IS THE CORIOLIS FORCE RESPONSIBLE FOR CURVED FEATURES ON VESTA?

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Introduction: The DAWN spacecraft orbited asteroid (4) Vesta from August 2011 until September 2012. The framing camera on board the space craft collected image data of the asteroids surface with a resolution up to 20 m/pixel in the low altitude mapping orbit (LAMO). Figure 1 shows an example.

The data revealed the presence of a large impact basin in the southern hemisphere, named Rheasilvia [1, 2]. Its diameter, about 500 km, is of the size of Vesta's own diameter (525 km). The basin is a complex crater with the central peak nearly coinciding with the rotation axis [1]. The rotation period of Vesta is 5.3 hours. The size and location of the basin and the relatively fast rotation of Vesta suggest that the Coriolis force is able to effect movements of masses related with the impact basin.

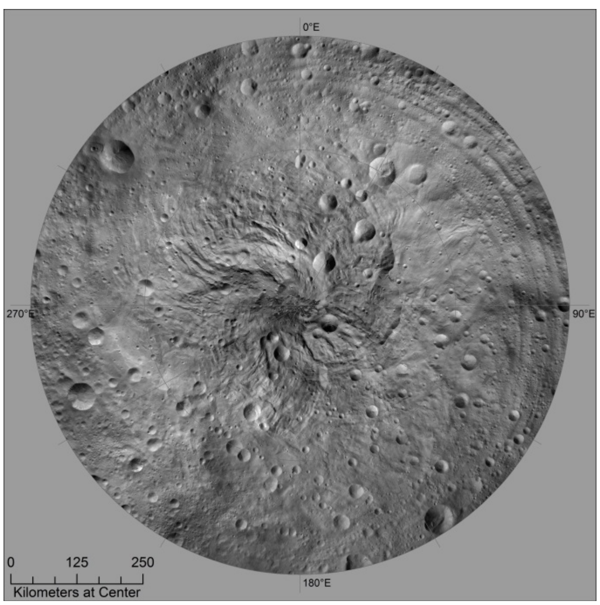

Figure 1: Stereographic projection of Vesta's southern hemisphere on a sphere of 255 km radius in LAMO resolution (~20 m/pixel). The Rheasilvia impact basin is noticeable by the ridge and groove terrain centered a little bit left and above the pole.

Features of the Rheasilvia Impact Basin: After the formation of the Rheasilvia basin (about 1 billion years ago [2]), seismic shaking of impacts on Vesta and gravitational variations caused the basin to collapse. The degradation features are not only concentric around and radial from the basin center (as expected in an undisturbed environment) but also reveal curved ridges that run along the slopes of Rheasilvia. Figure 2 shows the distribution of the curved features.

Possible explanations for the curved features are non-vertical stress components due to an oblique impact and the Coriolis effect on mass movements of the formation and collapsing process of the Rheasilvia basin [3, 4].

In this work we concentrate on the Coriolis effect and compare the observed curvature with the expected trajectories of masses moving on a rotating object.

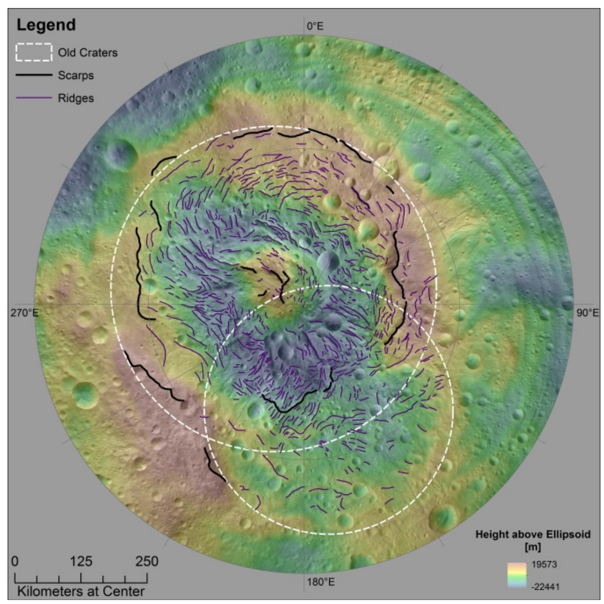

Figure 2: The distribution of ridges (purple lines) and scarps (black lines) in the Rheasilvia basin (dashed white circle at the center). The older underlying Veneneia basin is shown in the lower right for completeness (dashed white line). The map is a stereographic projection of Vesta's southern hemisphere on a sphere of 255 km radius with an underlying digital terrain model.

Coriolis Effect: The Coriolis force is a fictional force associated with rotating systems. The rotation deflects the motion perpendicular to the rotation axis to cause curved trajectories. The effect is well known from oceanic current and wind movements on Earth [5]. The Coriolis force $\vec{F}_C$ is given by

$$\vec{F}_C = -2m\vec{\Omega} \times \vec{v} \ ,$$

where m is the mass of the moving body, $\vec{\Omega}$ the angular velocity of the rotating body and $\vec{v}$ the velocity of a downslope moving object. Figure 3 illustrates the directions of the values.

The radius R of the curvature caused by the Coriolis effect is dependent on the magnitude of the velocity $|\vec{v}|$ perpendicular to the angular velocity, the latitude φ and the magnitude of the angular velocity $|\Omega|$. For a horizontal motion on a simple rotating sphere the radius is given by

$$R = \frac{|\vec{v}|}{2|\Omega| \sin \varphi}.$$

Note that the radius is only dependent on the speed of the moving body but not on its mass.

However, for Vesta with an uneven ellipsoidal shape and large elevation differences (up to 40 km) the trajectory curvature R is not simply dependent the on latitude but also on the topography and local gravity. They influence the perpendicular component of the velocity to the rotation axis.

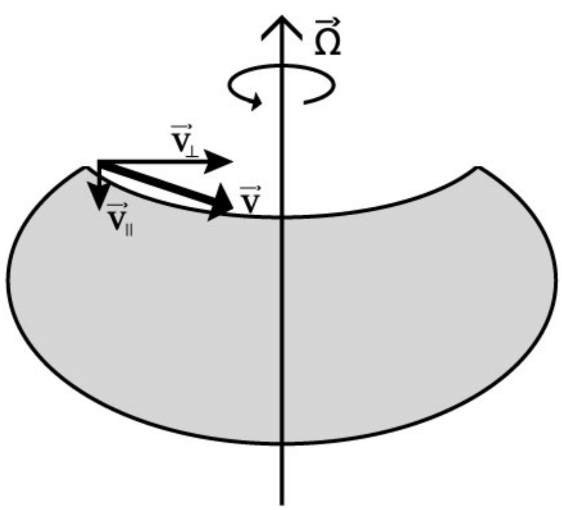

Figure 3: Sketch of directions of the angular velocity $\vec{\Omega}$ and a downslope moving object with velocity $\vec{v}$. Only the component $\vec{v}_{\perp}$ perpendicular to the angular velocity is affected by the Coriolis force.

Method: We assume two different scenarios in which the Coriolis force can affect mass movements on Vesta: during the early stage of the basin formation and the collapse process after the crater's initial formation. In the first case the mass motion is caused by the shock wave and relaxation of the asteroid material that formed the basin. Velocities of such motion can be estimated to about 5 m/s [6]. The second case includes the motion of debris material downslope. These velocities vary dependent on the debris properties, type of mass wasting and slope. An upper value of 15 m/s can be assumed [7].

We will determine the radius R of the ridge curvatures in the Rheasilvia basin by using an orthographic projection of Vesta's southern hemisphere. This prevents the effect of projection on the reading of the curvature. An orthographic projection displays the features of an ellipsoid's surface by using parallel projection lines that are perpendicular to the projection plane. In our case the projection lines will be chosen to be parallel to the rotation axis. Thus, only the perpendicular component of the ridges, which are affected by the Coriolis force, is displayed.

The ridges do not have the same curvature at each point of their elongation, because a curvature produced by the Coriolis force varies with the velocity and location of the motion. To determine the curvature at a given point we will divide the orthographic map in rings centered at the rotation axis. We will twist the rings against each other until the curved ridges will appear to be straight. The initial curvature will then be calculated from the twisting angel.

The angle φ between the rotation axis and the surface normal of a Vesta-like ellipsoid with axis equal to 286.3 km, 278.6 km, and 223.2 km will be ascertained at each point of the ridges [8]. We will use these values and the radius R to calculate the magnitude of the velocity $|\vec{v}|$ with the equation a$\vec{v}$bove.

Assumptions. In order to make the problem tractable some simplifications are necessary. Therefore we assume that the rotation period and axis location have been static since the Rheasilvia basin formation 1 billion years ago.

Furthermore, the calculations on the velocity of moving masses affected by the Coriolis force will be based on an ellipsoid. Vesta, however, is an irregularly shaped ellipsoid with elevations from -22 km to 19 km and slopes up to 40°. This changes the direction of the surface normal in relation to the rotation axis and thus the magnitude of the Coriolis force and resulting ridge curvature. However, it is reasonable to assume an ellipsoid, because the topographic conditions before the mass movements are unknown and the ellipsoid represents the globally averaged topography.

The results will be presented at the conference.

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