NEW SIMULATION OF PHOBOS STICKNEY CRATER A. Lucchetti[1,2], G. Cremonese[2], M. Pajola[1], M. Massironi[2,3], E. Simioni[4] ,[1]CISAS, University of Padova, Via Venezia 15, 35131 Padova, Italy (alice.lucchetti@oapd.inaf.it); [2]INAF-Astronomical Observatory of Padova, Vicolo dell'Osservatorio 5, 35131 Padova, Italy; [3]Dept. of Geosciences, University of Padova, Italy, [4]Inst. for Photonics & Nanotechnol., Padova, Italy.

Introduction Phobos is the largest (26.1 x 22.8 x 18.3 km, [1]) and the closest (≈ 6200 km from the Mars surface) satellite orbiting Mars. Phobos is locked into a spin orbit resonance, showing always the same side to Mars; its leading hemisphere is dominated by the biggest crater on the surface, Stickney, which with a diameter of roughly 9 km is of the order of Phobos' effective radius.

In this work we model the Stickney impact crater employing the iSALE hydrocode technique, specifically we consider different scenarios that could form the well-studied crater in order to provide important information about the composition and interior strength of this small body, correlate Stickney's associated features (as fracture grooves) with the impact geometry and improve our understanding on the formation of large craters on small bodies.

Furthermore, simulation results could be helpful to discriminate between multiple hypotheses that have been proposed and debated to explain Phobos' mysterious origin: (i) a remnant of the formation of Mars [2]; (ii) a result of a collision between Mars and a large body [3,4]; (iii) a reaccreted Mars formation remnant or a reaccreted Mars impact ejecta from a disk of debris [5]; (iv) a dark, primitive captured asteroid belonging to the C [6,7] or the D type family [8,9,10,11,12].

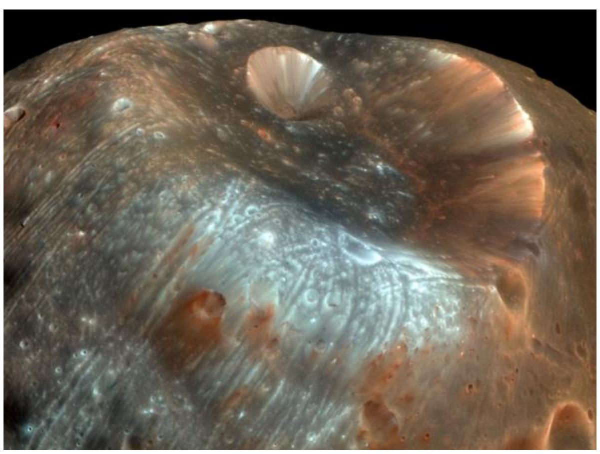

Fig. 1. Stickney crater and its eastern rim. Stretched color HiRISE image PSP 007769 9010 IRB.

Method The overall Phobos dimensions are 26.1 x 22.8 x 18.3 km, hence, in our hydrocode simulations, we modeled Phobos as an elliptic object with major and minor semi axis equal to 13,5 km and 10 km respectively. Prior models of the formation of Stickney performed by [13] have been completed employing two-dimensional SALE techniques. The authors modeled a spherical Phobos consisting of either solid rock or ice, using established scaling laws [14] to choose the relevant parameters of the impactor (size and velocity).

For our purpose we are using the two-dimensional iSALE hydrocode ([15], [16], [17], [18], [19]) considering that the Stickney impact involves the collision of an asteroidal origin projectile, with an impact velocity of 7,5 km/s, derived as $v_i = \sqrt{v_{rms}^2 + v_{esc}^2}$ where v_{rms} is the typical impact velocity on Mars [20] and v_{esc} is the escape velocity from Mars at the orbit of Phobos. Due to the axisymmetric nature of the 2-D hydrocode, we adopt a head-on geometry, where the projectile hits perpendicularly the target surface, as we have done in the case of the Main Belt asteroid 21 Lutetia [21].

We approximate our impactor to a spherical basalt projectile, with a porosity of 10% which is derived from the average meteorite types proposed by [22]. We vary the impactor size, ranging from 200 to 500 m projectile radius, to achieve the best resulting crater size (still obeying the scaling relations of [14]), whose profile is shown in Fig 2. For example, using a projectile size radius of 500 m, resolved by 10 CPPR (computational cells for projectile radius) the Stickney crater was modeled on a computational mesh of 300 x 600 CPPR. A spatially constant gravitational acceleration of 6 mm/s^2 was used in the simulation.

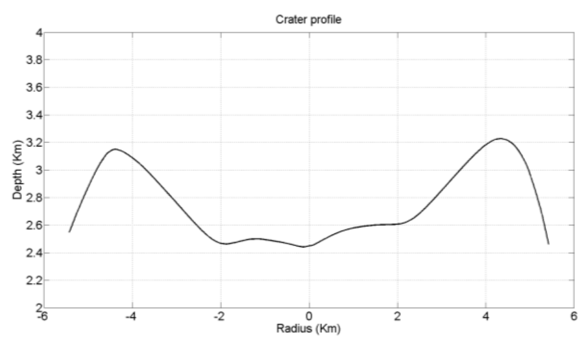

Fig. 2. DTM profile of the Stickney crater [1].

Material strength was accounted for using the rock strength model implemented in iSALE, which accounts for changes in material shear strengths [16] and the thermodynamic behavior of both the projectile and the target is described by the basalt ANEOS (Analytical EOS) equation of state, that is more accurate than the Tillotson equation state used in previous simulation [13]. We considered two different model setup varying the target density from 1,8 g/cm^3, i.e. Phobos bulk density [23], to 2,5 g/cm^3, in agreement with the model shown in [24]. These values of density are achieved using a proper target porosity in the hydrocode; furthermore, we run a set of simulations adding a regolith layer with a thickness of 100 m to verify if it affects the impact crater formation. The regolith of Phobos, as on other atmosphereless bodies, results from accumulation of impact crater ejecta, but also, by the direct deposition of the high-velocity fraction ejecta that escaped to near-Mars space during impact events [25] reaching Phobos surface.

Results and Discussion In Fig 3 we show one of the outcomes of the hydrocode simulation that involves a 1 km projectile diameter that penetrates the target with an impact velocity of 7,5 km/s.

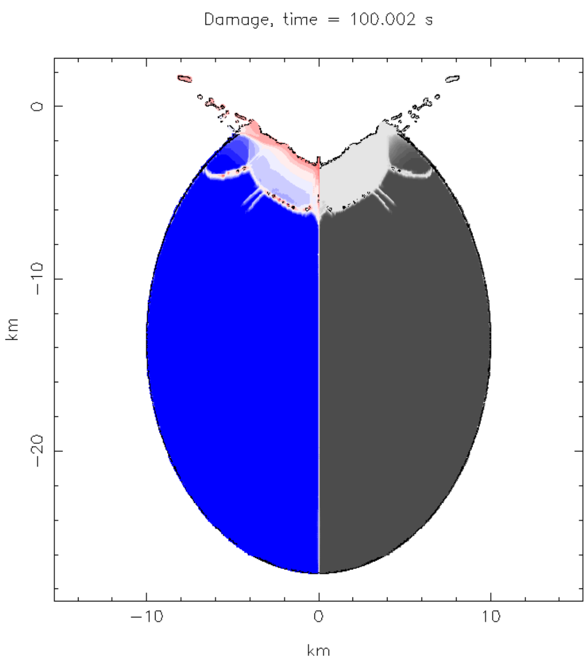

Fig. 3. Hydrocode snapshots of the Stickney crater formation. On the right side of the plot, contours of the amount of damage are shown on a gray scale where white corresponds to the maximum level of damage. On the left side of the plot plastic strain contours are illustrated for the same cross section in a color scale where red corresponding to the maximum deformation while blue means no deformation

The target is characterized by a density equal to 1,8 g/cm^3 without a regolith layer. The strength of the intact rock is set to 50 MPa in this case, but we run different simulations changing this value in order to understand how this parameter affect the final crater. A bowl shaped crater is initially produced on the asteroid and cracks form within the body. The stress wave, that emerges from the contact zone, encounters the target boundaries and produces a damaged layer with significant plastic deformation (left side of the plot).

Similar to [13], we have to assess our impact results by measuring the fraction of Phobos damaged (by volume or mass) and the velocity distribution of material to estimate crater excavation. Furthermore, we have to carry out a series of simulations over a broad range of parameters with the goal of understanding how different values of material strength, porosity, thickness of regolith affect the formation of the impact crater.

Impact modeling is the only way we have to infer about the interior structure of Phobos, by providing important hints on the composition and interior strength of this small body. Furthermore, the results derived from the numerical simulations, specifically the analysis of the damaged area correlated to the crater, could define the distribution of grooves associated to the Sickney impact crater.

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