STABILITY OF WATER AND GULLY FORMATION ON MARS. Derek Sears[1,2], Larry Roe[1,3], and Shauntae Moore[1,2]. [1]W. M. Keck Laboratory for Space Simulation, Arkansas Center for Space and Planetary Sciences, University of Arkansas, Fayetteville, AR 72701, [2]Department of Chemistry and Biochemistry, University of Arkansas, Fayetteville, AR 72701, [3]Department of Mechanical Engineering, University of Arkansas, Fayetteville, AR 72701.

Introduction: The water-carved gully features discovered by Malin and Edgett [1] in the Mars Global Surveyor images indicate that water has flowed onto the surface of Mars in recent times (Fig. 1). This is despite a thirty–year–old notion that water would evaporate immediately as it became exposed on the surface [2]. This has led to an interest in the evaporation rate of water of Mars [3-9].

Fig. 1. Fourteen gully features in the south-facing walls of Nirgal Vallis (29.7°S, 38.6°W) on Mars in a region ~2.3 km wide by ~2.8 km long imaged by the Mars Global Surveyor. The gullies have deposited a fine–grained apron of sediment onto dune fields at the bottom of the valley.

Experimental estimates of evaporation rate on Mars: Kuznetz and Gan [8] published four measurements between 5 and ~ 50 Torr and the data extrapolate to 0.25 ± 0.05 mm/h at 7 mb, (keep units consistent, you use torr and mb) however their data showed a much weaker dependency on pressure than theory or Hecht's data suggested. Hecht [9] published three sets of measurements at pressures of ~8 Torr to atmospheric pressure. We plotted a regression line through his data and extrapolated to 7 mb and found an evaporation rate of 1.9±1.0 mm/h. We measured evaporation rates at 7 mb under conditions much closer to martian than previous work and eight determinations yielded a value of 1.04 ± 0.14 mm/h [7].

Theoretical estimates of evaporation rate on Mars: There is no completely satisfactory theory for the evaporation of water into an atmosphere, and there is a large literature of papers attempting to develop empirical relationships for the evaporation of water on Earth [10]. However, a widely cited expression based on Fick's Law, an analogy with better understood processes, is:

$$E = 0.15\, D\, [(C_{surf} - C_{\infty})/x]\, Gr_f^{1/3}\, Pr_f^{1/3}\, Le^{1/3} \quad (1)$$

where D is diffusion coefficient for gaseous water molecules diffusing into gaseous CO_2, C_{surf} and C_{∞} are water vapor concentrations of water at and away from the surface, x is a characteristic length for the process, and Gr_f, Pr_f and Le are dimensionless parameters that describe the relative movement of mass and heat. The critical term is the Grashof number, Gr_f, which is effectively the ratio of buoyancy to viscosity forces. This expression assumes quiescent conditions in which evaporation is driven mostly by the buoyancy of water in CO_2. This relationship predicts an evaporation rate for water on Mars of 2.56 mm/h at 0 °C and 7 mb. While there are clearly improvements to be made in the experimental measurements, and theory is far from perfect, the agreement is sufficient for us to feel confident to apply it to problems less amenable to laboratory investigation.

Theoretical estimates of evaporation rate on Mars under advective conditions: Under conditions of advection, or forced convection, the physical removal of water vapor as it is formed, this expression becomes:

$$E = 0.664\, D\, [(C_{surf} - C_{\infty})/x]\, Re_f^{1/2}\, Pr_f^{1/3}\, Le^{1/3} \quad (2)$$

where Gr_f is replaced by the Reynold's number, Re_f, effectively the ratio of inertial force (a function of velocity) to viscous force. Essentially we are assuming that the water vapor is removed by a steady stream of atmosphere moving over the surface. Solved as a function of wind velocity, this relation yields Fig. 2. Also consistent with laboratory experiments, this relationship demonstrates the crucial importance of the physical removal of the water vapor by, for instance, winds, in determining the stability of liquid water on Mars. Other forms of advection on Mars are possible, such as local cold spots like areas of shadow that would act as cold fingers.

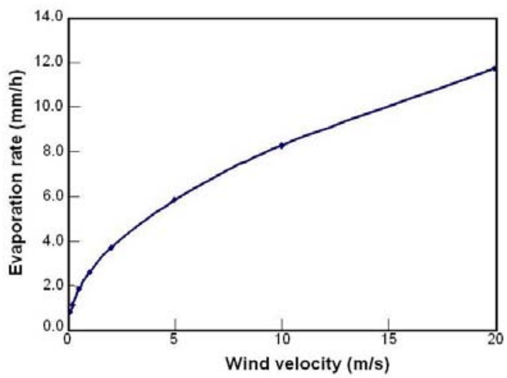

Fig. 2. Evaporation rate for water on Mars as a function of wind velocity obtained by solving expression (2). Typical wind speeds on Mars are 0-10 m/s with occasional excursions to 15 m/s.

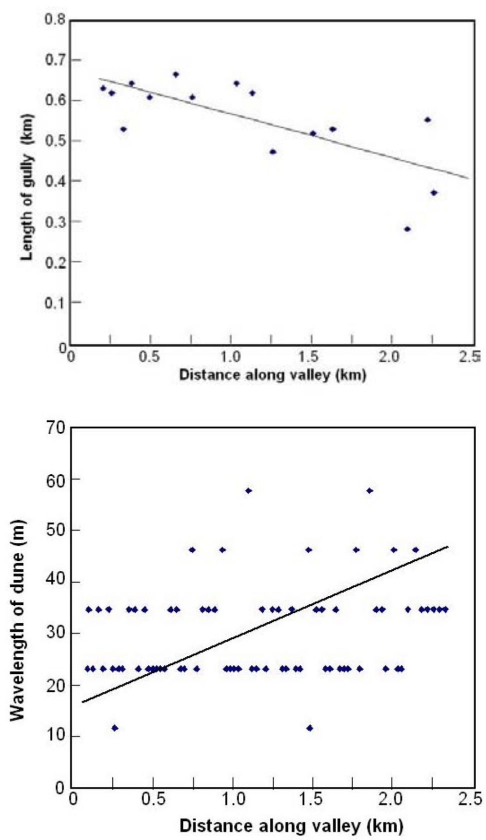

Fig. 3. The length of the gullies and the wavelengths of the dunes in Fig. 1 as a function of distance from the right side of the image. Although the precision of the dune measurements is barely adequate for this analysis, there is a suggestion that gully length decreases and dune wavelength increases with distance along the valley, suggesting that the gully length is determined by wind speed and therefore evaporation rate.

Elsewhere we have suggested that the presence or absence of wind is the dominant factor in determining the stability of water on Mars and argued that this explains the observed distribution of gullies [7].

Implications for gully shapes: Here we argue that these ideas – if correct – have implications for the shapes of gullies that will add to our understanding of the stability of water on present-day Mars and its likely distribution.

There are fourteen gullies in Fig. 1, with a frequency that appears to decrease from right to left (east to west) in the image. There is also a clear trend in Fig. 1 for gully lengths to increase as one goes from right to left in the image and this can be readily quantified (Fig. 3). At most wind velocities, the wavelength of dunes is related to wind speed and we attempted to measure wavelength of the dunes as a function of distance and plotted the data in Fig. 3. Unfortunately, the resolution of the image is not adequate to accurately measure wavelengths, but not-with-standing this there is perhaps a suggestion that wavelengths also increase with distance as if local topographic conditions cause differences in winds speeds along the valley. Thus gully length is related to wind speed, as would be the case if evaporation rates were important in determining the length of the gully and, therefore, the stability of water on the surface of Mars.

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