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Thermal analysis of boulders on the 67P/Churyumov-Gerasimenko comet

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Abstract

Through the data acquired by the OSIRIS camera [1], the surface of 67P/Churyumov-Gerasimenko comet (hereafter 67P) appears as a collection of morphological contrasts, with a huge variety of terrains and geological features [2]. The presence of large boulders is one of the ubiquitous, and most important morphological features of 67P: such features can be found both isolated and/or in cluster and their distributions depend on the formation and evolution they have undergone [3]. The analysis of thermal properties of boulders on a comet is pivotal in order to add relevant information to the composition and the structure of the comet itself. Thermal stresses are driven by thermal expansion and contraction of the cometary material too, this a natural tendency of the material in changing its shape, area and volume in response to thermal gradient. Both the expansion and contraction are elastic processes, but they are not enough to induce stresses in the material. Stress can be induced if the expansion or contraction of the material are constrained, or there are different layers of the material bonded each other that are expanding or contracting at a different rate. Furthermore, when a comet approaches the Sun, temperature increases and ices sublimate, making boulders unstable and vulnerable. These stresses can lead to the fragmentation of boulders, as thermally rock breakdown is thought to be an active process in the Solar System [4], contributing to the erosion of a cometary or planetary surfaces.

1. Method and preliminary results

In this study we modeled the thermal stresses occurring on boulders located in the Imhotep region of 67P comet, with the aim to i) analyze the heat transfer in airless rock, ii) investigate solid mechanics properties, and iii) quantify stress values beyond which a material failure occurs. Our first approximation is that we considered spherical boulders resting on the surface of the comet, in which we can find two different geometries: the first consists of a sphere made by water or CO_2 ice mixed by material in form of agglomerated particulates, surrounded by a frost layer. In the second model, the boulder is described as a sphere made by a porous medium whose icy part is sublimated, leaving some residual gases trapped in the porous structure [5].

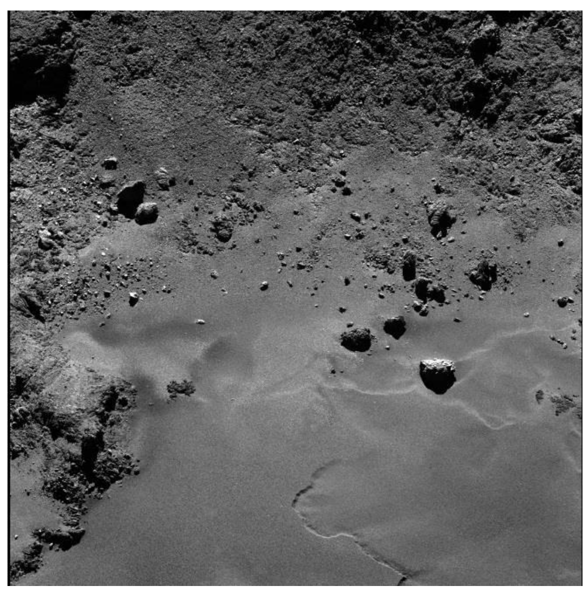

Figure 1: *OSIRIS NAC image taken on 29 September 2014. The scale of the image is 0.35 m/px. This area is located in the Imhotep region [2].*

Regarding the choice of materials, we decided to consider water and dry ice, dunite and graphite as solid part. As proposed by Cheng, S. C. et al. (1969) [6], we calculated the thermal conductivity and thermal inertia for each case. Figure 2 shows an example of the calculated thermal conductivity for a boulder made by dunite as a continuous material and water ice as discontinuous material. We performed our calculations with a temperature ranging between 150 and 230 K. Then, we calculated the relative thermal inertia values on all cases. After calculating the values of thermal conductivity and thermal inertia, we used these values as properties to be assigned to the two geometries in order to simulate the heat propagation, the temperature variation, and the behavior of thermal stress inside the different boulders. We performed this analysis using COMSOL Multiphysics, a 3D Finite Element simulator, calculating the position of the Sun with respect to the selected region of the 67P using the NAIF SPICE Toolkit. After testing the model, we performed the same analysis for boulders with different shapes, varying the values of compactness, circularity, convexity, and complexity, in order to correlate the stress trend with the shape variation.

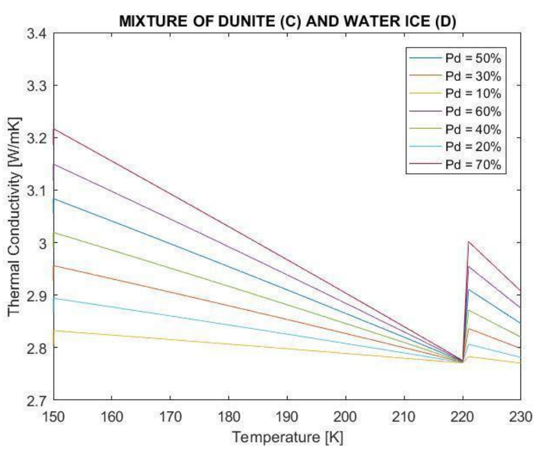

Figure 2: *Thermal conductivity of a boulder made by dunite as a continuous phase, and water ice as discontinuous phase. Each percentage Pd represents the amount of discontinuous material dispersed in the continuous one.*

Our preliminary results show that the establishment of a daily thermal gradient leads to very high thermal stress concentrations, having in some situations temperature variations of the order of hundred Kelvin. Moreover, the analysis performed for boulders with different shapes shows how corners and edges are sensitive parts to thermal fatigue.

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