MARTIAN GULLIES AND SALTY SIDEWALKS. D. M. Burt[1], L. P. Knauth[2], AND K. H. Wohletz[3] [1]School of Earth and Space Exploration, Arizona State Univ., Box 871404, Tempe, AZ 85287-1404, dmburt@asu.edu, [2]School of Earth and Space Exploration, Arizona State Univ., Box 871404, Tempe, AZ 85287-1404, knauth@asu.edu, [3]Los Alamos National Laboratory, Los Alamos, NM 87545, wohletz@lanl.gov.

Introduction: Martian orbital imaging provides strong evidence for active impact cratering and active fluid flow in gullies [1,2]. Impact cratering and gully flow might appear to be unrelated. We describe a model that relates them, if cratering has excavated chloride salts (directly, or via flash-evaporation of brine or condensation of salt vapor) from beneath ground ice [3]. Tossing salts on ice could cause some ice to melt. Because martian ground ice, except at the poles, lies beneath the surface, slow brine drip caused by frost condensation on excavated salts is inferred (a circum-polar moisture trap). The analogy “snowing on a salty sidewalk can cause melting” illustrates the basic principle. This hypothesis is an earlier melting idea [4] inverted (flipped over) by impact cratering.

Previous investigators [5] have noted that chloride brines, but not sulfate brines (whose freezing point depression is less than 5 C), remain liquid at temperatures over 50 C colder than otherwise (i.e., at temperatures approximating the mean Martian surface temperature of 220 K). However, sulfates, not chlorides, appear to dominate the Martian surface. Our chloride leaching hypothesis accounts for this observation, without invoking sulfuric acid as antifreeze, because acid in contact with basaltic regolith should be unstable [6].

Young Gully Formation: The recent gullies occur in both hemispheres of Mars, at mainly intermediate and some polar latitudes, and (in any given area) commonly concentrated on slopes facing in the same direction [e.g., 1]. Most occur in the walls of old impact craters (an obvious connection to impacts) although they also occur in other slopes. Commonly many gullies originate in the same horizon, generally at a slight break in slope, with the more resistant, blocky layer above having collapsed, forming alcoves. The quantity of aqueous fluid (if any) involved in gully formation appears to have been relatively small, because gullies die out in a distributary debris apron.

Many explanations have been offered for the gullies [7], ranging from ground water (from a shallow or deep aquifer), probably breaking through an ice plug, to surficial snow or ice melting from beneath a cover of dust, to brine melting along an ice-salt interface [4], to explosive CO_2 escape, to wet or dry debris flows [8], and probably others. The latitudinal and directional restriction suggests tight climate constraints (not too hot and not too cold). The variable orbital tilt of Mars and consequent sun angle and climate variability feature in some hypotheses. The extremely low atmospheric pressures and cold temperatures on Mars are problems for any model involving unstable liquid water. Geothermal heating of subsurface aquifers and local solar heating of dark surfaces could warm temperatures, however. Low pressure can be alleviated by dissolving soluble salts [3], which lowers vapor pressures and freezing temperatures, stabilizing liquid water with regard to both freezing and boiling. Also, a flowing mass of even unstable pure liquid water might form a gully before it boiled and froze (then sublimed).

Possible Salt Residues. The very light tone of present-day gully residues [1] suggests surface salts remaining after brine evaporation. (Light-toned dust or mud is another explanation [1,2].) Surface frost is presumably not the cause, because the features have persisted over months or years [1,2]. The lack of light-toned residues on most older gullies suggests that the salt coating (or other cause) is temporary, and has gradually disappeared or become hidden by dust. Many salts absorb enough moisture from the atmosphere to become sticky and attract dust. Deliquescent salts such as $CaCl_2$ can absorb sufficient moisture to liquify and drip into the subsurface. Frost deposited on a variety of salts could melt to brine, yielding the same result. By the same process on a larger scale, according to our model, impact-excavated salts in the circum-polar region could cold-trap moisture or frost that then drips into the subsurface as brine, much as the poles themselves cold-trap ice. Slow brine drip provides a possible source for the small quantities of ground water that presumably formed recent gullies [1,7], and explains their bright, temporary residue. The lack of hydrated sulfate salts detected via near-IR spectra [2] of these deposits does not rule out chloride salts. Sulfate salts would not be expected owing to their extremely poor freezing point depression [5].

Primary Layering and Impact Excavation: If an ancient Martian hydrosphere froze, then ice, brine, and salts should have become segregated by density in the regolith, in that order [3]. Sulfates, being less soluble and far less able to depress freezing points than chlorides [5], would crystallize early. Continued freezing (fractional crystallization), especially near the poles, plus ion exchange of Na-rich brines with the Ca-rich basaltic regolith, would drive brines to compositions rich in salts exhibiting the most freezing-point depression (mainly $CaCl_2$) [3]. If brines finally froze completely (at temperatures probably below -55 C), the interface between upper ice and lower salt would be enriched in $CaCl_2$ plus trace components such as Br, Li, and Zn. Ice sublimation would make the permafrost layer near the equator deeper and thinner. Lateral brine escape, local magmatic heating, or impact excavation could have perturbed this pattern in many areas [4]. Impact excavation of salts is of major interest, because Mars (in common with the Moon and Earth) appears to have been largely resurfaced by impacts about 3.8 billion years ago (when Mars finished losing most of its atmosphere and the surface freeze-dried to close to its present state), and impacting continues today.

Eutectic Melting and Salt Leaching: If salt grains are thrown on ice, ice will melt, unless the temperature lies below the eutectic temperature (the lowest possible melting temperature for a given mixture – always lower for a complex salt mixture than for individual salts). Ignoring waters of hydration, the salt-ice eutectic temperature for NaCl salt is about -21 C, for $CaCl_2$ salt, about -50 C; and for a NaCl-$CaCl_2$ mix, -52 C (with little pressure effect, because all phases are condensed). Obviously, multi-salt eutectic melting is dominated by the salt exhibiting the most freezing point depression ($CaCl_2$). Other common salts behave like NaCl (i.e., they play a secondary role), inasmuch as they likewise exhibit much less freezing point depression than $CaCl_2$ (although at -34 C, $MgCl_2$ comes close, and its eutectic with $CaCl_2$ is -55 C).

On ancient Mars, impacts probably excavated and distributed a wide variety of salts across the surface, but ground ice, even in the past, may have been too deeply buried to react directly with those salts, at least away from the poles. Therefore, the only means of getting those salts back underground, once the ejecta had cooled, would have been to expose the surface salts to frost or snow, including frost arising from deep permafrost sublimation (i.e., from below). On dry, cold Mars, such frost leaching, whether from above or below, would be slow, especially in equatorial regions. On exposure to frost, impact-excavated chlorides (especially $CaCl_2$) should leach first, owing to their greater solubility and much greater freezing point depression compared to sulfates. Selective leaching of impact-excavated chlorides provides one explanation for why the present-day Martian surface is apparently enriched in sulfates vs. chlorides, and for crystal-shaped cavities imaged by the Opportunity rover [9]. Also, measured high Br/Cl ratios might indicate fractional crystallization of chlorides during brine freezing prior to their excavation and leaching [9]. Selective leaching may also explain why active gullies are now a rare, limited feature (few appropriate chloride salts remain near the surface in most places), and contribute to why they are absent from equatorial regions (insufficient surface frost, plus too deep a permafrost layer). Local chloride deposits, as recently inferred [10], might therefore persist in equatorial regions, especially if they were Na-rich. By this hypothesis, an impact that excavated many chlorides could temporarily rejuvenate gully formation, at least in the right climate zone, with wind transport extending the effect. Sporadic impact excavation of chlorides (or gradual climate change) would assist in maintaining at least some gully flow.

Impact Inversion of Layering: Climate constraints are possibly thus explained, but not the tendency of many gullies to originate at about the same horizon. An impermeable layer is required, such as a lava flow or a layer rendered impermeable by, e.g., ice cement. In this regard, impact cratering should invert primary layering by ejecting deep salts on top of impermeable permafrost, thereby possibly provoking future gully formation along that impermeable horizon in the walls of the crater. Also, salts should provide a more durable rock cement than subliming ice, thereby possibly explaining why many gullies emerge from collapsing alcoves. Add positive feedback for eutectic overshoot in heterogeneous mixtures (autocatalysis of melting once some brine has actually formed), or time for the brine to get salty enough to melt its way through an ice plug, and the apparently infrequent and episodic nature of brine release to young gullies might be explained. Finally, any large accumulation of eutectic brine puddled on permafrost away from a slope should melt straight down (while freezing on top), and thus disappear in place – a possible explanation for why only relatively small amounts of fluid, near slopes, appear to be involved in gully formation.

Similar eutectic phenomena may have contributed to other aqueous flow phenomena on Mars, including outwash channels and drainage networks. Dissolved chloride salts thus permit an ancient martian climate as cold as (but probably wetter than) today's.

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