EVIDENCE AND MODELLING OF DUST TRANSPORT ON THE NUCLEUS OF COMET 67P/CHURYUMOV-GERASIMENKO. N. Thomas, B. Davidsson, M.R. El-Maarry, A. Gracia Berna, S.F. Hviid, W.-H. Ip, L. Jorda, H.U. Keller, J. Knollenberg, E. Kühl, I. Lai, Y. Liao, R. Marschall, F. Preusker, M. Rubin, F. Scholten, Y. Skorov, C.C. Su, J.S. Wu, and the OSIRIS team, 1Physikalisches Institut, Universität Bern, Sidlerstrasse 5, CH-3012 Bern Switzerland (Nicolas.thomas@space.unibe.ch), 2Department of Physics and Astronomy, Uppsala University, Uppsala, Sweden, 3Deutsches Zentrum für Luft- und Raumfahrt (DLR), Institut für Planetenforschung, Berlin, Germany, 4Institute of Space Science, National Central University, Taiwan, 5Laboratoire d’Astrophysique de Marseille, Marseille, France, 6Technical University of Braunschweig, Germany, 7Department of Mechanical Engineering, National Chiao Tung University, Taiwan.

Introduction: The European Space Agency’s Rosetta spacecraft entered orbit around the nucleus of the Jupiter family comet, 67P/Churyumov-Gerasimenko (hereafter 67P) on 6 August 2014. The scientific imaging system onboard is called OSIRIS [1] and comprises a dual camera system with a high resolution (scale = 18.56 μrad/px) narrow angle camera (NAC) and a lower resolution (101 μrad/px) wide-angle camera. Initial results from OSIRIS observations of the nucleus and the innermost coma have been published in [2] and [3].

Amongst other observations, the images suggest that accumulation of non-escaping dust particles emitted from areas of activity in a form of “airfall” is a significant process.

Furthermore, observations of aeolian ripples, dune-like structures, wind-tails, and smooth depressions with ponded dust suggest that surface dust transport is of major importance in defining the uppermost surface layer in many regions [3].

Although sublimation-driven ejection of material from an active area is the initiator of material motion, there appear to be several other processes that are involved in material transport. We discuss here evidence for some of these processes although we caution that alternative hypotheses for the formation of some of these features may be conceivable.

Airfall (deposit): The idea of particles emitted from active regions failing to escape the gravitational field of a cometary nucleus has been explored on several occasions. [4] produced a semi-analytical model which was used to determine the number densities of larger particles on bound orbits in the vicinity of the nucleus. It was shown that only particles of order 5 cm in size could achieve stable orbits. Similar calculations were performed by [5]. It is clear that escape forms a sink for these particles. However, impact of particles on the surface itself is also foreseeable in the presence of appropriate perturbations.

The importance of airfall might be enhanced by the presence of sub-surface super-volatiles. It has been postulated that dust emission is driven, particularly at high heliocentric distances, by localized sublimation of super-volatiles such as CO, CO₂, or the amorphous-crystalline ice transition [6]. The build-up of pressure in the sub-surface by super-volatile sublimation can lead to ejection of larger particles via quasi-explosive events. This might lead to emission but extremely rapid de-coupling resulting in lower velocities relative to the nucleus. Furthermore, localised sources may result in de-coupling at the edges of the gas “jet” again producing lower initial velocities for particles. Hence, conceptually, airfall might be expected.

Within the Ma’at, Ash, and Seth regions on the nucleus (see [3] for the nomenclature) we see features where horizontal surfaces are relatively smooth but adjacent vertical surfaces are rough and fractured. An example in Seth was shown in [3]. We see similar examples in the Ash region. Pit depressions have steep walls. Usually there are no deposits on the walls. It is also apparent that the deposit is rather thin. Similar conclusions can be drawn from several other views at interfaces between deposit-covered terrain and more fractured material.

Airfall (bright chunks): Also evident in several places on the nucleus are bright chunks of material in the deposit. A possible interpretation is that these are bright icy chunks of material which have been ejected from an active region and have landed back on the surface. They then become sources of gas increasing the net production rate. There is strong evidence for low velocity, large chunks in bound-orbits around the nucleus [7] and the bright icy chunks have spectra similar to dirty water ice [8].

Possible Aeolian ripples: The effects of extreme pressure gradients on loose surface material on comets has rarely been explored. [9] appears to have been the first to consider erosion driven by cometary outgassing using formulations similar to those used by Greeley and Iversen to study saltation on Mars and, following [10] noted the importance of cohesive forces between particles on bodies with low surface gravity. The importance of cohesive forces in crust formation had been discussed in [11]. The OSIRIS observations suggest that these ideas may be even more applicable than previously realized.
When a gas flux over an immobile bed of cohesionless grains becomes sufficiently large, the grains are set in motion and dunes form. The surfaces of aeolian sand dunes are not smooth but are usually in the form of regular patterns (ripples), transverse to the wind direction.

We see what appear to be aeolian ripples in the Hapi region [3] on 67P. The ripples are roughly aligned and one can estimate a wavelength by counting the number of crests along a line orthogonal to the aligned ripples giving values of around 12 metres when taking into account the viewing geometry.

The extremely low gravity implies that cohesive forces dominate in resisting the influence of gas drag. This, in turn, implies that large particles will be more easily moved that the 100 micron particles typically seen for Martian saltation [12]. In order to study this more closely, we have been using Direct Simulation Monte Carlo models of the outgassing from the nucleus to determine velocities and pressures compatible with our current knowledge of the gas production rates. Preliminary calculations seem to suggest that a type of saltation can be initiated under optimum conditions.

Other dune-like deposits: The Maftet region shows what appear to be dune-like structures which are resting on a fractured substrate [3]. Unlike the Hapi region, which is essentially enclosed from two sides, the Maftet region is on a convex surface where one would expect gas to expand more radially to the nucleus surface rather than laterally. We are also investigating this more challenging case and studying unusual pits in their surfaces.

Ponded deposits: In areas where we see consolidated material (e.g. the Khepy and Aker regions), there are depressions with smooth flat surfaces and limited numbers of boulders. These appear very similar to the ponded material observed on asteroid 433 Eros [13]. At present, the favoured theory for their production is electrostatic levitation and subsequent transport.

Conclusions: Transport of material from one part of the nucleus to another seems to occur in several ways. This re-distribution of material can influence the gas emission and the surface properties of the nucleus. The efficacy of the different mechanisms remains somewhat unclear but modelling work is proceeding with the aim of clarifying their relative importance.
