THE IMPACT HISTORY OF VESTA: DEVELOPING AND TESTING AN ABSOLUTE CRATERING CHRONOLOGY.

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Introduction: The Dawn mission has completed its Survey and High-Altitude Mapping Orbit (HAMO) phases at Vesta, resulting in 60-70 meter per pixel imaging up to ~50 degrees north latitude (the north pole was in shadow during these mission phases), and is currently taking data in its Low-Altitude Mapping Orbit (LAMO) with resolution as high as ~20 m/px [1]. From this imaging data, global topography models are being developed [2]. These data have provided unprecedented views of the south polar impact structure first detected in HST imaging [3], now named Rheasilvia, hint at the existence of a population of ancient basins, and allow for the measurement of crater densities over most of the surface. With this data, along with insights provided by dynamical models and constraints from HED (howardite, eucrite and diogenite) meteorites, we are working towards developing an absolute cratering chronology for Vesta's surface.

Large Basins: Vesta's largest crater, the south-pole basin Rheasilvia, is a broad depression approximately 500 km in diameter, with a pronounced central peak roughly 100 km across that rises 20-25 km above the relatively flat basin floor [4]. Numerous other depressions can be identified in the imaging and topography data that may be the remains of large impact basins [5]. All appear to be more eroded and heavily cratered than Rheasilvia, suggesting an older age, although detailed crater counts will be necessary to constrain the sequence of their formation. The largest of these basins is approximately 350-400 km in diameter and is partially overlain by Rheasilvia, indicating an older age. This basin does not appear to have a central peak, although the region where the central peak would occur corresponds to the rim of Rheasilvia, and thus it may have been destroyed or obscured.

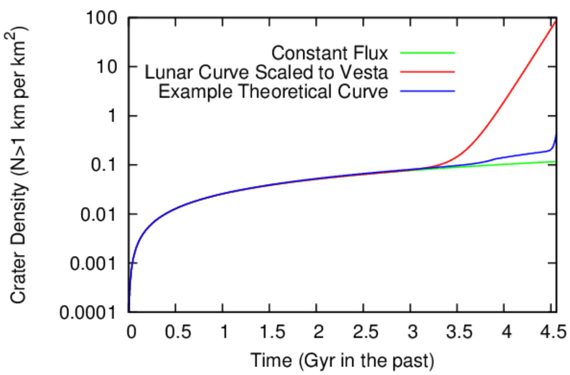
The number of large basins may provide an important constraint on the impact history of Vesta and the dynamical history of the main belt. Furthermore, basin-forming impacts can potentially reset Ar-Ar ages of rocks on the surface of Vesta, and subsequent large impacts can then eject these rocks to space. Basins are thus important for understanding the Ar-Ar ages recorded in the HED meteorites [6,7].

Smaller Craters: Excluding the large basins, nearly all craters appear to have a simple bowl-shaped morphology, although there are a few that could be central peak craters. Many craters show gravitational collapse and slumping from their walls. This may affect the determination of the original transient crater size, which is important for estimating absolute ages of the surface.

Developing a Cratering Chronology for Vesta: Radiometric dating of HED meteorites shows that Vesta dates back to the beginning of the Solar System [e.g. 8], and its cratered surface potentially provides a record of impacts dating back to that early era. Understanding Vesta's impact record requires a crater chronology curve that relates crater density to surface age (which may be the formation age of the local crust or the time since the last major resurfacing event). One approach to the chronology is to use a lunar chronology curve [e.g. 9] scaled to Vesta's current impact rate [10]. Another approach, which we are currently developing, is to base the chronology on models of the primordial depletion and subsequent dynamical evolution of the main belt under the influence of giant planet migration and chaotic diffusion processes [e.g. 11-13]. Additional effects can also be included, such as the effect of a primordial 'E-Belt' interior to the main asteroid belt [14], the influx and possible implantation of comets during the Late Heavy Bombardment [15,16] and early impacts from planetesimals excited and scattered by Jupiter [17]. Possible chronology curves are shown in Fig. 1.

The theoretical curve (blue) shown in Fig. 1 is preliminary and is currently being tested and refined, although for all reasonable ranges of parameters, it lies significantly below the scaled lunar curve (red) prior to 3 Gyr ago, and somewhat higher than a curve assuming a constant impact flux over time (green). Note that a constant flux is unlikely, but is shown for comparison and reference. Prior to 3 Gyr ago, a given crater density would imply a much older age using the theoretical curve than would be obtained using the scaled lunar curve, which has profound implications for the identification and dating of ancient surfaces on Vesta. The maximum crater density for the theoretical chronology curve of ~0.4 craters larger than 1 km diameter per km^2 is broadly consistent with the highest crater densities measured by [5], and corresponds to an age of ~4.5 Ga.

FIGURE 1: Crater Chronology Curves for Vesta



Analysis of Vesta's cratering record may be able to discriminate between these different curves. In particular, the number of large basins may provide a constraint on the total number of large impacts that Vesta has experienced over its history, since they are very difficult to completely erase. The fact that Vesta's mostly basaltic crust has not been eroded away by collisions also places an upper limit on the early impact rate [18].

For the large basins, we can estimate their formation rate from the observed number of asteroids and calculated collision probabilities. For this estimate, we use the scaling law for rock from [19-21], mean impact velocity on Vesta of 4.75 km/s [22], and an average impact angle of 45 degrees. The final crater size is assumed to be 25% larger than the transient crater because of gravitational slumping and collapse (but we still assume simple crater shape, not complex). We estimate that a 100 km diameter basin would be formed by a 12 km diameter projectile and a 200 km basin would be formed by a 29 km projectile. Rheasilvia, since it is so large, can not realistically be treated with this scaling law, but [23] use hydrocode modeling to estimate a projectile diameter of ~80 km. Using the cataloged main belt size distribution and the albedo-diameter conversion of [24], there are roughly 6300, 1250, and 330 main belt asteroids with diameters 12, 29, and 80 km, respectively.

With an intrinsic collision probability P_i of 2.72 x 10^{-18} km^{-2} yr^{-1} [22] and a mean radius of 264 km [25] we can calculate the impact frequencies and timescales based on the current number of main-belt impactors, giving 5.7 100 km basins, 1.2 200 km basins, and 0.4 Rheasilvia-sized basin over Vesta's 4.5 Gyr history.

That estimate is for the case where the impact rate has always been constant (i.e. the green curve in Fig. 1). The theoretical chronology curve (blue in Fig. 1) predicts a cumulative number of impacts ~3.75 times larger than the constant-flux case, and hence would predict that ~21 100 km, 4.5 200 km, and 1.4 Rheasilvia-sized basins would form over Vesta's history, which is broadly consistent with what is seen on Vesta [5].

In contrast, the scaled Lunar curve (red in Fig. 1) predicts roughly 750 times more impacts over Vesta's history than the constant-flux case, and 200 times more than the theoretical chronology curve, i.e. 4300, 900 and 280 100 km, 200 km, and Rheasilvia-sized basins over 4.5 Gyr. Even going back to just 4.0 Gyr ago, the total number of impacts would be ~19 times larger than in the constant-flux case, or ~95, 20 and 6 100 km, 200 km, and Rheasilvia-sized basins.

In addition to the cratering record, we have meteorites from Vesta, the HEDs, that record the ages of major impact events in their Ar-Ar ages. The Ar-Ar ages of eucrites suggest that several such events occurred between 3.4 and 4.1 Gyr ago, and that an especially large impact event occurred 4.48 Gyr ago, but few impacts capable of resetting the Ar-Ar chronometer occurred in the interval from 4.1 to 4.5 Ga [6]. The scaled lunar chronology would predict a much larger number of resetting events in the 4.1 to 4.5 Ga timespan than in the 3.4 and 4.1 Ga timespan, which may be difficult to reconcile with the meteorite data. Dynamical and impact modeling consistent with the theoretical chronology discussed here is able to reproduce the main features of the eucrite Ar-Ar age distribution [7].

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References: [1] R. Jaumann (2012) LPSC. [2] F. Preusker (2012) LPSC. [3] P.C. Thomas (1997) *Science,* **277**, 1492. [4] P. Schenk (2012) LPSC. [5] S. Marchi (2012a) LPSC. [6] D.D. Bogard (2011) *Chemie der Erde* **71,** 207. [7] S. Marchi (2012b) LPSC. [8] L.E. Nyquist (2009) *Geochim. Cosmochim. Acta* **73,** 5115. [9] G. Neukum (2001) *Space Sci. Rev.* **96**, 55. [10] N. Schmedemann (2012) LPSC. [11] D.P. O'Brien (2007) *Icarus* **191**, 434. [12] A. Morbidelli (2010) *AJ* **140**, 1391. [13] D.A. Minton (2010) *Icarus* **207**, 744. [14] W.F. Bottke (2011) LPSC, 1608. [15] R. Gomes (2005) *Science* **435**, 466. [16] H.F. Levison (2009) *Nature* **460**, 364. [17] D. Turrini (2011) *MNRAS* **413**, 2439. [18] D.R. Davis (1985) *Icarus* **63**, 30. [19] B.A. Ivanov (2001) *Space Sci. Rev.* **96**, 87. [20] B.A. Ivanov (2007) in *Catastrophic Events Caused by Cosmic Objects*, 91. [21] B.A. Ivanov (2008) in *Treatise on Geophysics*, **10**, 207. [22] D.P. O'Brien (2011) *Space Sci. Rev.* **163**, 41. [23] B.A. Ivanov (2011) LPSC, 1717. [24] J.W. Fowler (1992) in *The IRAS Minor Planet Survey,* Tech. Report PL-TR-92-2049. [25] C.A. Raymond (2012) LPSC.