time units that define a geologic time scale for Vesta (**Figure 1**). During the Dawn nominal mission it became clear that the south pole of Vesta hosts two large impact basins, the older Veneneia superposed by the younger Rheasilvia [6,7]. Two separate sets of large ridges and troughs were identified, one set encircling much of Vesta equatorial region (Divalia Fossae), and the other preserved in the heavily cratered northern terrain (Saturnalia Fossae). Structural analysis of these ridge-and-trough systems demonstrated that they are likely a tectonic response to the formation of the south polar basins: the Rheasilvia impact led to the formation of the Divalia Fossae, the Veneneia impact led to the Saturnalia Fossae [6,8]. Crater counts provide cratering model ages for the Rheasilvia impact of ~3.6 Ga and ~1 Ga, and ages for the Veneneia impact of ~3.8 Ga and >2.1 Ga using the lunar-derived and asteroid flux-derived chronologies, respectively. Despite the differences in absolute ages, it is clear that these two large impact events had global effects, and thus delineate the major periods of Vesta's geologic history.

Zones of heavily cratered terrain (HCT: [9]) in the northern hemisphere adjacent to the Saturnalia Fossae Formation [1] likely are heavily modified portions of Vesta's ancient crust. Additionally, geologic and geophysical evidence [8, 10] suggest that Vestalia Terra is probably a large surviving fragment of Vesta's original crust. Thus, these geologic units suggest that a Pre-Veneneian system and Pre-Veneneian period must be included as part of Vesta's geologic history.

We debated what the Dawn data informs us about the youngest part of Vesta's geologic history. The geologic units in and around the 68 x 58 km Marcia crater appear to delineate the most recent large impact event on Vesta. Crater counts of areas of the Marcia ejecta blanket give cratering model ages of ~120-150 Ma and ~220-390 Ma using the lunar-derived and asteroid flux-derived chronologies, respectively (Williams et al.). In contrast, a unit of smooth material on the floor of Marcia crater, interpreted to be impact melt, has a cratering model age of ~40 Ma and ~60 Ma using the lunar-derived and asteroid flux-derived chronologies, respectively. There is disagreement on the Dawn Team whether this smooth unit was formed at the time of the Marcia impact, or sometime later by a post-emplacement process, or whether the younger age of the putative floor melt is due to the effects of the different material properties of this material relative to the

ejecta blanket on the crater statistics. Regardless, the units associated with the Marcia impact event together make a set of related geologic units defined as the Marcia Formation [11], which we propose as the base of Vesta's youngest system and period. We are continuing to refine the absolute model ages of the Marcia Formation at the time of this writing.

Acknowledgements: The success of the Dawn mission is due to the efforts of a large team of engineers, scientists, and administrators in industry and government laboratories both in the United States and abroad. The Dawn mission is managed by NASA's Jet Propulsion Laboratory, a division of the California Institute of Technology in Pasadena, for NASA's Science Mission Directorate, Washington DC. UCLA is responsible for overall Dawn mission science. The Dawn framing cameras have been developed and built under the leadership of the Max Planck Institute for Solar System Research, Katlenburg-Lindau, Germany, with significant contributions by DLR German Aerospace Center; Institute of Planetary Research, Berlin; and in coordination with the Institute of Computer and Communication Network Engineering, Braunschweig. The framing camera project is funded by DLR, the Max Planck Society, and NASA/JPL. VIR has been developed under the leadership of INAF-Istituto di Astrofisica e Planetologia Spaziali, Rome, Italy and is funded by ASI, the Italian Space Agency. DAW is supported by NASA's Dawn at Vesta Participating Scientist program. RJ is supported by DLR and the German Space Agency. Dawn data are archived with the NASA Planetary Data System. We thank the Dawn team for the development, cruise, Dawn orbital insertion, and operations of the Dawn spacecraft at Vesta.

References: [1] Yingst, R.A., et al. (2014) *PSS*, in press. [2] Williams, D.A., et al. (2014a) *Icarus*, in review. [3] Wilhelms, D.E. (1987) *USGS. Prof. Pap. 1348*. [4] Wilhelms, D.E. (1990), *Planetary Mapping*, Cambridge Univ. Press, New York, 208-260. [5] Spudis, P.D. (1985) *NASA TM 87563*, 595-97. [6] Jaumann, R. et al. (2012) *Science* 336, 687-690. [7] Schenk, P. et al. (2012) *Science* 336, 694-697. [8] Buczkowski, D.L. et al. (2013) *GRL 39*, L18205, doi:10.1029/2012GL052959. [9] Marchi, S. et al. (2012) *Science* 336, 690-694. [10] Raymond, C.A. et al. (2013) EGU Gen. Assem., Abs# EGU2013-12408. [11] Williams, D.A. et al. (2014b) *Icarus*, in revision. [12] Schmedemann, N. et al. *PSS* (in revision).

Table 1. Proposed time-stratigraphic system for protoplanet Vesta. The correlation of Vesta's rock units, time-rock units, and time units is derived from geologic mapping and other Dawn data analyses [1,2,6,8].

Rock Unit	Time-Rock Unit	Time Unit
Marcia Formation	Marcian System	Marcian Period
Rheasilvia Formation, Divalia Fossae Formation	Rheasilvian System	Rheasilvian Period
Cratered highlands, Saturnalia Fossae Formation	Veneneian System	Veneneian Period
Cratered highlands, Vestalia Terra?	Pre-Veneneian System	Pre-Veneneian Period

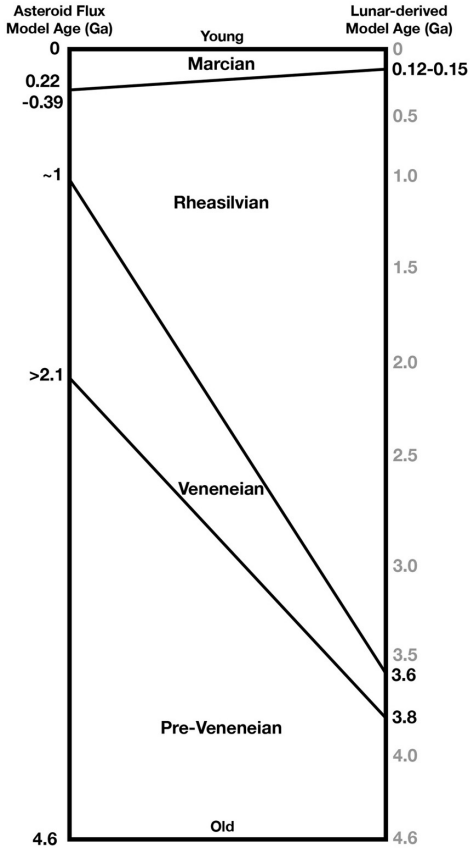

Figure 1 (right). Proposed geologic time scale for protoplanet Vesta. The age dates at left are cratering model ages derived from the asteroid flux-derived chronology function [e.g., 7,9]. The age dates at right are cratering model ages derived from the lunar-derived chronology function [12]. The black lines that separate the different periods are not horizontal because of the differences in age estimates from the two vestan chronology systems.