Landform Evolution on Icy Planetary Surfaces

Alan D. Howard

The dominant exogenic process modifying icy satellite surfaces is related to the joint action of volatile redistribution that may be coupled with mass wasting. When a nearly pure icy surface is eroded by sublimation, surfaces tend to develop sharp projections and rounded reentrants (decrescence). If this is reinforced by aspect effects of solar radiation, albedo decrease due to dust, and IR re-radiation, this can produce rough surfaces such as sun-cups and penitents found on terrestrial and martian polar caps. If decrescence occurs primarily laterally, as in the case of the martian south polar CO_2 cap, pointed projections and rounded embayments form during a contagion-like erosion of steep-sided pits triggered from local centers. Depressions of similar shape occur in many of the dry alkane paleolakes of Titan. Sublimation is one of several possible processes eroding the lake boundaries.

In contrast, volatile deposition directly on a surface (accrescence) tends to produce rounded projections and narrow, deep embayments. Such landforms appear to be less common on icy surfaces, although the rounded, icy rims of degraded craters on Callisto may be an example.

Sublimation at the lower-albedo base of a thin, translucent ice surface can produce localized gas "geysers" such as the seasonal "spiders" on the martian south polar caps and the gas jets on Triton. If the gas movement beneath the surface is sufficiently energetic, it can erode the spider-like troughs forming in the martian spiders. Redeposition of material carried by the jets can produce surficial windstreak deposits, such as on Triton.

Coupling of volatile redistribution with other processes produces unique landforms. One example is the spiral troughs of the water ice polar caps of Mars. These troughs form through an instability maintained by a combination of 1) ice sublimation on equator-facing scarps darkened by surface accumulation of a minor component of dust in the ice, 2) removal of ice and enhancement of sublimation by katabatic winds, and 3) net deposition of ice on pole-facing trough walls.

If particulate material forms a large component of surficial ices, then the accumulation of dust on the surface interacts with volatile redistribution. Where particulates accumulate as thick deposits (often through downslope mass wasting), sublimation becomes retarded. The low albedo of mineral and organic particulates produce warm surfaces that can radiate thermal IR radiation to accelerate sublimation of surfaces exposed to the reradiation. The combination of sublimation, dust accumulation with mass wasting, and reradiation produce unique landforms such as the skeletal craters with bright, icy rims of Callisto and the "spongy" surface of Hyperion. In these latter cases the interaction of these processes can be incorporated into spatially-explicit models of landform evolution that replicate the observed morphology.

The abundant ices of Pluto and Charon's surfaces will probably reveal definitive landforms related to volatile redistribution, probably coupled with mass wasting and possibly with wind action.