**EVOLUTION OF PHOBOS' ORBIT, TIDAL FORCES, DYNAMICAL TOPOGRAPHY, AND RELATED SURFACE MODIFICATION PROCESSES.** X. Shi[1], K. Willner[2] and J. Oberst[1,2] [1]German Aerospace Center (DLR), Institute of Planetary Research, Rutherfordstr. 2, 12489 Berlin, Germany (xian.shi@dlr.de), [2]Technical University Berlin, Department for Geodesy and Geoinformation Science, Straße des 17. Juni 135, 10623 Berlin, Germany.

**Introduction:** At a range from Mars of less than 1.8 Mars radii, Phobos is much affected by tidal drag and rapidly approaching its Roche limit, which makes it one of the most interesting small bodies for exploration and scientific study. Long term observations have shown a secular acceleration of $1.27\times10^{-3}\,\mathrm{deg}\cdot\mathrm{yr}^{-2}$ in its orbital motion [1]. Increasing tidal forces and spin have most likely altered the dynamical topography of Phobos hence influenced its surface processes.

In this work we modeled the dynamical topography of Phobos in the light of its orbital evolution. Tidal and centrifugal effects were taken into consideration in different orbital stages. Results show that the dynamical topography of Phobos has been undergoing significant evolution, with tidal effects dominating. These may have triggered surface processes such as downslope movements of regolith.

**Data and Method:** Three factors are taken into account when modeling Phobos' dynamical topography: surface gravity field, tidal forces and centrifugal forces. For surface gravity, we used a shape-based modeling method by assuming Phobos' mass to be homogeneously distributed. We used the updated Digital Terrain Model (DTM) based on Mars Express image data[2] in the form of a triangulated shape model. The latest *GM* estimate[3] was used for bulk density calculation.

While assuming that Phobos' overall shape has remained constant after the formation of crater Stickney, we modeled tidal and centrifugal forces according to the orbital evolution. The semi-major axis of Phobos' orbit $\Delta t$ ago is calculated by taking into account the tidal torque exerted by Mars as [4]:

$$a_t = \left( a_0^{13/2} - \frac{13}{2} \cdot \frac{3k_2}{Q} \sqrt{\frac{G}{M}} m R^5 \Delta t \right)^{2/13}$$

where $a_0$ is the current semi-major axis. $k_2$ and $Q$ are the Love number and tidal dissipation function of Mars respectively. $M$ and $R$ are the mass and radius of Mars. $G$ is the gravitational constant. A mean tidal effect is assumed for each orbital altitude taking $a_t$ as the mean distance to Mars. Corresponding centrifugal forces were calculated assuming synchronous rotation at every orbital stage.

Dynamic height and dynamic slope are two parameters commonly used for depicting the dynamical topography. Similar to the concept in the Earth geodesy, dynamic height on small bodies is in principle the effective potential ($P$) of static points on the surface, scaled to be of the same dimension as height, calculated as [5]:

$$H = \frac{P_0 - P}{g_0}$$

where $P_0$ and $g_0$ are the constants of reference potential and gravity. Dynamic slope is defined as the angle between surface acceleration and the inward-pointing surface normal at a given point. Both effective potential and surface acceleration consist of three parts: shape-based gravity, tidal force and centrifugal force.

**Results:** In the scenario of in-situ origin, chronology results from crater counting [6] show that the last global resurfacing on Phobos took place 4.3Ga ago. According to the tidal evolution model, the orbital semi-major axis then was 5.73R (as shown in figure 1), which is just inside the synchronous orbit of 5.95R.

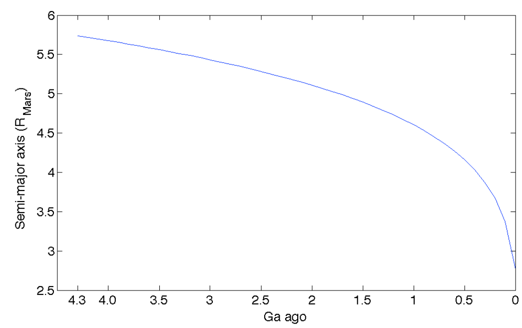


Figure 1. Decrease of the semi-major axis of Phobos' orbit in a tidal evolution model.

*Global evolution of the dynamic topography.* As shown in figure 2, the map of dynamic height when Phobos was at further distance to Mars is quite different from that of today. Differences show clearly that tidal forces are dominating the change. In areas where this effect is most prominent, i.e. sub-Mars and anti-Mars region, tide has caused a depression in dynamic height of more than 1 km (note that this refers to a change in surface potential, not the geometric deformation of the shape).

*The Stickney area.* Stickney is the largest crater and one of the most prominent features on Phobos' surface, which is centered on the equator and extends from longitude ~25°W to ~70°W. This means tidal forces grow stronger from west to east across Stickney. As shown in figure 3, this asymmetry in the tidal force gradually reduces the dynamic height on Stickney's east rim to become lower than on the west.

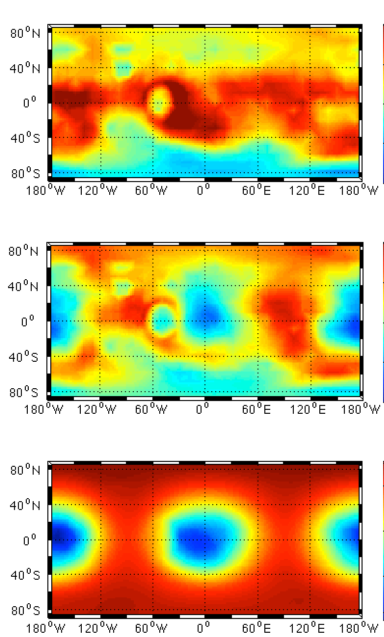


Figure 2. Dynamic heights on Phobos at the time when Stickney formed at 4.18Ga (top) and present (center) as well as their difference (bottom).

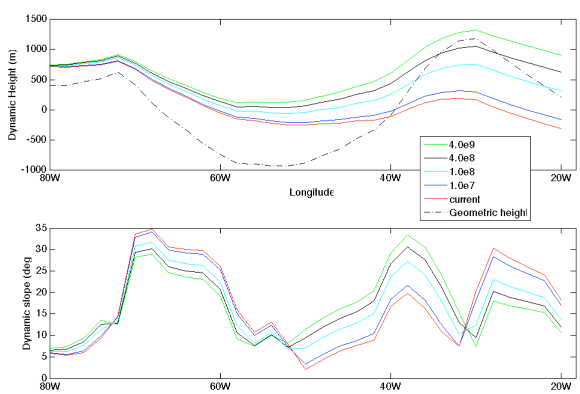


Figure 3. Equatorial profile of Stickney's dynamic height (upper) and slope (lower) at different time in Phobos' history.

Due to the same reason, slopes on Stickney's west wall have becoming larger over time and likely exceeded the angle of repose (typical value: 34-37deg [7]). Around 100 million years ago, many locations on the west wall became steep enough for triggering downslope movements (see figure 4). The maximum acceleration is found to be around (68°W, 4°N), having the value of 0.33cm/s$^2$, and the mean value on the west wall achieved 0.25cm/s$^2$. This is consistent with the presumably very recent downslope displacement of regolith on Stickney's rim observed by spacecraft [8].

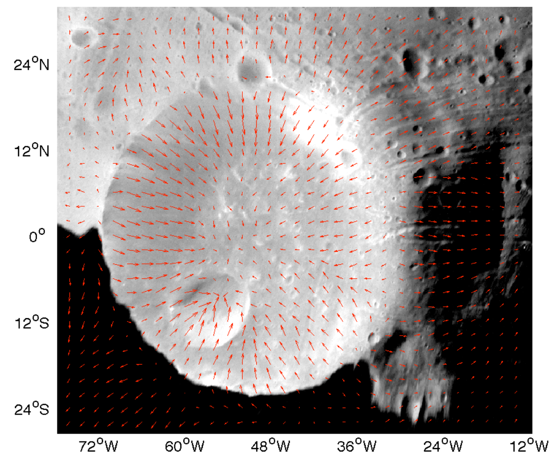


Figure 4. Accelerations along surface plane in the Stickney area 0.1Ga ago (background: mosaic from High Resolution Stereo Camera on board Mars Express spacecraft).

**Conclusion and Discussion:** As its orbit decays, Phobos has been experiencing ever-increasing tidal forces exerted by Mars, which we believe have played an important role in the modification history of its surface. An evolutionary model was developed to depict the changes in Phobos' dynamical topography subject to the prominent tidal effect. We find intriguing agreement between recent downslope displacement of regolith on the west wall of crater Stickney and the increasing dynamic slope in this area, suggesting activity possibly not more than 100 million years ago.

Though in this study we assume the shape of Phobos to stay the same throughout its history, it is possible that tidal effects and significant material displacement have modified Phobos' primordial shape. The homogeneous density assumption is also idealistic, and awaits further observations for verification.

Future works may include investigations of other surface features, especially the geometric patterns of its vast groove system and accumulations of scattered boulders. Simulations of displacement of surface material can also be computed within a dynamical environment described by our model.

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