AN OPEN, SNOW-BASED HYDROLOGIC SYSTEM AS ON NOACHIAN MARS.

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Properties of Noachian valley networks on Mars suggest that the conditions under which they formed were marginal for liquid water formation. The networks are sparsely scattered, poorly dissected, and tend to be small; a majority occupy areas only a few hundred km in extent. Models in which networks formed by mass wasting are contra-indicated by the discovery of channels within the valleys (Malin et al., 1998). Greenhouse hypotheses for the stability of liquid water have foundered on familiar problems: first, a very substantial CO_2 atmosphere would be required to bring global average conditions to 273K; the CO_2 should still be present in extensive carbonate deposits that have not been detected. Explanations that call upon groundwater sapping are hampered by the need for a hydrologic system to recharge the groundwater system, which effectively reinstates the need for a heavy CO_2 atmosphere (Goldspiel and Squyres, 1991).

Based upon field experience and geomorphic similarities between drainage developed in the periglacial terrain in and around the Haughton impact structure, Devon Island, Nuunavuut, Canada, we have suggested that some of the channel networks may have formed either subglacially, or as ice marginal structures (Lee et al., 1999). Channels similar to some martian features cut the fallback breccia at Devon because the total degree-days above freezing are adequate to generate melt. Water is supplied as snow, derived from the terrestrial hydrologic system, and is available because Earth's global average temperature is > 273 K.

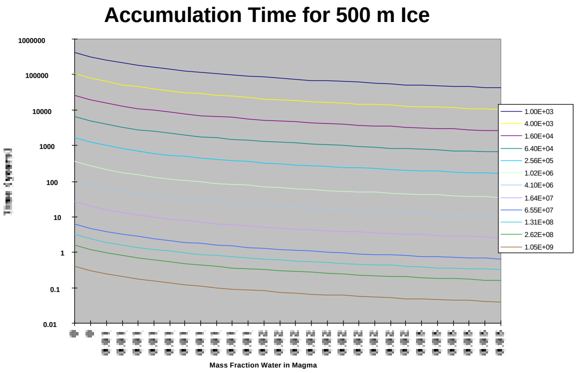
There is a series of similar issues to be resolved in developing a model for valley network formation. 1) How were the water molecules supplied to the surface? 2) Where did the energy to heat the water come from? 3) How was evaporation suppressed sufficiently to allow flow for hundreds of kilometers?

How was the water supplied? We remove the requirement for warm global conditions in our model by supplying H_2O to the atmosphere via outgassing, primarily during vent or fissure eruptions. The disappearance of channels early in martian history has suggested to many workers that high heat flow played a role in channel formation. Tanaka et al. (1999) report that valleys tend to originate (1) on Noachian to Early Hesperian large volcanoes, (2) within 50-100 km of stages 1 and 2 rift systems, and (3) within 100 km of Noachian impact craters >50 km in diameter. The primary variables in the supply equation are the eruption rate and the mass fraction of H_2O in the magma. We estimate the ability of a volcanic source to supply the mass of H_2O required to erode the networks measured in the Margaritifer region (Goldspiel and Squyres, 1991). The area drained by the system is on the order of 8×10^4 km^2. The time to erupt the required mass is shown in Figure 1 as a function of eruption rate and mass fraction of H_2O in the magma. Reasonable eruption rates for fissure systems are on the order of 10^7 10^9 kg s^{-1}. In light of the discovery of magnetic striping in the ancient martian crust, (Connery et al., 1999) some version of plate tectonics has been hypothesized; we are probably justified in assuming relatively high eruption rates. Reasonable mass fractions of H_2O are on the order of 1%, suggesting eruption durations considerably less than 1 year are required to provide the necessary H_2O (Wilson and Head, 1981).

The water is vented into an extremely cold atmosphere, and substantial condensate deposits are the inevitable outcome. Although condensation will certainly occur in the convecting plume, sedimentation will probably be dominated by fallout from the umbrella cloud, which forms at the neutral bulk density altitude (Sparks et al., 1991).

Where did the thermal energy come from? Melting can procede either subareally, or subglacially.

The conditions under which both subglacial melting and retarded evaporation are possible are contingent upon a moderate CO_2 greenhouse, possibly strengthened by high sulphur content in the magma. Global average temperatures need not be substantially higher that at present to achieve 273 K in temporally and spatially sparse locations. Globally averaged temperatures on the order of 235 K can be achieved, even at 0.8 Solar luminosity, with a 2 bar CO_2 at-

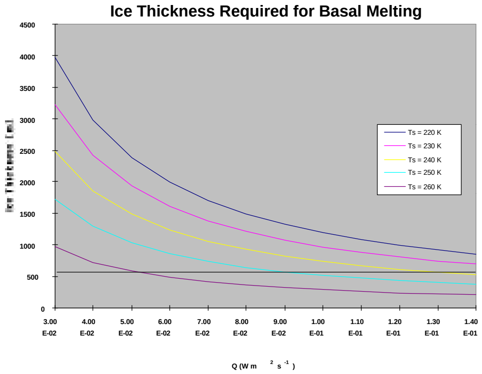


mosphere (Haberle, 1998; Kasting, 1991).

The thickness of ice required for basal melting can be found from

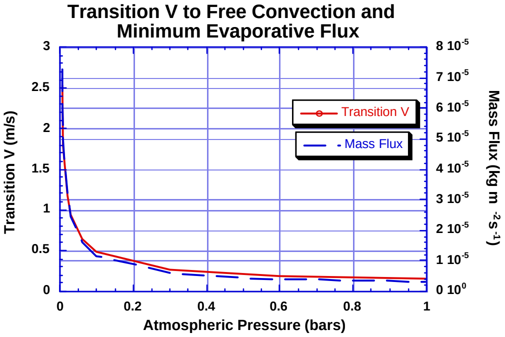
$$Z = K \frac{T_m - T_s}{Q}$$

where T_s is the surface average temperature, K is the thermal conductivity of ice, and Q is the heat flow. Figure 2 shows that if regional average temperatures are 250 K, 500 m of ice will produce basal melting for heat flows on the order of 100 mW m^{-2} s^{-1}, a value not unreasonable for early Mars.



Melting at the surface is also energetically likely. McKay and Davis (1991) show that if mean temperatures are 230 K, there are still 40 degree-days above freezing.

How was evaporation suppressed? Evaporation rates from a liquid H_2O surface must be such that melt could travel hundreds of km before evaporating. Evaporation rates for both free convection and wind-driven conditions were calculated by Clow and Haberle (1991).. Evaporation in a free convection regime is minimized, because only diffusion and buoyancy drive the removal of H_2O molecules from the interfacial sublayer. In Figure 3, the transition velocity from free to forced convection, and associated minimum evaporative flux are plotted as a function of atmospheric pressure, subject to the important assumption that the air is completely dry when it encounters the liquid. At moderate pressures, (0.8 bar) the transition velocity is ~0.3 m/s, and the associated mass flux is ~10^{-6} kg m^{-2} s^{-1}. Evaporation rates on the order of 10^{-5} to 10^{-6} kg m^2 s^{-1} suggest a stream with 2 $m^3 s^{-1}$ discharge, flowing 1 m s^{-1} could persist for hundreds of days and cover distances greater than any valley reach. The critical wind velocity to maintain free convection is so low that the assumption of a dry atmosphere must be abandoned. The evaporation rate can be significantly depressed by partially saturating the atmosphere, due to an extended fetch over ice or snow fields.



Observational Tests: The model above makes predictions which can be tested observationally. An association between channels and vents should be demonstrable (c.f. Tanaka et al., 1999). A search for buried vents, such as those associated with magnetic striping in the ancient highlands would increase the statisitical validity of the correlation. The depth and diameter of channels within valley networks as a function of distance down the valley reach could be used to test whether liquid H_2O was lost to the system as it flowed. Conversely, the channels may merge and grow, as would be required if all feeder streams were simultaneously active, and water were not evaporating rapidly.

Summary: The sparseness of Noachian drainage suggest that conditions were just at or below the threshold for valley formation through early Mars history. Melting associated with volcanically-derived surface ice, and retarded evaporation, both facilitated by CO_2 pressures too low to raise global average temperatures to 273K, are a possible explanation for the valley formation. This hypothesis is suggested by drainage at the Haughton crater, where annual average temperatures are on the order of 255 K, yet abundant fluvial erosion takes place, almost entirely during the warmest few weeks of the year. Similar erosion might have occurred on Mars at the warmest, highest pressure conditions, only sporadically achieved.

References

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