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Landslide on comets as a result of impacts

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Introduction: Landslides were observed on a few comet's nuclei, e.g. [1], [2]. The mechanism of their origin is not obvious because of very low gravity. According to [2] fluidization and multiphase transport of cometary material could be an explanation. We consider another option, namely, earthquakes resulted from meteoroids impacts as a trigging mechanism.

Material of comets: Comets nuclei are believed to built of soft materials like snow and dust. The recent landing of Philae on the comet 67P/Czuriumow-Gierasimienko indicates a different situation. According to [1]: "thermal probe did not fully penetrate the near-surface layers, suggesting a local resistance of the ground to penetration of >4 megapascals, equivalent to >2 megapascal uniaxial compressive strength". Here we assume that elastic properties of comet's nuclei could be similar to elastic properties of dry snow, namely Young modulus is assumed to be 10^6 – 10^8Pa, see [3] and [4].

The model and results: We consider cometary nucleus in the shape of two spheres (with radius 1400 m each) connected by a cylinder (with radius of 200 m and length of 200 m). Density is 470 kg m^{-3}. This shape corresponds approximately to shapes of some comets (e.g. 67P/Churyumov- Gerasimenko [1], 103P/Hartley 2 [5]) A few vibration modes of such body are possible. In present research we consider 3 modes: bending, lengthening-shortening along axis of symmetry, and torsion. We calculated periods of basic oscillation in each of these modes for different values of Young modulus - Table 1.

Table 1 Basic results of calculations

Young modulus [MPa]	Periods [s] of vibration	Maximum acceleration [m s^{-2}]
4	110 - 950	0.0001- 0.0004
40	38 – 290	0.0004- 0.0014
400	12 – 92	0.0012- 0.0045

Rotation and nutation: the impact results in changing of rotation of the comet. In general, the vector of angular velocity will be a subject to nutation that results in changing of centrifugal force, and consequently could be an additional factor triggering landslides.

Discussion: Let assume that the comet are hit by small meteoroid of the mass of 1 kg and velocity 20 km s^{-1}. The mode of excited vibrations and their amplitudes depends on many factors. Of course, the energy of vibration cannot exceed energy released during impact. Generally a few modes of vibration are excited but for some special place of impact and the special velocity vector of the impactor one mode could take most of the energy and this mode will prevail. In calculations for Table 1 we assume that only one mode is generated. The maximum values of acceleration of the surface resulting from the impact are given in Table 1.

The acceleration of the cometary surface could be vertical, horizontal or inclined with respect to local gravity or local normal to the surface. Note that acceleration is often higher than acceleration of the gravity of the comet. Consequently, the vibrations could throw loose material into space that could lead to massive instability of loose material, i.e. to landslides. It could be alternative mechanism to that presented in [2] (i.e. fluidization).

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