Modelling the Rheasilvia impact. M. Jutzi1 and B.A. Ivanov2, 1Space Research and Planetary Sciences, Physics Institute, University of Bern, Switzerland, martin.jutzi@space.unibe.ch, 2Institute for Dynamics of Geospheres, Russian Academy of Sciences, Moscow, Russia.

Introduction: Detailed views of Asteroid Vesta by NASA’s Dawn mission reveal an interesting and unexpected geology [1]. The south polar depression is deeper and larger than estimated from previous Hubble Space Telescope [2] observations, consisting of two overlapping giant craters [3]. The partial overlap of the two basins (the ~500 km Rheasilvia basin on the ~400 km Veneneia basin) provide a prime example of the interaction of an younger and an older giant crater. Ejecta from collisions forming such craters are massive and globally distributed, with exhumed and deposited materials dominating the surface mineralogy. Moreover, escaped ejecta from these crater forming events are at the origin of the Vestoid asteroid family. Understanding the formation of these craters and the provenance and specific distribution of ejecta is key to understanding the observed properties of Vesta, such as the topography and the surface mineralogy, and it also allows to constrain models of the internal structure.

Impact modeling: A number of recent numerical impact modeling studies investigated the formation of the largest impact structures [4-7], possible effects on the antipodal terrain [8], and the formation of the surface troughs on Vesta [9]. Here we present an overview of recent 2D ([4],[5]), and 3D ([6],[7]) modeling of the formation of the giant Rheasilvia basin. In these studies, the effect of the presence of the underlying Veneneia basin is investigated as well.

2D modeling: Two-dimensional axisymmetric (2-D) numerical modeling of the formation of Vesta’s basins was performed in [5]. The model target is presented as 3-layer sphere without rotation [5] or as a 3-layer ellipsoid rotated as a solid body [11]. The equilibrium shape and structure of the rotating target is determined by special pre-impact modeling of a liquid 3-layer sphere relaxation with self-gravity. The average for Main Belt asteroid-to-asteroid impact velocity of 5.5 kms-1 was assumed for the undifferentiated projectile with the Vesta crust density. The acoustic fluidization model was fitted to reproduce the Rheasilvia profile by diameter. Crust thickness of about 20 or 40 km seems has a weak effect on the final crater shape (Figure 1). The secondary nature of the Rheasilvia impact (over the assumed Veneneia older crater) was tested in 2D geometry with the axisymmetric impact in the central mound of the first crater.

3D modeling: The successive formation of the Veneneia and Rheasilvia basins was studied by [7], using a 3D Smooth Particle Hydrodynamics (SPH) impact code. In this modeling, the first impact in a spherical, monolithic, differentiated nonrotating asteroid leads to a basin of roughly 400 km diameter (comparable to Veneneia) and a small central peak. This result is then used as initial condition to study the formation of the second basin, Rheasilvia, which partly overlaps Veneneia. In this modeling, a spin along Vesta’s axis is used. Including pre-impact rotation and taking into account the presence of the underlying Veneneia basin distinguishes these simulations from 2D axisymmetric modeling approaches.

Figure 1: “Best” fit crater profiles [5]. The thick black curve is the published Rheasilvia cross section [2]. (a) ~ 40 km crust. (b) ~20 km crust.

The outcome of the modeling of the two successive major scale collisions, Veneneia followed by Rheasilvia (Figure 2) is in reasonable agreement with the shape of Vesta as observed by Dawn. The diameter of the modeled Rheasilvia basin, though difficult to map (in the model as on Vesta), is consistent to ~ 10 % with the observations. Underlying the second structure is the Veneneia basin from the first simulation; the older basin is partly covered by ejecta from Rheasilvia but is still partly visible in Figure 1. Successive ejection of the same terrain digs deeper into Vesta. According to this modeling, rocks exposed in the Rheasilvia area come from ~60-100 km, digging beneath the crust, according to standard interior structure models. Most of the ejecta emplaced in the northern hemisphere come from ~20 km deep.
Discussion

In the 2D modeling by [4,5], projectile sizes ranging from ~30 km to 90 km were investigated. The best fit model uses 37 to 44 km projectile (providing the impact velocity of 5.5 km s\(^{-1}\)) and is able to reproduce quite well the observed crater profile. Using the impact angle efficiency for targets with dry friction [10] the equivalent projectile size for an oblique impact at 45\(^\circ\) is estimated from the 2D model in the range of 43 to 51 km. Results of the 3D direct modeling in [7], using a 60 km projectile and more complex (non-axis symmetric) impact conditions, are also in reasonable agreement with the observed large basins and the global topography of Vesta.

Due to the different impact conditions, the models predict different degrees of damage resulting from the large impacts, varying from a fully damaged Vesta in the modeling by [7] to a only partially damaged antipodal hemisphere in the “best fit” model by [5].

Some of the uncertainties regarding the projectile sizes which form the large basins on Vesta arise from the large crater diameter to target diameter (Dc/Dt) ratio, the unknown pre-impact shape, the impact angles, the rotation axis of the target, the determination of the crater radius, etc. Furthermore, differences in numerical and material model approaches can also lead to different outcomes for a given impact geometry.

Despite these differences, the two modeling approaches also lead to results which are similar in both cases. For instance, whenever the existence of the underlying Veneneia basin is taken into account in the modeling of the Rhea silvia impact, both models predict a significant amount of material from initial depths >50 km exposed on the surface of Vesta after the two overlapping collisions [5,7]. This finding provides important constraints regarding the internal structure of Vesta (e.g. [7]).

Despite the reasonably well simulated post-impact shape of Vesta, the numerical modeling outlined many unresolved questions.

1. An essential result of the numerical modeling is the central mound in Rhea silvia formed by the structural uplift of deep-seated material. The structural uplift should deliver target layers that were initially located deeper than 50 to 70 km to or close to the surface. If the standard geochemical models of a differentiated Vesta, which predict a crustal thickness of 20 to 40 km, are correct, it means that mantle material should be excavated by smaller impacts at the Rhea silvia central mound and should be present on Vesta’s surface in the Rhea silvia area. The prediction is not confirmed by spectral imaging. Recent studies suggest that olivine is present locally on Vesta’s surface but it has not been found within the south-pole basins [12].

Moreover, the first detailed geophysical modeling of observed gravity anomalies indicates that there is only a small density contrast between upper layers (“crust”) and lower (“mantle”) layers [13]. This is in contradiction with internal structure models of Vesta with distinct crustal layers and a sensibly dense contrast between crust and mantle minerals.

2. What is the origin of “mantle” Vestoids [14]? A thick upper layer with a small density contrast, if it exists, could make the ejection of dense “mantle” material difficult, even with a double impact.

3. The slow 5.5 km s\(^{-1}\) impact produces a relatively small amount of impact melt, while some DAWN observation may be interpreted as the impact melt at the surface. Hence the modeling should be extended to larger possible impact velocities and/or to include possible initial porosity into the target properties.

The differences and similarities between the various models will be discussed in the context of the observations of Vesta by Dawn. Some new results regarding the provenance (within Vesta) of the escaped ejecta will be presented as well.

References: