MASS WASTING AND GROUND COLLAPSE IN TERRAINS OF VOLATILE-RICH DEPOSITS AS A SOLAR SYSTEM-WIDE GEOLOGICAL PROCESS: THE PRE-GALILEO VIEW; Jeffrey M. Moore, Michael T. Mellon, Aaron P. Zent; Space Sciences Division, MS 245-3, NASA Ames Research Center, Moffett Field, CA 94035

The polar terrains of Mars are covered in many places with irregular pits and retreating scarps, as are some of the surfaces of the outer-planet satellites (e.g., Io, Europa, and Triton). These features are diagnostic of exogenic degradation due to the loss of a volatile rock-forming matrix or cement. It has gone generally unrecognized that the same (or very similar) geologic process responsible for the martian polar terrains also operates on some of the outer-planet satellites. The development of many of the scarps on Triton, and the depressions they surround, appears to involve scarp recession, as the planimetric traces of these scarps are inconsistent with formation either by faulting or as flow fronts. Scarp recession can occur on the Earth when a structural or stratigraphic inhomogeneity near the scarp base is mechanically weakened. On Triton, where conditions are unfavorable for some of the processes which cause scarp retreat such as erosion by abrasion from wind, rainfall, or channelized running fluid, mechanical weakening of material exposed in the face of a scarp probably involves the loss of a cementing or matrix-forming material by sublimation. A somewhat similar hypothesis has been offered for the formation of scarps and enclosed depressions on Io. The current data do not allow an unequivocal identification of sublimation-degradation landforms on the icy Galilean satellites. Mesas and rimless and irregularly-shaped pits observed on Europa have may have been formed in this matter. In the highest resolution *Voyager* images of equatorial Ganymede there can be seen (at the limits of resolution) low-relief, crenulate scarps whose shapes may indicate a sublimation-degradation evolution. The improvement in resolution from *Venera 15/16* (~2 km/pixel) to *Magellan* (~150 m/pixel) was essential in the recognition and classification of exogenic degradation on Venus (Malin, 1992). With this as a guide, candidate regions on the icy Galilean satellites will be examined by *Galileo* at high (<250 m/pixel) resolution and low sun angle for expressions of sublimation degradation.

Our observations and inferences have led us to propose two end-member hypotheses or mechanisms. Case one is that of scarp retreat. Though clearly observed on Io and Triton as well, the best currently imaged examples occur in martian south polar terrains where craters above scarp brinks are destroyed as the scarp retreats through them, leaving no trace on the surface below the scarp foot . The second end-member is that of scarp-bounded enclosed depressions or pits, such as exhibited by the etched terrain of the martian south polar region. The formation of the pits are speculated to be the result of the decay of thick but laterally limited lenses of volatile. Scarp retreat, on the other hand, is thought to be do to the progressive undermining of a of cap rock (or a surficial "cap" lag) underlain by an areally extensive layer of volatile-rich material.

To address the validity of our hypotheses and evaluate candidate volatiles we employ a simple model of sublimation and diffusive loss to space, derived from Fick's Law. We invoke a scenario where well-mixed volatile and refractory materials are locally to regionally spewed out across the surfaces of Io and the other Galilean satellites by pyroclastic eruptions, resulting in fine-grained porous deposits. In porous deposits, buried volatiles will sublimate rapidly and maintain vapor equilibrium against loss. Diffusion then occurs through the overlying layer of porous material, transporting vapor from a volatile table (top of the volatile-rich zone) to the nearly vacuous atmosphere. We model this process for several candidate volatile species and a range of thermal conditions expected on the Galilean satellites. By calculating the corresponding timescales for the formation of characteristic geomorphic features and comparing these timescales with the range of surface ages, we then constrain which volatiles and conditions facilitate the formation of sublimation-degraded landforms.

Sublimation Degradation on the Galilean Satellites; Moore, J.M. *et al.*

The thermal conditions can vary significantly between satellites and geographically over each satellite's surface. Since diurnal variations in surface temperature dissipate within a meter of the surface, we generally ignored diurnal effects on the 1 to 100 meter scale of our interest and assume the surface temperature is the average diurnal temperature. A range of surface temperatures are appropriate depending on geographic location and satellite; we span this range by using 90, 110, and 130 K as representative temperatures. Lower temperatures are typical in the polar regions and this regime is represented by calculations at 90 K. The intermediate temperature 110 K is typical of the mid latitudes of the Galilean satellites, except for Europa, where equatorial temperatures are relatively low. The highest temperature 130 K is representative of the equatorial regions of the remaining bodies.

The geothermal gradient, which will drive the direction of diffusion, also depends heavily on which satellite is of interest, with Io being an extreme case. We examined values between 0.3 and 30 K/km to span the expected range. Callisto and Ganymede are considered relatively geothermally cold and lower gradients would apply, 0.3 K/km; however 5 K/km may apply during the early solar system. Europa and to a larger degree Io undergo tidal heating and higher gradients are anticipated. Except for extreme values we find the geothermal gradient to have only second order effects on the flux, compared to the effects of surface and subsurface temperatures and so we present results for the intermediate case of 3 K/km.

The flux of vapor lost by sublimation and diffusion can be calculated for a given burial depth, surface temperature, and geothermal gradient. To find the gradient in the vapor density we also assume the atmosphere contains negligible amounts of the volatile gas; the gradient then becomes just the vapor density at the point of sublimation divided by the depth. By subliming a specified mass of the volatile, estimated by the physical scale of geomorphic features, a timescale can be calculated and compared with the surface age (see Table 1).

Principle results of our modeling are that for these satellites, H_2S, CO_2, and NH_3 are the only viable candidate volatiles for sublimation-degradation of landforms, in light of Galilean satellite cosmochemistry. For Io, only H_2S, sublimating from polar region slopes that face the sun and have thin lags, is volatile enough to cause the observed erosion there. SO_2 is not a viable candidate on Io as an agent of erosion for these landforms. We predict that H_2S will be unambiguously detected on Io. In the case of Europa, only CO_2 and H_2S are viable candidates (given surface age constraints). Both species could be efficient eroders in non polar regions. H_2S could generate erosion within the polar regions if the deposition and erosion conditions were essentially identical as those we invoked for Io's polar regions. For Ganymede (and Callisto) NH_3 might be an agent of erosion in equatorial terrains of great age. The sublimation of CO_2 and H_2S is much more robust than NH_3. (However, bear in mind that it is unlikely that NH_3 and H_2S will co-exist on the same body.) The much slower rate of sublimation degradation from NH_3 might be detectable by *Galileo* and used as a compositional indicator.

Table 1. Approximate timescale for loss of 10^5 kg of volatiles (~100 m) mixed 50/50 with 100 meters of porous matrix (loss times in yrs). Note that shaded values indicate loses which exceed a geologically reasonable timescale to be observed on the Galilean satellites.

$T_{surface}$	H_2S	CO_2	NH_3	SO_2	H_2S_2	H_2O
90 K	3.15×10^9	5.42×10^{11}	6.22×10^{13}	1.24×10^{16}	2.43×10^{19}	4.28×10^{24}
110 K	2.66×10^7	1.19×10^8	3.61×10^{10}	1.57×10^{12}	1.81×10^{15}	2.69×10^{19}
130 K	9.90×10^5	1.57×10^6	2.10×10^8	3.17×10^9	2.53×10^{12}	6.41×10^{15}