EPSC Abstracts
Vol. 10, EPSC2015-543, 2015
European Planetary Science Congress 2015

Comet 67P/Churyumov-Gerasimenko: structure of the sub-surface layer

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Abstract

From the operation of the MUPUS thermal probe [1] concluded that the material of the nucleus of 67P/Churyumov–Gerasimenko at the Philae landing site is likely to have a high crushing strength of >4 MPa and a compressive strength of >2 Mps. In this work we consider the derived strength of the material in order to constrain its granulation. For this purpose we performed numerical simulations of the long–term sintering of ice–dust granular mixtures of different granulation, covered by a dust mantle. The dust mantle has a thickness of 0 - 16 cm, and a (pore size and temperature-dependent) thermal conductivity. According to our simulations a hardened layer at least a meter thick forms beneath the dust only when the grains are tens of microns in radius, or smaller. See also [2].

1. Introduction

Comet 67P/Churyumov-Gerasimenko has a long orbital history. We focus our attention on the time span between the last major change of orbit in 1959, when the heliocentric distance at perihelion decreased from more than 3 AU to 1.29 AU, and the 2015 perihelion (8.5 orbital periods) [3]. In this time frame the orbital elements, and orientation of the rotation axis in space, are roughly constant.

Calculations are performed for selected locations on the nucleus, including likely Philae landing region. The physical structure of the surface at Philae's final landing site is currently not known, neither is the exact orientation of Philae. For simplicity, we therefore assume the surface to be horizontal and smooth in this work. If the surface investigated by MUPUS is significantly inclined, and shadowed most of the day, the material should sinter slower than indicated by the presented simulations. Thus, when our simulations predict negligible sintering, the real process should happen even slower.

In our model, the uppermost layer of the nucleus is composed of dust only. It is called the dust mantle. Deeper is a mixture of crystalline H_2O grains and dust. The material underneath the dust is composed either of ice grains with dust cores, or of agglomerates of grains.

The dust grains do not sinter. In the material underneath the dust mantle, the sintering process leads to a depth dependence of the hardness. The rate of sintering of ice grains depends on their sizes. Small ice gains sinter much faster than large ones. Thus, individual ice particles may sinter to form agglomerates much faster than the agglomerates can clump together through sintering. The rate of sintering is significantly depends on the local temperature. Hence, the presence of a thick dust mantle of low thermal conductivity should have significant influence.

The average tensile strength is proportional to the volume fraction of the material, which is (1 - porosity ψ) and the ratio between the grain-to-grain contact areas and the cross sections of the grains, described by the Hertz–factor h.

2. Results

In the figure below we show the thickening of the hardened sub–dust layer for a dust mantle that is 4 cm thick. The hardened layer is considered as the layer where the hertz factor exceeds a threshold value h_{th}, which is 0.33 i.e. approximately the limit of efficiency of the sintering mechanism dominating under considered conditions. The location is at the latitude 15°N. Plotted is the thickness of this hardened layer versus time for cases in which: the grain radius r_g is 1.5 μm, and 15 μm; the radius of pores in the dust layer r_d is 3 μm and 30 μm; the initial Hertz factor h_0 is 0.001 and 0.01; and the initial temperature is 80 K and 40 K. When the material is fine–grained and unconsolidated, the hardened layer thickens to 5 meters within just 2 - 3 orbital periods, depending on the initial tem-

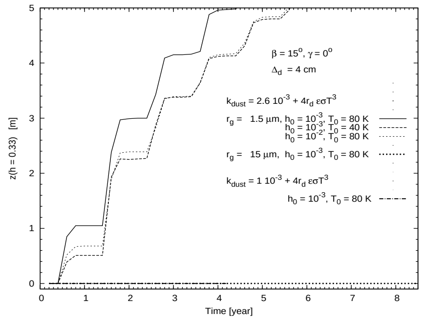

Figure 1:

perature. When the radii of grains and pores are ten times larger, or the initial Hertz factor is hundred times higher, the sintered layer grows only to 2 m thickness during the considered period. When $r_g = 15$ μm, $h_0 = 0.001$ and $k_{dust} = 2.6 \times 10^{-3} + 4 r_d \epsilon \sigma T^3$, the layer of $h > 0.33$ does not form in the considered period. When $r_g = 150$ μm, and $k_{dust} = 2.6 \times 10^{-3} + 4 r_d \epsilon \sigma T^3$, the Hertz factor increases only to 0.14.

3. Summary and Conclusions

The performed numerical simulations of the long–term sintering of ice–dust granular mixtures of different granulation indicate, that in the Philae landing site a hardened layer at least a meter thick forms beneath the dust. This hardening can only be observed in the models when the ice grains are smaller than a few tens of microns in radius.

Acknowledgments

EK and AH were supported by STFC under grant no. ST/L000776/1.

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