IMPACT SHAKING OF THE PHOBOS SURFACE

B. A. Ivanov

[1]Institute for Dynamics of Geospheres, RAS, 119334, Moscow, Russia (baivanov@idg.chph.ras.ru),

Large impacts on Ceres could resurface the surface with seismic waves

Introduction: The impact resurfacing of asteroids is an important issue of asteroid's surface geologic evolution (including the crater retention age estimate) [1, 2]. The Phobos specific feature is the presence of prominent grooves assumed to be fractures or rolling stones tracks [3, 4]. However a simple modeling and new observations result in more related questions [5, 6]. The present work describe new numerical modeling of impact cratering on the model Phobos with emphasizing the relation between the crater size and the amplitude of the stress wave propagating through Phobos after impact. Our results seem to put more constraints in the discussion about preservation of pre-impact features at the surface of Phobos.

Model Phobos: In the 2D axisymmetrical numerical model the real Phobos of the unknown structure is replaced with the sphere of 22 km in diameter.

The first impact runs the Model Phobos (MoPh) were done for the uniform body made of "tuff" (density 1.97 kg m-3, sound speed of 2.8 km s^{-1}). The target is initially balanced in the self-gravity field (see more model technique details in [7, 8]). A spherical projectile impacts the target vertically to the "North pole" with velocities from 1 to 5 km s^{-1}. The size of the projectile varies to cover the range of crater diameters around Stickney size (D~8 km, the largest observed crater on Phobos). Due to the low self-gravity the code computes the physical time about 1 hour (3600 s) after impact. This time allows us to see the final crater but is not enough long to see the deposition of all ejecta, returned to the surface.

In this straightforward model we find the global spallation, destroyed the pre-impact surface (Fig. 1).

The second model set reconstructs the MoPh as a target with the internal structure. Taking in account the unknown Phobos structure we make a trial to model Phobos as a set of block/layers of "tuff" separated with layers of a less stiff material ("sand"). We test horizontal layers (target #2), vertical layers (target #3), and the "control" case of the pure sand MoPh (target #4). The model "sand" has density of 1.76 kg m^{-3}, the longitudinal sound speed of 2 km s^{-1}, cohesion of 10 kPa and the dry friction coefficient 0.5 or 0.6 (strength notations in terms of the model [9] used here). In the grid "tuff" block layers consist of 15 cells separated with 5 cells of "sand".

The main finding: Stress wave reflection at multiple "tuff"/"sand" boundaries dramatically decreases the free surface spallation velocities in comparison with mechanically "weak" but uniform Phobos. The pure "sand" (soft) target gives a similar effect.

Spallation velocity: Fig. 2 illustrates the late stage of cratering for the blocky target #3 (6x6 cells of "tuff" separated with 4 cells of "sand"). The motion of distant surface tracers is not visible at the "global" scale. Fig. 3 shows the decay with the distance of the maximal near-surface tracer velocity. The minimum velocity is observed near the "equator". Toward the "South pole" the spallation velocity increases due to the close-to-normal reflection at the free surface. Targets with the internal structure decrease dramatically (factor of to 50) the spallation velocity.

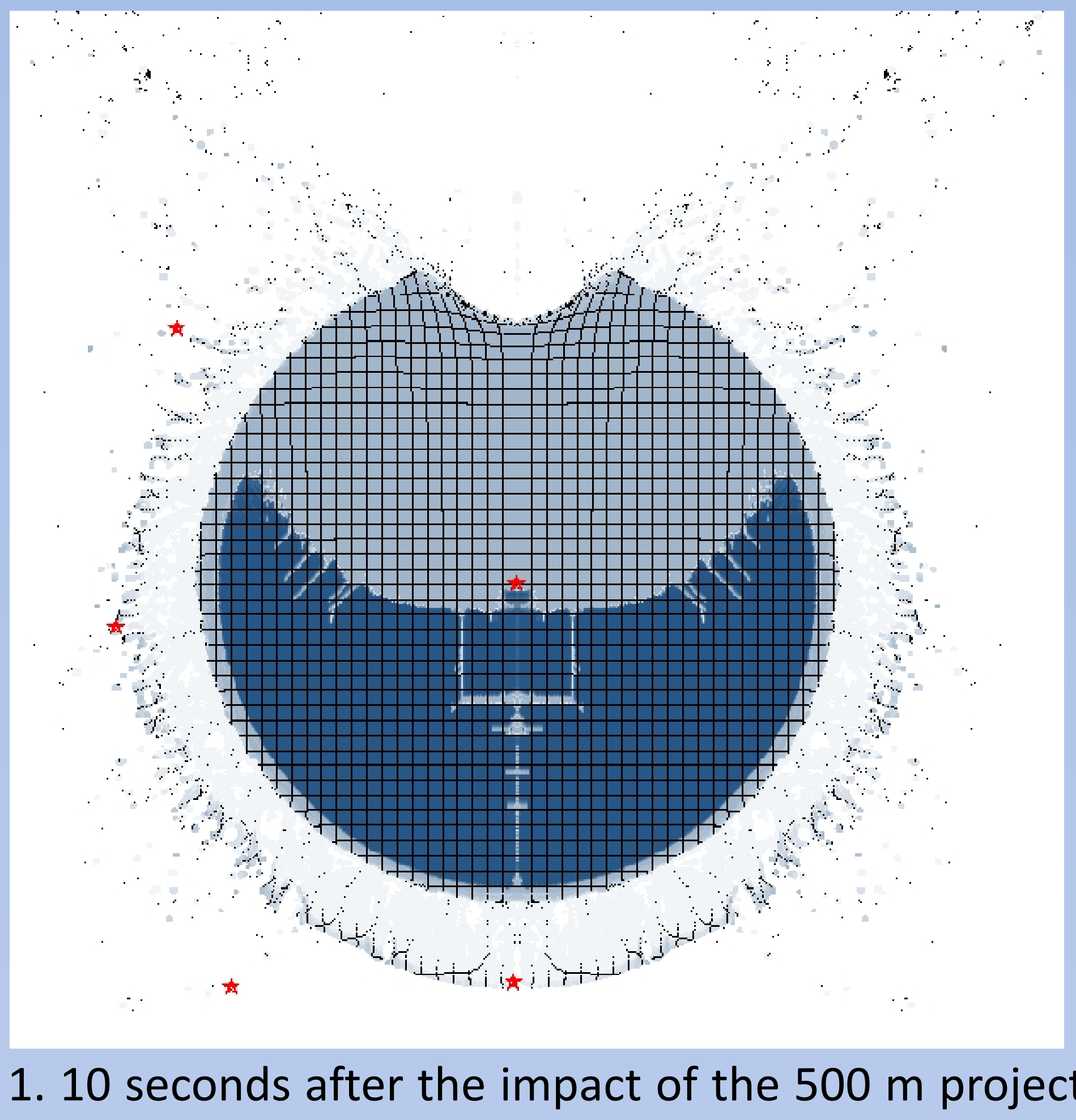

Fig. 1. 10 seconds after the impact of the 500 m projectile (5 km s^{-1}) in the uniform target (1970 kg m^{-3}, longitudinal and shear elastic wave velocities 2.86 and 1.53 km s^{-1} correspondingly. Initial cohesion 10 MPa, residual ("damaged") friction of 0.4. Dark shading is for the non-damaged material. Red stars are tracers with the full parameter records. Initial target diameter is 22 km.

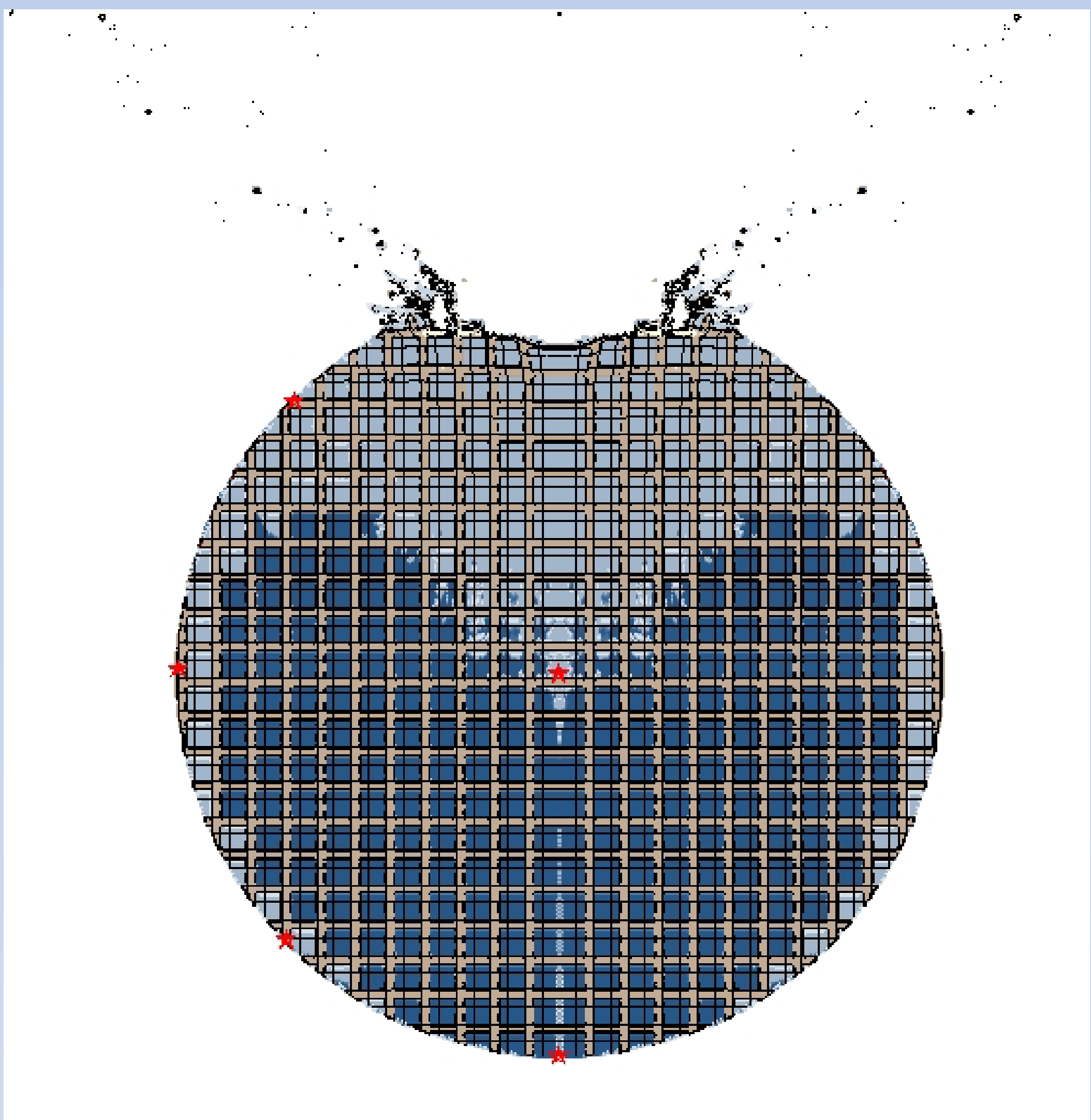

Fig. 2. The impact into a blocky target #3. Projectile diameter ("tuff") is 500 m at 2 km s-1. Blue is for "tuff" blocks, brown is for "sand" gaps. Lighter color intensity is for damaged "tuff". "Sand" is assumed to be "damaged" initially. Target diameter is 22 km, cell size is 50 m.

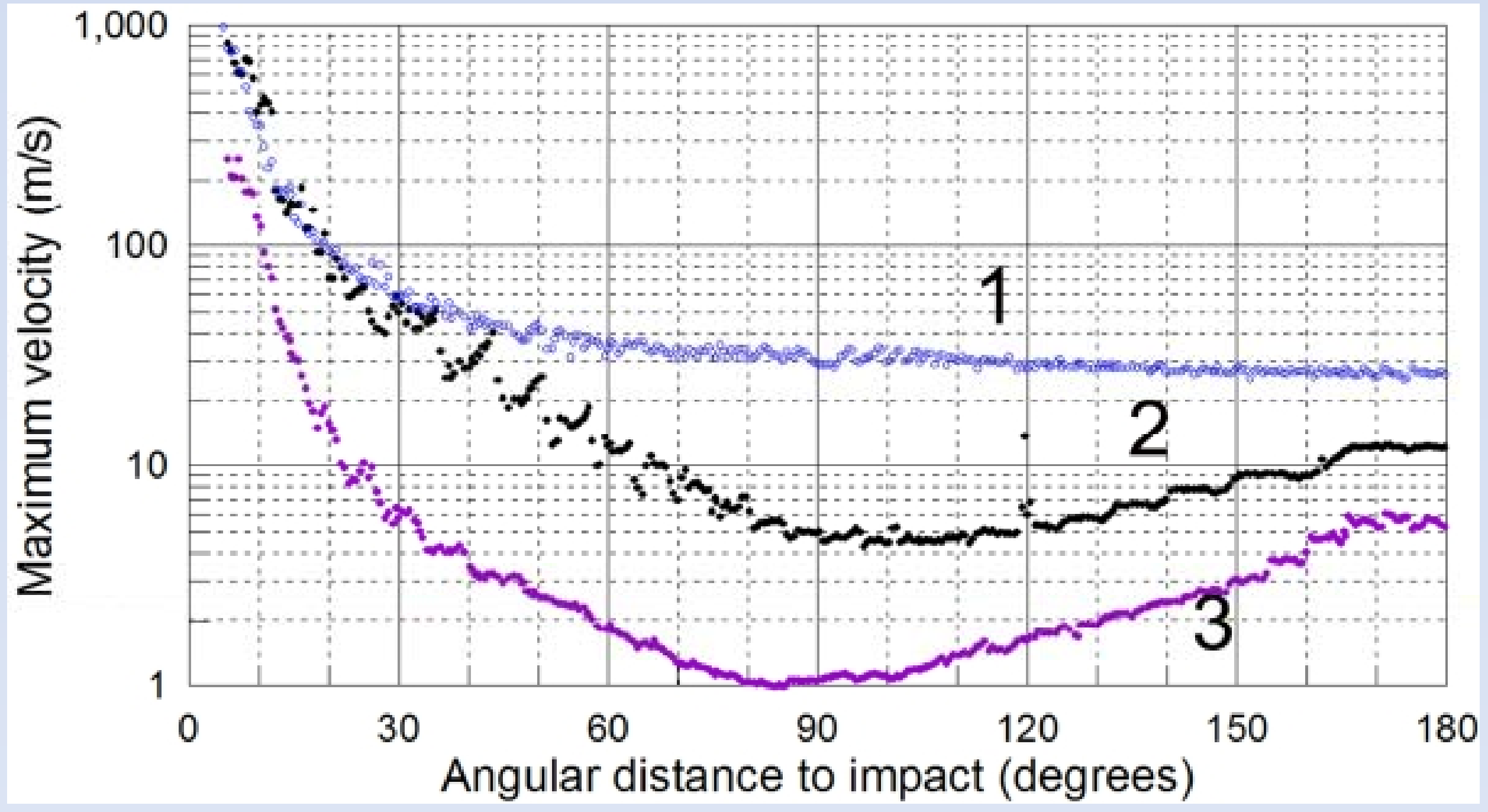

Fig. 3. The comparison of the maximum velocities for near-surface tracers vs. distance from the impacted "North pole" for three targets: uniform "tuff" (1), horizontal (2) and vertical (3) "tuff"/"sand" layers. The target with a structure decreases the surface (spallation) velocity a factor of 10 to 50. Projectiles diameter of 1 km and the velocity of 5 km s^{-1}

Crater relation: Processing of the modeling data in π-coordinates is shown in Fig. 4. The π-points are very close to gravity scaling for planar dry friction targets.

Discussion and conclusions: The numerical modeling of impacts at the model Phobos reveals (as anticipated the dramatic influence of the target structure. The Stickney-size crater formation in the uniform Phobos results in the spallation velocity at the surface (after the stress wave propagation) exceeded the escape velocity. The non-uniform Phobos structure (in the form of more hard blocks/layers, separated some "sand" material) results in 10 times lower surface velocity due to multiple wave refraction at internal boundaries. However, in this "shielded" case the Stickney-size crater formation results in velocities >0.3 m s^{-1}. In a weak Phobos gravity such a shaking seems to be able to destroy many pre-existing features. It may cause the regolith modification, creating problems for groove's creation by rolling stones.

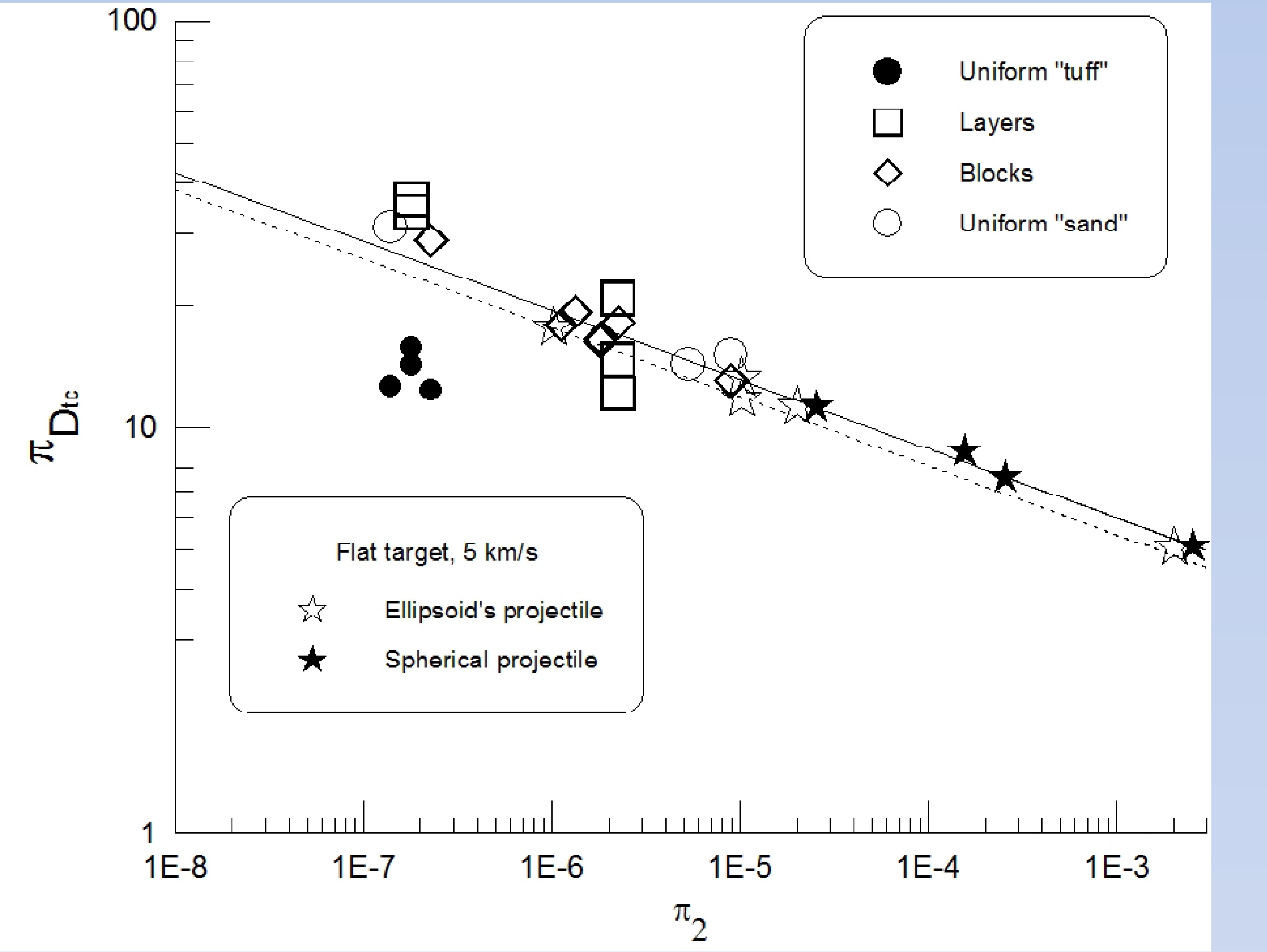

Fig. 4. Pi-scaling of modeled craters. Stars are for the flat surface modeling.

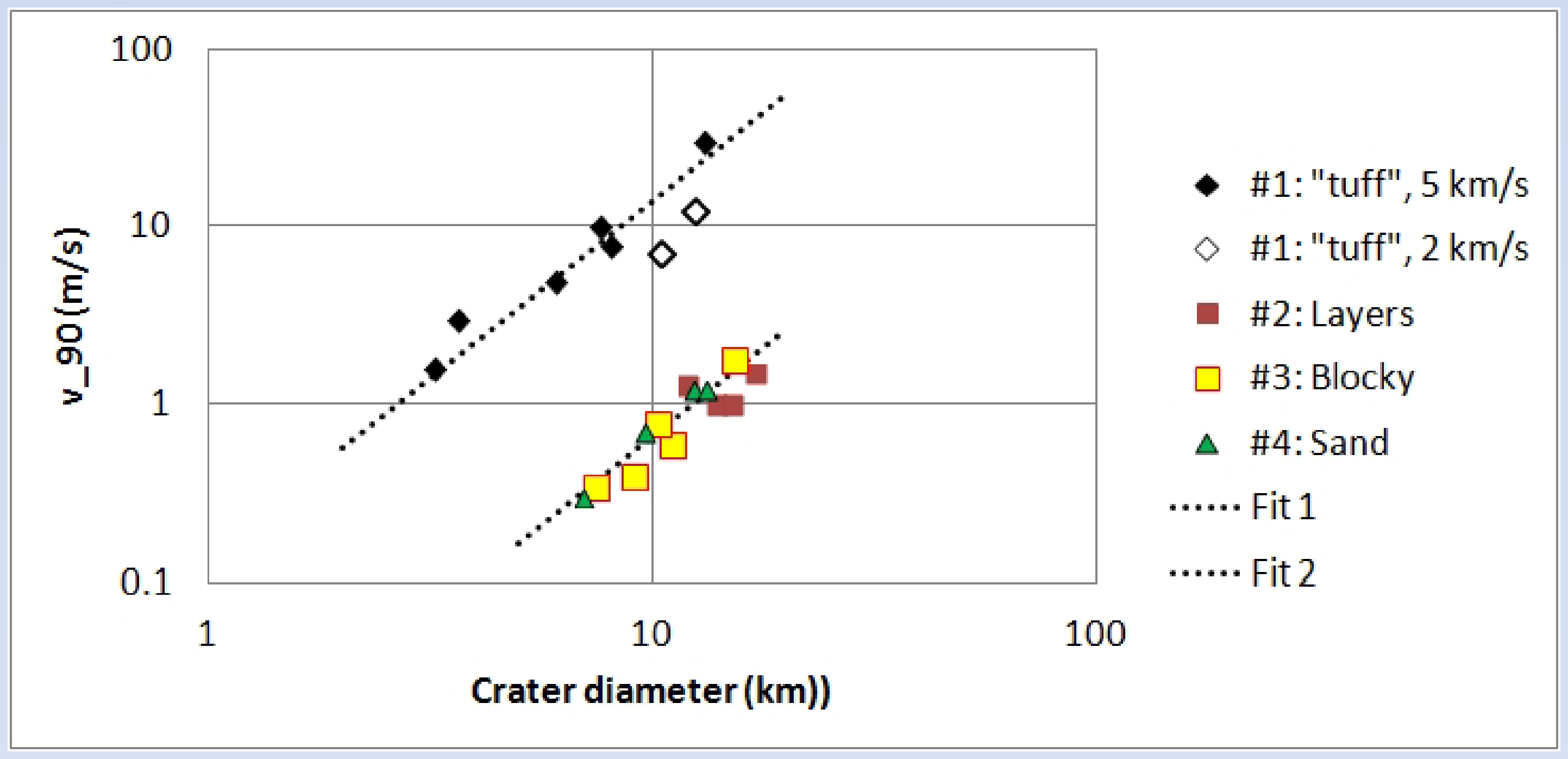

Fig. 5. The correlation between computed crater diameters and the maximum near-surface tracer velocity at the target "equator" (see Fig.3). Dashed lines are correlation fits v90 ~ 0.14 D2 for the "tuff" uniform tar-get (the upper line) and v_{90} ~0.0065 D^2 for "sand" and blocky/layered targets (the lower line).

Acknowledgements: The work is supported by Program 7 from the Presidium of Russian Academy of Sciences.

References: 1] Richardson J.E. et al. (2005) Icarus, 179, 325-349. [2] Asphaug, E. (2008) Meteoritics & Planet. Sci.,, 43, 1075-1084. [3] Horstman K.C. and H.J. Melosh (1989) Journal of Geophysical Research, 94, 12433-12441. [4] Wilson L. and J.W. Head (2015) Planetary and Space Science, 105, 26-42. [5] Hamelin M. (2011) Planetary and Space Science, 59, 1293-1307. [6] Simioni E. et al. (2015) Icarus 256, 90-100. [7] Ivanov B.A., H.J. Melosh, and E. Pierazzo (2010) In: GSA Special Papers 465, edited by R.L. Gibson, and W.U. Reimold, pp. 29-49, Geological Society of America, Boulder, Colorado, USA. [8] Ivanov B. A. and H. J. Melosh (2013) JGR-Planets, 118, 1545-1557. [9] Collins G. et al. (2004) Meteoritics & Planet. Sci., 39, 217–231.