SOIL EFFECT ON THE EVAPORATION RATE OF PURE WATER ICE UNDER MARTIAN CONDITIONS.

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Introduction: Past evidence of water on Mars has been well documented and discussed at length. However, the mechanism by which liquid water could be present on current day Mars is poorly understood. We have performed experimental studies in order to better understand how water behaves on Mars. Prior work focused on measuring the evaporation rates of pure water and comparison with model dependent theoretical calculations published by Ingersoll. [1,2] In addition, the dependence of the evaporation rates of brines as a function of temperature has been measured under Martian conditions [3].

Current work is focused on determining the dependence of the evaporation rate of water ice on the depth of soil covering the ice surface. Farmer [4] theorized that a layer of soil could provide a barrier to the diffusion of gaseous water molecules. This could extend the lifetime of an ice layer lying beneath a solid layer and also allow liquid water to remain in the liquid state until its evaporation is complete.

An extended lifetime of a buried ice layer could increase the possibility that liquid water could be produced by melting during a diurnal warming cycle. These experiments were designed to determine the length of time an ice layer could exist under the Martian surface.

Experimental: A typical experiment involved evacuating the Andromeda chamber [2,3] to lower than 0.09 mbar then filling the chamber with dry gaseous CO_2. After the chamber had been filled to ambient pressure, it was then cooled to approximately 0°C using a methanol/dry-ice slurry. A sample was prepared by freezing a sample of pure water inside either a beaker or a graduated cylinder, placing a thermocouple on the ice surface then adding JSC Mars-1 simulant soil on top of the ice. The depth of the soil was varied between 0 cm and 10 cm. The sample was kept as close to 0°C as possible. The chamber was then opened and the sample was placed on a top loading analytical balance. The platform containing the balance set-up was lowered into the chamber using a winch assembly. The lid was then lowered and sealed, and the chamber was evacuated to 7 mbar. As soon as 7 mbar was reached, an operator in the adjacent control room began logging data into an Excel spreadsheet, recording mass, pressure, temperature, and humidity. The pressure was maintained between 6.5 and 8 mbar. Two hygrometers measure the amount of water vapor in the chamber and three digital television cameras viewed the beaker and enabled the balance to be read.

Results: Fig. 1 shows the summary of data collected. Unlike the experiments of pure liquid water at 0°C, water ice under soil did not produce enough water vapor in the atmosphere to depress the evaporation rate as experimental time progressed.
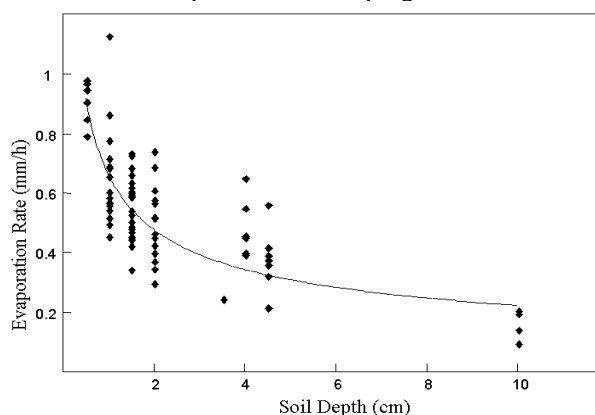

Figure 1. Experimental evaporation rates as a function of soil depth. All values have been corrected for temperature variations and are given at 0°C.

The temperature of the sample varied from –0.7°C to –17.3°C due to continued cooling after the sample froze completely. Because it is important to understand how the evaporation rate is suppressed only due to the presence of soil, we accounted for the varying temperature by calculating a correction factor in the evaporation rate using the Ingersoll [1] equation.

$$\Delta_T = \left(\frac{E_T}{E_0} \right)_{Calc}$$

where E_T is the evaporation rate for the temperature of the sample as calculated by the Ingersoll equation and E_0 is the evaporation rate at 0°C also calculated by the Ingersoll equation. This correction factor was then used for each data point to calculate the evaporation rate at T=0°C.

The evaporation rates after correcting to 0°C ranged from 0.91 ± 0.028 mm/h for 0.5 cm of soil to 0.16 ± 0.026 mm/h for 10 cm of soil.

Discussion: Ingersoll's equation [1] describing the evaporation of water illustrates the different factors that affect the evaporation rate. These include partial pressure of water vapor, the atmospheric pressure and composition, and temperature.

Farmer [4] continued the theoretical discussion of water evaporation on Mars by investigating issues such as water vapor diffusing through a layer of soil. The theoretical calculation developed by Farmer for this situation is:

$$E = \frac{D_{eff} P_{sat}}{kTl},$$

where D_{eff} is the effective diffusion coefficient of the soil, P_{sat} is the saturation water vapor pressure, k is Boltzmann's constant, T is the temperature, and l is soil depth in cm. D_{eff} is dependant on grain size and porosity and is unknown for Martian soil.

For this case, the evaporation rate is inversely proportional to the depth of the soil, l. As seen in Fig. 1, the experimental data does show a decrease with increasing soil depth. However, the question then became whether the experimental data agreed with Farmer's theory.

Fig. 2 depicts the experimental results as average evaporation rates at each soil depth and the theory line calculated from Farmer's equation.
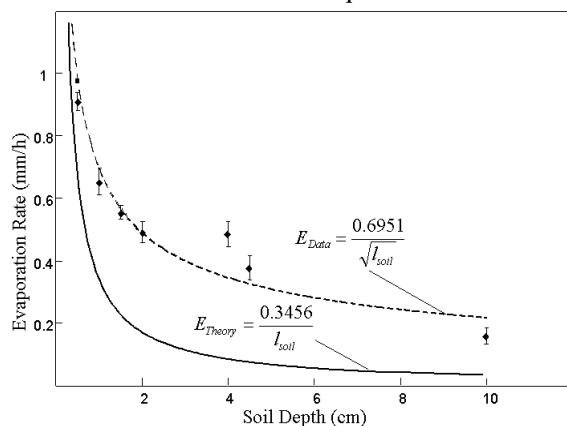

Figure 2. Comparison of the experimental data and the theoretical line calculated from the Farmer equation. The upper line is calculated using the average evaporation rates from experimental data and is proportional to $l^{1/2}$. The lower line is the evaporation rates calculated from the Farmer equation and is proportional to l^{-1}.

The theoretical calculation was done using a temperature of 273K and the saturation vapor pressure (p_{sat}) at 0°C (273K). Farmer used effective diffusion coefficients from Smoluchowski [5] which ranged from 0.0004 to 12 cm^2s^{-1} depending on porosity and grain size. A range of values were tested for our cal-

culations. The best fit to our data had a diffusion coefficient of 2.0 cm^2s^{-1}.

As seen in Fig. 2, the Farmer line does not agree with the experimental data. The theory line equation is inversely proportional to the soil depth, whereas the data line equation is inversely proportional to the square root of the soil depth.

The discrepancies between theory and experimental data could be explained in many ways. The theoretical treatment assumed steady state conditions, no chemical interaction between the water vapor and the soil, etc. These and other aspects will need to be investigated in more depth in the future.

However, the evaporation rate does show a significant decrease by the presence of soil. The implications for such a slowed evaporation rate are far reaching. With very little soil (0.5 cm), the evaporation rate is 0.91 mm/hr, which equates to 1 cm of ice lasting approximately 11 hours. At 10 cm depth, the same 1 cm of ice would last 62.5 hours. At 20 cm and 100 cm of soil, the ice would remain for approximately 102 and 144 hours respectively.

Future experiments include continuing to add soil to the ice at greater soil depths and obtain a more comprehensive trend of evaporation rates. More distant experiments include determining that water ice can and will melt under current Martian conditions and under what circumstances this will occur. This will be established by placing a conductivity probe at the interface between the ice and soil. When melting occurs, the resistance will decrease markedly due to the conductivity of liquid water. Preliminary research indicates that this is a likely occurrence.

Conclusions: This project was designed to determine the affect varying depths of soil would have on the evaporation rate of water ice in a simulated Martian environment. For the soil used, the evaporation rate declines considerably from 0.91 ± 0.028 mm/h for 0.5 cm of soil to 0.16 ± 0.026 mm/h for 10 cm of soil. This trend supports the hypothesis put forth by Farmer that ice can exist longer once covered with a layer of soil. But further investigation is needed to explain the discrepancies between the theory and the experimental data.

References: [1] Ingersoll, A.P, *Science*, 168, (1969). [2] Sears, D.W.G and Moore, S.R., (2005) *GRL* 32 (16) L16202. [3] Sears, D.W.G. and Chittenden, J.D. (2005) *GRL,* 32, L23203. [4] Farmer, C.B. (1976) *Icarus, 28,* 1344–1345. [5] Smoluchowski, R. (1968) *Science*, 159 (3821), 1348-1350.