MESOSCOPIC SIMULATIONS OF SURFACE FRACTURES DRIVEN BY THE TIDAL ORBITAL DECAY OF PHOBOS. B. Cheng[1,2], E. Asphaug[2], S. R. Schwartz[2], R.-L. Ballouz[2], Y. Yu[3] and H. Baoyin[1], [1]School of Aerospace Engineering, Tsinghua University, Beijing, China, chengbin.thu@gmail.com, [2]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ, USA, [3]School of Aeronautic Science and Engineering, Beihang University, Beijing, China.

Introduction: The long, shallow grooves (Fig. 1) cutting across the surface of Phobos represent one of the most monumental surface structures in our Solar System. These grooves, some 80–200 meters wide, and up to 30 kilometers long, went over the long history since their origin, which stand as records of past and on-going geological processes on this tiny moon. Gleaning information about the formation of the grooves, therefore, will help us to understand the evolution history of its surface regolith and the origin of the Martian moons.

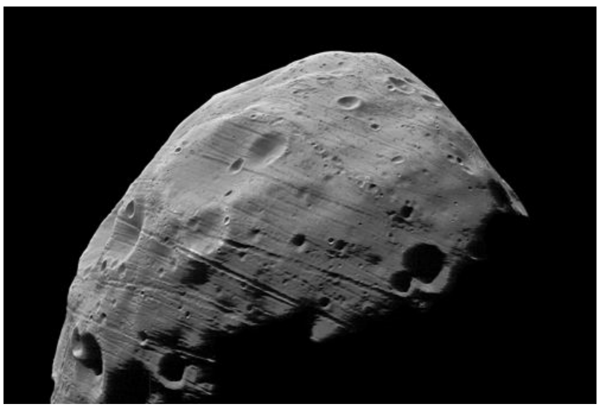

Fig. 1 Linear grooves cutting across Phobos' surface. Image Credit: ESA/DLR/FU Berlin.

Previous works suggest that more than one mechanism are responsible for groove formation. One hypothesis proposed that ejecta from impact events on Mars [1] or Phobos [2] can produce chains of secondary crater resembling grooves. Another theory suggested that the grooves were the result of structural failure driven by tidal forces as Phobos spirals inward. T. A. Hurford et al [3] calculated the surface stress field of the deorbiting satellite and showed that its pattern qualitatively lines up well with the orientation of grooves on Phobos surface. However, the formation of tidal fissures was not modeled explicitly, and it is still a puzzle that if their geometry and orientation are consistent with Phobos' grooves, which need deeper understanding of the mesoscopic dynamics in this process.

In this work, we simulate the response of a regolith layer to tension/compression imposed by the tidal orbital decay. A code capable of simulating millions of particles, *DEMBody* [4], is implemented to track the regolith behavior based on Soft-Sphere Discrete Element Model (SSDEM). We systematically explore the effect of cohesion strength on fracture formation, and find that the regolith layer with large enough cohesion is the prerequisite for the formation of groove-like fractures. Through mapping into Phobos geomorphology, we find the orientation to fail perpendicular to the direction of local principal tensile stress, which is consistent with the characteristic of grooves on Phobos.

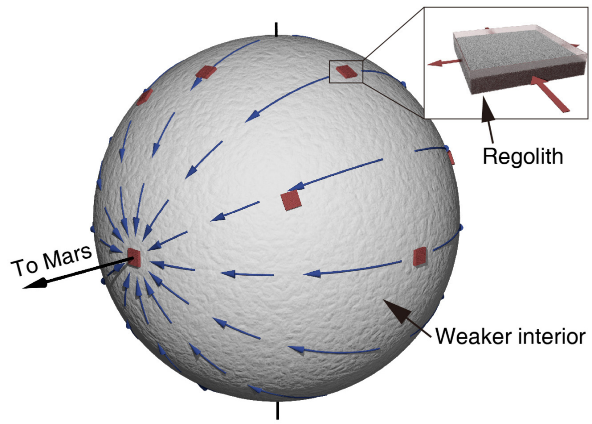

Fig. 2 "Two-layer structure" with a weaker interior covered by a loose regolith bed. Blue arrows show tidal forces exerted by Mars. Inset shows a simulation cell of granular regolith, with tension and compression induced by the deformation of the interior as Phobos spirals inward. Red patches show the eleven local simulation cells chosen in this paper.

Method: We preform discrete element simulations using soft-sphere model [4]. Any two contacting spheres exert nonlinear normal and tangential forces on one another based on Hertz-Mindlin contact theory. A physically based rotational resistance model incorporating rolling and twisting forces is developed in our code. A simple dry cohesion model is adopted to mimic the weak attractive interparticle force.

The Phobos interior is represented as a week shell, barely holding together like rubble piles, surrounded by a layer of rocky regolith about 120 meters thick. This weak interior structure allows stress from tidal forces to alter its surface easily and forces the outer layer to reshape [3]. Due to the limitation of computational cost, we simulate 11 local regolith cells rather the global outer layer as shown in Fig. 2. We set up simulations of regolith beds with initial size of 800 m by 120 m settled in Phobos gravity, and made up of 2,433,796 grains with radii between 1.0 and 2.0 m. Periodic boundaries are imposed in the directions perpendicular to the initial local gravity vector. To mimicking the deformation of the regolith layer forced by the interior, the simulation cell was expanded and shrunk in the directions of local principle stresses, respectively, with ratio derived from tidal stress field [3]. The tension/compression velocities are set to slow enough to maintain quasi-static equilibrium.

Results: Granular layers yield and flow upon applied stress. For vanishing cohesion, the layer deforms without fissures, and a rather smooth modulation of the layer thickness is observed, instead, showing high plasticity upon mechanical loading. However, when cohesion is increased, the formation of bonded bridges between contacting particles leads to a fast increase of tensile strength, while at the same time, destroy the plasticity of granular materials [5]. When excessively stretched, the interparticle bonds collapse and split. These ubiquitous microfractures in granular system propagate and grow perpendicular to the direction of tensile stress, during which macroscopic cracks appear and form an organized network as shown in Figure 3. These grooves, with uniform spacing and parallel orientation, resembles grooves seen in images of Phobos. This explanation also fits with the observation that some grooves on Phobos are younger than others, which is observed in simulations that several grooves grow after others. Therefore, we conclude that surface fractures induced by tidal disruption act as potential building blocks—at least in part—of these striking grooves on Phobos.

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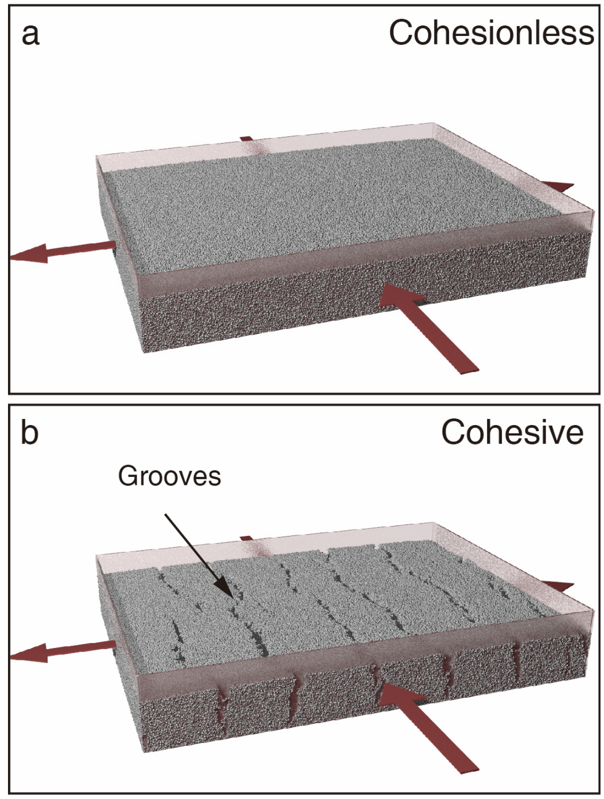

Fig. 3 Mesoscopic evolution of regolith beds under tension/compression. Cohesionless regolith shows high plasticity upon mechanical loading, distorting evenly and keeping surface intact; while for the granular layer with cohesion similar to lunar regolith, cracks appear and form a parallel network, resembling grooves on Phobos.