PSEUDO-GRAVITY EVOLUTION AND MOTION ON THE SURFACE OF PHOBOS. M. Hamelin, Laboratoire Atmosphère, Milieux, Observations spatiales (LATMOS), 4 av. de Neptune, 94107, Saint Maur, France, michel.hamelin@latmos.ipsl.fr

Introduction: Phobos, which can be represented as an ellipsoidal body is orbiting around Mars in a locked configuration as the Moon around Earth. At geological time scale the quasi-circular orbit of Phobos becomes closer to Mars with a current ratio of R/R_M ~2.75 between the Phobos-Mars center distance and Mars radius. In a first part I show the pseudo-potential energy on the surface and its geological time evolution, which indicates the slant for surface material motion. However as Phobos cannot be considered as an inertial frame for velocities as low as ~1m/s, I study in a second part the motion of grains, stones or blocks that can glide or roll on the surface. The possibility that some grooves were dug by rolling blocks is then discussed as well as the conditions of downward motion.

Static approach: The gravitational field used here is the ellipsoidal model of Davis [1] that describes as well the past and future orbital distances of Phobos. Gravity features on the surface including tidal effects are shown in Fig. 1 in the current orbit (R/R_M = 2.75).

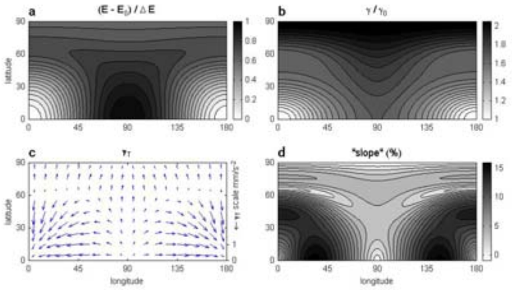

Figure 1

a) Normalized pseudo-potential energy (scaled between highest and lowest values). **b)** Normalized gravity.

c) Tangent component of the gravity (arrows, scale in mm/s2). **d)** slope amplitude (in %). Note the 'crest' feature at ~65° latitude on the prime meridian.

The relative energy variations on the surface, E_n , are shown in Figure 2 as a function of R/R_M. Owing to the symmetries of the problem, only 1/8 part of the ellipsoid surface is presented in triangular figures corresponding to ellipsoidal triangles. The apexes are the sub-Mars point (SM), the trailing edge apex (TR) and the North pole (NP). The coordinate system is shown on the top-left panel; both latitude λ and longitude ϕ vary linearly in the 0-90° range. The panels start with ancient location of Phobos at R/R_M= 5, follow the decrease of the orbital distance through the current position (R/R_M ~2.75) and continue down to R/R_M = 1.5. As the energy is normalized to its range of variation on the whole surface, for each panel, the color scale is always the same, divided in 20 steps. In fact the energy range reaches a minimum at R/R_M.= 3.2 and increases continuously towards unrealistic high values when Phobos approaches Mars.

For R/R_M = 5, the first panel of Figure 2 shows a minimum of energy at the pole and a maximum at the sub-Mars (or anti-Mars) point. Approaching Mars both low energy and high energy patterns move. Between R/R_M ~3.9 and R/R_M ~3.6 , the maximum has moved from the sub-Mars point to the trailing (or leading) point. Within the same R/R_M range a secondary minimum appeared on the prime meridian close to ~40° latitude. At R/R_M ~3.2, this minimum becomes the main minimum, drifting along the prime meridian to the sub-Mars point for R/R_M ~3.1. For lower values of R/R_M the sub-Mars point will stay as the minimum energy point. At the current value of R/R_M ~2.75, the maximum is still at the trailing point, but along the prime meridian a maximum stands at ~60° latitude as seen before in Figure 1. In the future values of R/R_M , the maximum will leave the trailing point at R/R_M ~2.2 as a secondary maximum was formed on the trailing meridian at ~45° latitude; at R/R_M = 1.7, the maximum is at the pole (which was a minimum at the beginning).

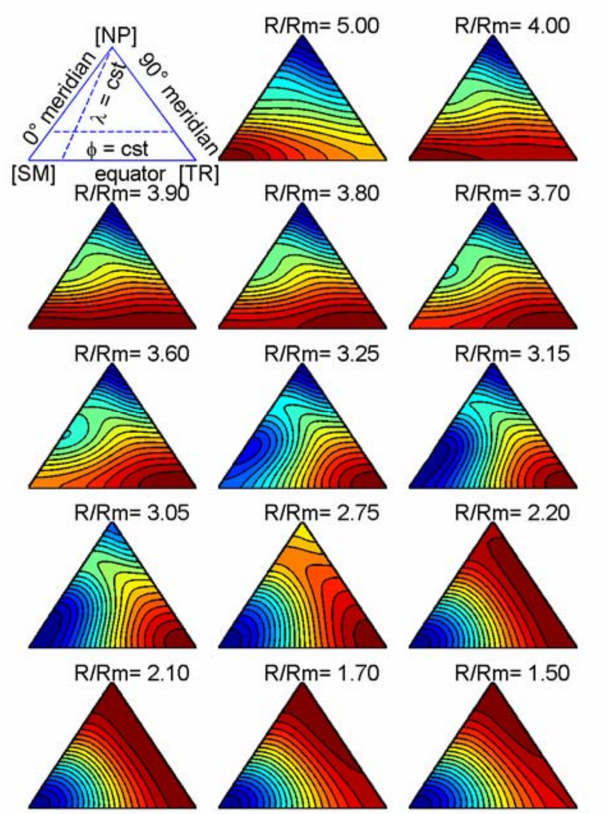

Figure 2.

Normalized pseudo-potential energy (scaled between highest and lowest values) for various values of R/R_M . See text and upper left drawing for coordinates.

Dynamic approach: The static approach is not adequate to fully understand the motion of material on the surface. In fact as the Phobos reference frame is not inertial, real trajectories of test masses shall be computed and the static pseudo-potential maps indicate only accessibility in terms of energy. With the present ellipsoidal model, and with the current orbit of Phobos, the slopes are under the typiccal angles of repose. Spontaneous regolith avalanches could occur when the local topography provides higher slopes but this is out of scope of the present model which accounts for large scale motion or when the surface is relatively smooth. On the past and present Phobos surface material motion is supposed to be triggered by impacts. For small regolith grains lifted as well as large blocks ejected the trajectories depend on the velocity range. For very low velocities (<< 1m/s) and over short distances the motion is likely always down slope, but for velocities of the order of ~1 m/s the Phobos rotating frame effects cannot be neglected. For high velocities (>> 1 m/s), escape from Phobos is also possible.

I compute the trajectory of a gliding test mass for any initial position and velocity. Depending on these initial conditions a gliding mass stay gliding or can in some cases take off after some distance and land again on Phobos as shown in Figure 3.

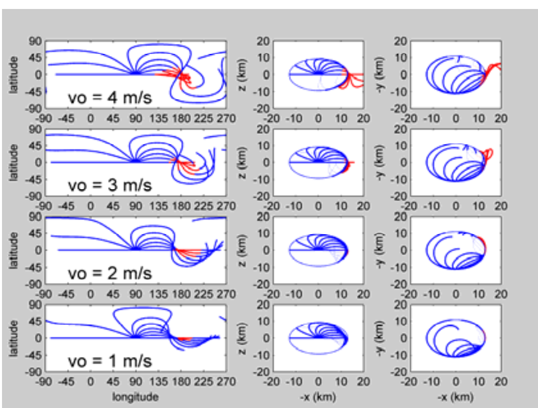

Figure 3. Current Phobos orbit. Trajectories of a test mass launched tangentially from the trailing apex (highest potential as for the leading one). Coordinates: +x = to Mars; +y = trailing direction. Starting velocities are 1,2,3 and 4 m/s; launch azimuths are multiples of 22.5°. The red part of the curves corresponds to a flying part of the trajectory.

Dynamics of blocks launched from Stickney and grooves. The same calculations performed for launches from the Stickney crater area (longitude -50°, latitude 5°) and for the tentative orbital distance of R/R_M = 3.50 for Stickeney impact lead to Figure 4 trajectories. As the pseudo-potential range on Phobos is smaller than the current one the trajectories do not leave the surface but their shape is similar, particularly the East-West asymmetry. Comparing Figures 3 and 4 with the grooves patterns of Figure 5 (Thomas, 1997) the western curves for initial velocities ~2 m/s appear like the actual ones. The density of eastern trajectories is also similar. However, for R/R_M = 3.50 the blocks would not take off as for the current orbital distance. The grooves fading around longitude 270° in Figure 5 would be better explained with a closer orbital distance than 3.50, but, at this point we have to notice that the ellipsoidal model shows differences as high as 2 km with the real surface. In consequence this discussion should be confirmed later with a more precise model.

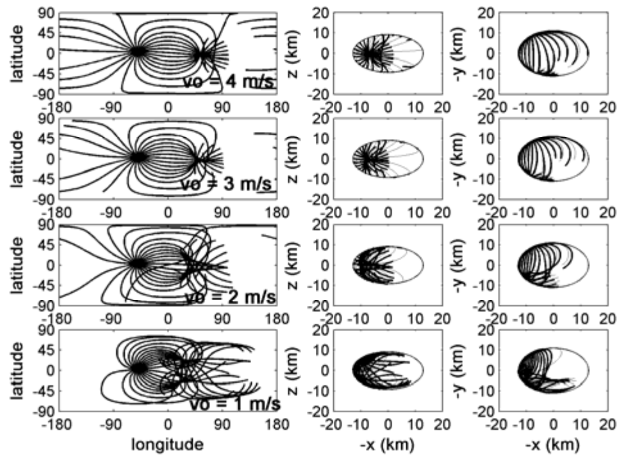

Figure 4. Same as Figure 3 for a lainch from Stickney and for R/R_M = 3.50. (curves have been limited for clarity)

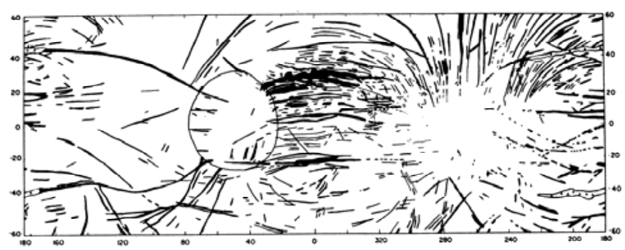

Figure. 5. Grooves patterns, from Thomas [3]

Conclusion. Among many hypotheses about the formation of grooves on the surface of Phobos, it has been suggested that they could have been plowed by impact ejecta, but this was questioned using the arguments that no block was observed at the end of the grooves and that the grooves do not run down slope[2]. The present study shows that both arguments fail as computed trajectories do not run generally down slope and that they can leave the surface. The grooves patterns around Stickney can be explained in several aspects by the track of rolling or gliding blocks, but this could not be extended to all types of Phobos grooves for which other processes could be involved.

References: [1]Davis, D.R. et al. (1981) *Icarus 47*, 220-233; [2] Thomas, P.C. (1997) *Icarus 131*, 78-106. [3] Thomas, P. et al. (1979) *J. Geophys. Res. 84*, 8457-8477.