THE CESSATION THRESHOLD OF SEDIMENT TRANSPORT IN NEWTONIAN FLUID

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One of the classical problems in sediment transport science is to predict the threshold fluid shear stress below which a bed of loose sediment particles sheared by a homogeneous flow of Newtonian fluid ceases to move. Here, we investigate this problem using simulations with the coupled DEM/RANS numerical model of sediment transport in Newtonian fluid by Duran et al. [1]. We simulate conditions with particle-fluid-density ratios ($s = \rho_p/\rho_f$) within the range $s \in [1.2, 2000]$ and particle Reynolds numbers ($\mathrm{Re} = \nu^{-1}\sqrt{(s-1)gd^3}$) within the range $\mathrm{Re} \in [0.1, 100]$. We find that sediment transport is at least partially sustained through impacts of already transported particles onto the sediment bed for all simulated conditions, except viscous bedload (i.e., sufficiently small Re depending on s). This has been well known for turbulent sediment transport in light air, such as on Earth and Mars. However, turbulent sediment transport in liquids, such as water, and heavy air, such as on Venus and Titan, were previously thought to be solely sustained through fluid entrainment (with the notable exception of the recent study by Clark et al. [2]). From our simulations, we further find that sediment transport does not vanish at the cessation threshold. Based on these numerical findings, we propose a physical, analytical model predicting the cessation threshold of sediment transport in Newtonian fluid, which can be applied to arbitrary s and Re. Each equation of this model and the cessation-threshold predictions are consistent with numerical data within the entire range of simulated conditions. Moreover, the cessation-threshold predictions are consistent with measurements in water (Shields diagram), Earth's air, and with an observational estimate on Mars. When applied to conditions on Triton, Pluto, and the comet 67P/Churyumov-Gerasimenko, which all have very thin atmospheres, it predicts much smaller threshold wind shear velocities (u_t) than previous models. In particular, it predicts $u_t \approx 1$m/s for particles with size $d \approx 2$mm on Triton and Pluto, which is a wind shear velocity often reached during storms on Earth and Mars, and thresholds consistent with estimates of wind shear velocities on 67P/Churyumov-Gerasimenko (e.g., $u_t \approx 45$m/s for $d \approx 1$cm). We thus conclude that the surface features, including what appear to be ripples and dunes, photographed on these planetary bodies during space missions are, indeed, of aeolian origin.

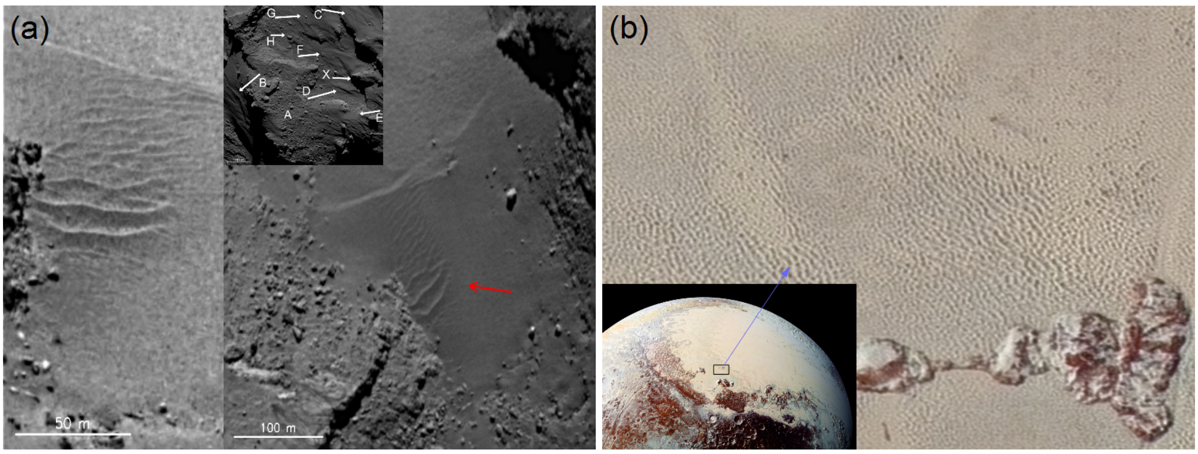

Figure 1. Images of possible ripples and dunes on (a) the comet 67P/Churyumov-Gerasimenko from Thomas et al. [3] and (b) Pluto from Stern et al. [4].

References

[1] O. Durán, P. Claudin, B. Andreotti *Numerical simulation of turbulent sediment transport, from bed load to saltation*, Physics of Fluids **24**, 103306 (2012).

[2] A. H. Clark, M. D. Shattuck, N. T. Ouellette, C. S. O'Hern *Onset and cessation of motion in hydrodynamically sheared granular beds*, Physical Review E **92**, 042202 (2015). A. H. Clark, M. D. Shattuck, N. T. Ouellette, C. S. O'Hern

[3] *Redistribution of particles across the nucleus of comet 67P/Churyumov-Gerasimenko*, Astronomy & Astrophysics **583**, A17 (2015).

[4] S. A. Stern *et al.*, *The Pluto system: Initial results from its exploration by New Horizons*, Science **350**, aad1815 (2015).