DIVERSE SURFACE MORPHOLOGIES OF COMETS: EVOLUTION OR GEOLOGY?

A. F. Cheng[1], DIXI/EPOXI Team. [1]The Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20723, USA (andrew.cheng@jhuapl.edu).

Introduction: Recent spacecraft encounters with Jupiter Family Comets have revealed markedly diverse surface morphologies. Wild 2 encountered by Stardust [1] is dominated by steep-walled and flat-floored depressions, while Tempel 1 and Hartley 2 [2, 3 respectively], encountered by Deep Impact/EPOXI, are notable by absence of such features. Tempel 1 is relatively smooth and exhibits evidence for flows and layering. Hartley 2 is bi-lobed, with knobby terrain at its ends and a much smoother terrain in its middle, and it is surrounded by a blizzard of icy chunks lifted off its surface. Wild 2 has the most surface relief features, Hartley 2 (in the smooth regions) the least. Only Tempel 1 shows classic impact craters, but Wild 2 has many depressions with generally round planforms. Hartley 2 has the most non-spherical shape and largest fraction of smooth regions of the three comets. Do the markedly different surface morphologies seen at Wild 2, Tempel 1, and Hartley 2 represent an evolutionary sequence, or are they different outcomes of geologic processes?

Jupiter Family comets undergo a time-averaged mass loss equivalent to average surface recession rates of cm to m per perihelion pass, and in addition they exhibit outbursts in activity and large-scale disintegration events (splitting). This mass loss and surface recession cannot be uniform across the surface, nor is the recession steady, and comets must be considered as geologically active, with activity driven by the volatile sublimation which is responsible for gas and dust production. We will develop a picture in which surface morphology differences between Wild 2, Tempel 1 and Hartley 2 are attributed to differences in geographic distribution and strength of vapor outflow, such that the styles and rates of surface recession can differ substantially depending on how and where material is removed and transported.

Geologic Activity Driven by Outflow: One manifestation of vapor-driven geologic activity has previously been discussed, production of fluidized flows [4]. We will discuss another important process, wind-driven erosion of the surface, which may produce ventifacts on comets as previously discussed by Brownlee et al. [1] who also suggested the possibility of fluidization on comets “on small scales”. In our view, these vapor-driven processes are considered as competing with other processes traditionally considered for small bodies, like impact cratering (with re-deposition of ejecta onto the surface) and downslope mass motions.

Alternatively, an evolutionary sequence was proposed by Belton [5] in which the Wild 2 style of surface morphology is the youngest, the Tempel 1 style is of intermediate age, and the Hartley 2 style is the oldest. In this view Wild 2 encountered Jupiter in 1974 (when its orbit was perturbed from its previous orbital range 4.9-25AU to its present range between 1.6-5.2 AU) as a comet new to the inner solar system, and thus may have a relatively fresh surface, only recently subjected to heating from close perihelion passes.

Eolian Erosion on Comets: We consider eolian erosion that may be driven by the outflow of cometary vapor, making use of information from wind tunnel experiments [6,7] and in situ studies of eolian erosion on Mars, where wind-oriented scouring of rock, oriented ripples and dunes, and erosional remnants downwind of resistant obstacles are well-documented [8]. We adopt the model of van der Waals cohesion recently proposed by Scheeres et al. [9] and find that the average vapor outflow flux at Hartley 2 of 5.7×10^{17} $cm^{-2}s^{-1}$ implies wind speeds sufficient to mobilize particles of 10 cm size even close to the icy reservoirs where the vapor is evolved, below the surface. We suggest that particles are mobilized and entrained in flows within sub-surface outflow channels, emerging to be readily lifted into the coma [10], and fragmenting in the process. On the other hand, the much lower vapor outflow flux at Tempel 1 of 4×10^{14} $cm^{-2}s^{-1}$ is insufficient, in the present model, to mobilize particles but is consistent with generating repeated fluidization episodes [4]. The Wild 2 case is intermediate, with average outflow flux 7×10^{16} $cm^{-2}s^{-1}$ which would be, in our model, sufficient to support eolian erosion and produce steep-sloped features as in the pinnacles and the steep-walled, flat-floor depressions. These depressions may have originated as impact features but have been subsequently modified by eolian erosion.

Conclusion: Various forms of geologic activity driven by vapor outflow may account for diverse surface morphologies of Jupiter Family Comets. We do not provide a definitive discriminator between the evolutionary sequence hypothesis [5] and the present idea, diverse outcomes of geologic activity. Future *in situ* comet missions, like ROSETTA, might do so.

References: [1] D. Brownlee et al. 2003. JGR, 108, 8111-24. [2] M. A’Hearn et al. 2005. Science 310, 258-64. [3] M. A’Hearn et al. 2011. Science, 332, 1396-1400. [4] M. Belton, H. Melosh 2009. Icarus 200, 280-91. [5] M. Belton, 2010. Icarus 210:881–897. [6] J. Iversen et al. Icarus 29, 381-393. [7] R. Greeley et al. GRL, 7:121-124. [8] R. Sullivan et al. 2005. Nature 436:57-61. [9] D. Scheeres et al. Icarus 210 (2010) 968–984. [10] P. Gronkowski et al. 2011. Astron. Nachr. 332:785-794.