A MECHANISM FOR RECENT PRODUCTION OF LIQUID WATER ON MARS.

M. H. Hecht[1] and N. T. Bridges[2], [1]Jet Propulsion Laboratory, 4800 Oak Grove Dr., Pasadena, CA 91109 (michael.h.hecht@jpl.nasa.gov), [2]Jet Propulsion Laboratory, 4800 Oak Grove Dr., Pasadena, CA 91109 (nathan.t.bridges@jpl.nasa.gov),

Introduction: Though Mars is a cold, dry planet, with respect to the thermal stability of liquid water at low altitudes it is not terribly different from comparably cold places on Earth [1]. In dry air such water would evaporate faster on Mars, at a rate comparable to a 60°C hot spring on Earth, but the heat loss associated with that evaporation would be mitigated by the poor thermal convection in the thin Martian air. Even at higher altitudes where the atmospheric pressure does not reach the triple point of water, liquid water might theoretically exist in a low-vapor pressure form such as wet soil, in a briny solution, or simply under a layer of dust or snow [2,3].

The theoretical stability of liquid water does not suggest its occurrence, either on Mars or in Antarctica. In fact, global models have suggested that locations capable of providing sufficient heat for melting are, precisely for that reason, too dry for water to be present [4-6]. However, the temperature of irregular local structures such as trenches or craters can be markedly warmer than those of the uniform surfaces of global models [7-11]. The work described here suggests a plausible scenario in which seasonal liquid water might be produced locally, in sheltered locations, through a process of condensation, cold-trapping, buffering, and melting. While the amounts produced in the present climate would be small, copious amounts of meltwater may have been produced at other phases of the orbital cycle, as recently as 20,000 years ago.

Condensation: The seasonal variation in atmospheric water vapor on Mars results in seasonal frost deposits (or regolith adsorption) equivalent to 10-100μm of ice, depending on latitude [12]. This water exchanges diurnally with the atmosphere in a broad latitude band below the edge of the seasonal polar cap. Fanale et al. [13], noting the small latitudinal variation in atmospheric water vapor, argued that global humidity is determined by the saturation vapor pressure at the North Pole, which is in turn determined by the polar surface temperature. This arguable assumption leads to the conclusion (figure 1) that humidity may have been two orders of magnitude greater in other orbital configurations. Seasonal deposits may thus have been as large as 1 g/cm^2 in some locations as recently as 20,000 years ago, when perihelion approached the northern summer solstice.

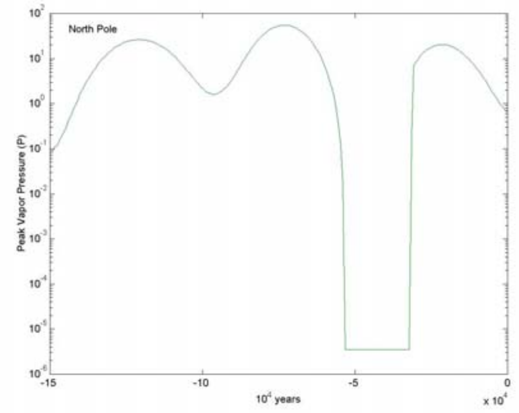

Figure 1: Calculated saturation vapor pressure at the North Pole over 150,000 years as determined from surface temperature. Calculation balances radiation, latent heat, and insolation using orbital parameters from Ward [14], albedo and emissivity values suggested by Fanale et al [13]. Residual CO_2 frost coverage is carried over from year to year.

Coldtrapping: Coldtrapping was suggested by Svitek and Murray [7] as an explanation for the redistribution of frost seen at the Viking Lander 2 site. They concluded that the uniform 10-20 μm thick frost layer was converted to frost patches, 100-200 μm thick, covering the most sheltered 10% of the surface. It was proposed that water sublimed from sun-exposed surfaces and recondensed into local cold traps, the shaded regions behind rocks. According to their model, up to 100:1 concentration is possible by this mechanism in a single day. In terrain featuring severe slopes and gullies, it is thus conceivable that frost deposits exceeding 100 g/cm^2 may have accumulated in sheltered geometries in recent epochs. Experience with coldtrapping in vacuum chambers [16] suggests that such a deposit would be of extremely low density, and could thus correspond to many meters of frost.

Buffering: Actual melting of a frost layer on Mars requires a sudden change of temperature to avoid complete sublimation during slow warming. Such a rapid change is naturally brought about by thermal buffering by condensed CO_2 deposits, which maintain the surface at ~148K and effectively suppresses sublimation of water ice. Recently, Bridges [10] identified springtime dark spots confined to gully channels in the southern hemisphere, the first reported documented seasonal changes (figure 2). The spots are absent later in the spring after complete defrosting, revealing a dark substrate, indicating that the spots were associated with defrosting of CO_2. Compilation of the location and time of observation of the defrosting spots (figure 3) allows determination of the time when the CO_2 buffer disappears. For the region south of –60° latitude, this occurs very close to L_s=270 — precisely when the insolation is at a maximum at the gully locations.

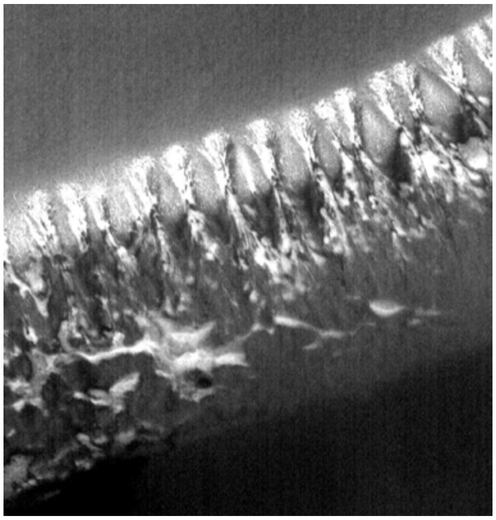

Figure 2. Defrosting gullies. MOC image M0906352 at Ls=253. Credit NASA/Malin Space Science System

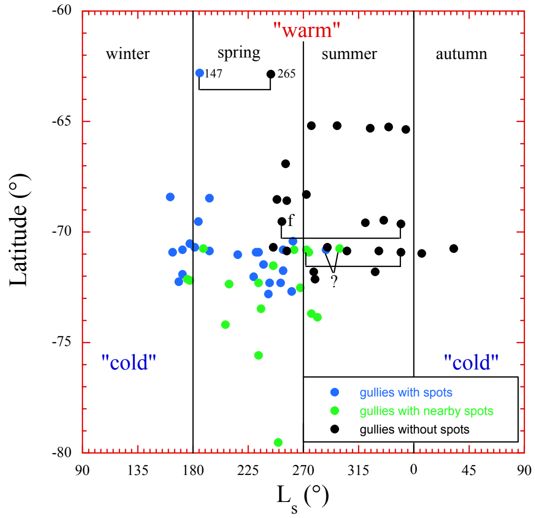

Figure 3: Distribution of gullies below –60° latitude from MOC images. Colored spots indicate gullies in the process of "defrosting," black spots are already defrosted. The transition occurs abruptly around L_s=270 when the sun is highest in the sky at all azimuths.

Melting: Melting in thick, dusty frost layers was first described by Clow [2]. Hecht [1] recently argued that ice in any form would melt in sheltered geometeries, such as Martian gullies, when slopes cause incident sunlight to impinge at near-normal incidence. The favorable thermal balance is largely due to the suppression of radiative cooling by the gully geometry. Other factors were identified that could accelerate the process, such as atmospheric saturation that would suppress evaporative cooling. Ice would melt at a rate of approximately 0.1 g/cm^2 per hour for every 100 W/m^2 excess insolation above that required to reach the melting point.

Conclusions: Seasonal liquid water could be formed in gullies and other sheltered locations by a process of condensation, concentration, buffering, and melting. In the present epoch such deposits are unlikely to reach 1 g/cm^2 in thickness or to produce more than a trickle of water. As little as 20,000 years ago, in a more favorable orbital geometry, the process may have been much more vigorous. Seasonal water would explain the uniformly youthful appearance of martian gullies and possibly their actual formation. Moreover, seasonal recurrence of wet soil would fundamentally change our expectations in our search for extant microbial life on Mars.

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