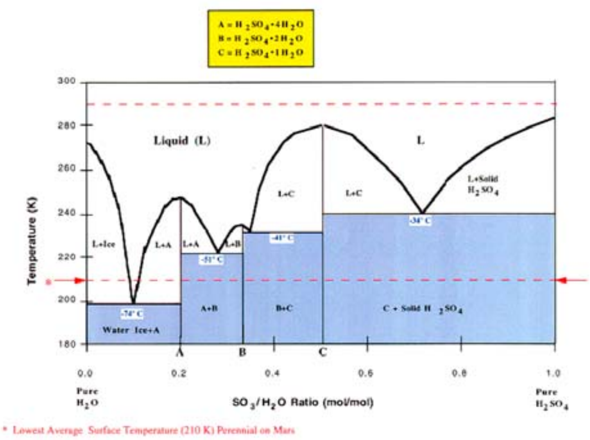
ACID SNOWBANK AS SOURCE, SINK AND ABODE. Benton C. Clark, Lockheed Martin, Space Exploration Systems, POB 179, Denver, CO 80201. benton.c.clark@LMCO.com

Introduction: Persistent deposits of water ice may exist at the surface, even in certain non-polar regions on Mars. Their origins can include: atmospheric precipitation (snow); surface adsorption; clathrate formation; upward percolation of H2O vapor or wicking of liquid created by subsurface heat sources; or deflation of overburden to expose buried ice or ice-rich permafrost (for purposes of expediency, such surface-exposed deposits will be referred to in this paper as "snowbanks", regardless of the source or mechanism of transport of H2O to the surface). Many of the characteristics discussed here are relevant to any exposed body of ice. Such deposits may have unique roles as a source of H2O, a sink of chemically active gases injected into the atmosphere, and through various favorable factors, providing a haven for growth and reproduction of biological organisms on Mars which would, on Earth, be considered extremeophiles.

Snowbank Interactions with the Atmosphere: Long-term survivabity of ice against sublimation is abetted by location on anti-solar slopes and/or covering by high albedo, low thermal inertia material. Location in a natural shaded cavity is a mechanism often observed in rugged mountainous terrain on Earth for the preservation of snow deposits well into summertime. Deposits can even summer-over, depending on shadowing, local weather, and climatological conditions. Winds and dust loads in the atmosphere provide varying inputs of new material, warm or moist atmosphere, shielding of solar insolation, and erosive forces.

The high degree of eolian activity on Mars maintains a source of atmospheric dust fallout, which coats the surface ice and may, especially if saltation is active at that site, admix with it to some depth, depending on the degree of snowbank porosity. Albedo is lowered, so that heat transfer from solar insolation is amplified, but a surface debris mantle, not unlike that hypothesized for the inactive portions of cometary surfaces, can develop and evolve. These concentrations of water ice can be in communication with the atmosphere to an extent that many other reservoirs, deep underground or at polar locations, are not.

Acidification of the Martian Snowbank: Gases in the martian atmosphere which are chemically reactive with H2O will be taken up and sequestered from their source. Such gases arise from all magmatic exhalations, whether explicit extrusive releases or seepage through vents, fumeroles, or sulfataras. Typical releases include the sulfur and chlorine-containing gases as well as water, and less reactive gases such as CO2 and CH4. Impacts by large bolides will also cause the release of S from the relatively S-rich igneous rocks (based on martian meteorites). Reduced compounds, such as H2S, S, SO, SO2, and CH4 will be quickly converted into their high oxidation state analogs by the plethora of oxidative species (atomic oxygen, OH radical, H2O2, superoxide ion, ozone) that reside in the martian atmosphere as a result of the intense UV-mediated photochemical environment. As a result, SO3 will be readily available from these transient events to combine with the H2O ice. These two molecules have an extremely high affinity for reacting together, and once they do the resulting solution is both hygroscopic and reactive with SO3.



Consequences of the Acidic Snowbank: Liquefaction and Geological Processes: As seen in the accompanying phase diagram, several eutectics are formed, each with freezing points which are depressed relative to pure water or, for that matter, sulfuric acid "neat" (pure). These freezing points range from –34 to –74 ºC, well below the depressing capabilities of most salts and below peak and average temperatures, respectively, in non-polar regions on Mars (polar temperatures of –125 ºC cause freeze-up, slowing the process to one limited by solid-state diffusion). The first eutectic, which has the strongest depressant effect, requires only 1 molecule of SO3 per 10 molecules of H2O, and hence will form in the earliest stages of conversion of native ice to acidic ice. Liquefaction is therefore physically possible, without even accounting for supercooling effects. The proportion of material which becomes liquid may be small since transformation to the solid phase can alter the composition of the residual liquor. Physical affects on the macroscale can vary from solid plasticity to slush to free liquid, depending on the exact chemical makeup and bulk temperature. Macro-movement is inevitable in response to gravitational forces, resulting in regimes encompassing sliding, creep and free flow. A premier example of intense current interest is the side-wall gullies found on crater walls at high latitudes. Many other less obvious manifestations should occur, however, from sapping to analogs of glacial activity.

Abode for Extremeophiles: On the microscale, liquefactions enable all the special benefits that render liquid H2O so beneficial to life forms on Earth (mobility for transport of nutrients and waste products, consumption as a chemical reactant; stabilization of macromolecular tertiary structure; as a diluent; as a catalyst; as a medium for organism motility). From the standpoint of microorganisms, this is perhaps the single most critical prerequisite to their ability to function metabolically. The acidic snowbank therefore provides an abode for these organisms which can survive the low pH of the environment. Acid-compatible extremeophiles are abundant on Earth, and encompass a variety of detailed lifestyles. However, the acidic habitats on our planet are almost always at high temperatures, the hydrothermal and sulfateric environments associated with magmatic centers of activity. Such environments are possible on Mars as well, but the overall aridity and very low pressure of the atmosphere mitigate against the longevity of hydrothermal regions, unless buried and isolated from communion with the surface.

Acidophiles on earth often are hyperthermophilic. Any putative martian organism in this environment must, rather, be a psychrophile as well as acidophile, and able to function at stressingly low levels of water activity, hence an osmophile. On the other hand, such organisms need not be as xerophilic (desiccation-loving) like their non-ice dwelling cousins in the surface regolith of Mars.

Energy metabolism may take advantage of a number of possibilities. Sunlight can penetrate ice and even "dirty" ice, which attenuates the lethal, short wave-length UV that penetrates the thin atmosphere to reach the surface of Mars. Hence, phototrophs may exist within this ecoenvironment. A number of chemolithotrophs are acidophiles, but their typical energy source is from the oxidation of reduced iron or sulfur compounds. It has been proposed that H2 is almost sufficiently abundant in the martian atmosphere to support sulfate reduction. The source of such sulfate could that thought to be in the ubiquitous soil, and the resulting sulfide could be recycled in a sufuretum ecology to produce sulfate again.

Nutrient availability is enhanced in many respects. Low pH solubilizes many ions, especially the metal cations (e.g., transition elements) that enable enzymes to have high specificity and catalytic kinetic effect. It is also now known that the shergottite martian meteorites can be extracted with acidic solution to yield abundant phosphate and other nutrients.

Persistence and Lifetime: Once acidified to even just a low degree, the equilibrium partial pressure of H2O is reduced over the H2O-H2SO4 solution. Thus, the acid snowbank can effectively "pump" H2O from a non-saturated atmosphere to not only prevent sublimation losses but to even grow. During neutral-atmosphere periods when the content of chemically active gases is extremely low, as in the present epoch, the compositional shift of the snowbank will be toward further dilution of the acidic mix. After a major meteoroidal impact or magmatic release of gases, SO3 uptake may dominate over H2O uptake, and the pH will drop as the snowbank evolves toward the H2SO4 end-member. Once SO3 is reduced sufficiently towards final depletion, the H2O uptake will again predominate. The stasis point for the acidified ice will depend, of course, on availability of these gases as well as the physical nature of the body – whether is is highly porous and equilibrated throughout, or exhibits rinds and layers reflecting "seasonal" effects.

Non-ice areas of martian regolith may also take up SO3 or any H2SO4 formed in the atmosphere, and react with it. Igneous minerals, and especially their glassy counterparts, are typically rich in cations (Ca, Mg, Na, Fe, even Al) which can react to form sulfites and sulfates. These tend to irreversibly bind up the S-containing molecules and remove them from the recyclable inventory. However, under desiccated, cold martian conditions, the reaction rates of these active molecules with minerals are suppressed, yet they will react rapidly with the snowbank ice. Thus, these objects serve as highly efficient sinks for the reactive gases. The apparently universal martian fines, which include the soils and dust grains, are very rich in S, most probably in the sulfate form, that their intrinsic reactivity may have already been used up, rendering them relatively inert with respect to the reactive gases injected into the atmosphere. Thus the snowbank ice and dust serves the purpose of isolating ice from the igneous minerals which would otherwise serve as an irreversible loss mechanism for the reactive forms.

Exploration of Martian Snowbanks: If this thesis has merit, then acid snowbanks should be a high priority for astrobiological exploration. It extends "follow the water" to "find the liquid water and bioavailable nutrients." A major problem here is that the known gully topographies are extremely steep for safe spacecraft landing and operations, most likely aggravated by poor bearing strength of associated soils. It is not known how many gully systems actually arise from snowbank sources of liquid, but recent tantalizing evidence could be taken as a clue that it may be common.

How can acidic ice deposits on more accessible terrain be detected? There could be morphological clues, since snowbank or ice forms can evidence rounding and globular appearance. General examples are known, such as the gently ridged and featureless material in Newton crater. Acidity cannot be detected by remote sensing, and we still do not have substantive evidence of the pH of martian soil. Small hard lander or penetrator probes could easily make the required measurement, with a low cost instrument and in a matter of minutes or hours. However, the cost of the probe itself is, today, substantial, especially if targeting is required for what generally are small opjects on the scale of landing errors. Highly mobile landers, such as hoppers, might be a more cost-effective solution for reconnaissance to explore several identified targets within a general region of interest.

Conclusion: Deposits of snow or any other forms and origins of ice at the surface of Mars at moderate to low latitudes could be important as an abode for extremeophiles because their interaction with reactive atmospheric gases could result in acidic state with greatly suppressed freezing point. The resultant liquidity is favorable to life processes, as well as certain geological processes. Detection and exploration of such features will be challenging.