Evaporation/Sublimation & Heat Transfer Model for a Paleolake at Columbus Crater, Terra Sirenum, Mars.

V. O. Akunyili[1], E. G. Rivera-Valentin[2], V. F. Chevrier[2], and R. Ulrich[3], [1]Physics Department, Drury University (vakunyili@drury.edu), [2]Arkansas Center for Space and Planetary Sciences, [3]Dept. of Chemical Engineering, University of Arkansas Fayetteville

Introduction: Numerous features have been found on Mars pointing towards the possibility that liquid water existed on the surface in the past [1-3]. Examples are well defined shorelines [1] and hydrated minerals found in impact crater beds [2,3]. In this study, we examine the potential paleolake at Columbus crater in Terra Sirenum, 29.8°S, 166.1°W, which is roughly 100 km in diameter with a depth of ~1.5 km [2,3].

To understand the temperature constraints both on the surface and at lake depths, we build a time-dependent heat transfer model. As the lake freezes, the solution activity decreases until the freezing point of the solution is depressed below the average annual skin-depth temperature of the lake. From this, we derive the amount of remaining liquid. In order to determine a maximum lake lifespan, we assume the lake is pure water and apply a modified semi-emperical Ingersoll evaporation/sublimation equation [11,12].

Methods: We use MATLAB to model the system affecting the lake through finite element analysis. First, an annual temperature profile is calculated for the lake based on solar insolation and the temperature dependent thermodynamic properties of water and ice. Using these results, we employ our lake evaporation/sublimation model to derive the lifespan of the lake. Initially, we assume instantaneous phase change. With this assumption, we are overestimating the lifetime of the lake and thus provide an upper bound.

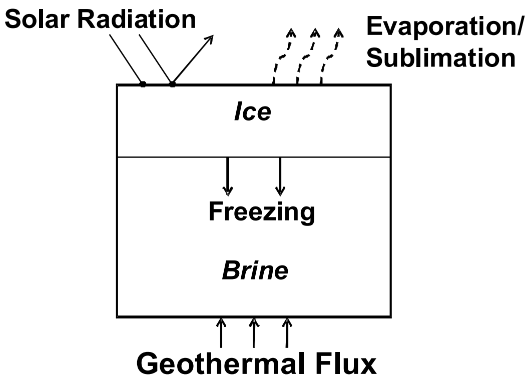

Fig. 1: Schematic showing boundary conditions

Heat Transfer: In order to account for heat transfer through the lake, we take into account only conduction. We also assume the initial lake temperature is 280 K. The boundary conditions are shown in Fig. 1. We do not assume that the crater bed has remanent heat from impact as suggested by Barnhardt *et al* [4], but instead assume average geothermal heat flux (30 mW/m^2) [5].

To model surface incident heat flux, we adopt the equations proposed by various authors [5-8]. The incident solar radiation is accounted for in four ways: the diffusion of the direct solar beam, the indirect solar raditation due to scattering, the thermal emission of the atmosphere due to absorbed solar energy, and the thermal emission of the atmosphere at night. The equation set are as follows:

$$Q_{DB} = I_{sun}(1-A)\cos(z)T(z,\tau) \tag{1}$$

$$Q_{atm} = I_{sun}(1-A)\varepsilon\, f_{atm}\cos(\delta-\varphi) \tag{2}$$

$$Q_{scat} = \left(I_{sun}\left(1-e^{-\frac{\tau}{\cos(z)}}\right)-I_{ab}\right)(1-A)f_{scat} \tag{3}$$

$$Q_{atm\_night} = I_{sun}f_{atm}(1-A)\varepsilon\cos(z)|_t \tag{4}$$

where I_{sun} defines the solar radiation received at any point in Mars orbit, z is the zenith angle, A is the lake surface albedo (0.4 for ice [9] and a function of zenith angle for water [10]), T is the transmission coefficient derived from Pollack (1990) and is defined by the zenith angle and the atmospheric opacity, which we assume to be constant at 0.5, ε is the thermal emmisivity of the atmosphere, f_{scat} and f_{atm} are fractions of flux provided by Schmidt *et al.* [6], and I_{ab} is the amount of solar flux absorbed by the atmosphere.

Evaporation/Sublimation: To account for evaporation, we use a one direction vertical transport equation proposed by Chevrier *et al.*, which is modified from the semi-emperical Ingersoll equation [11,12]. This equation takes into account the diffusion of water vapor through a CO_2 atmosphere driven by both temperature and buoyancy. The evaporation rate (E) given in *m/s* is as follows:

$$E = 0.17D_{H_2O/CO_2}a_{H_2O}\frac{\rho_{sat}}{\rho_{sol}}\left[\frac{g(\Delta\rho/\rho)}{\upsilon^2}\right]^{\frac{1}{3}} \tag{5}$$

where $D_{H2O/CO2}$ is the diffusivity of water in the CO_2 atmosphere, a_{H2O} is the activity of water, g is gravity (3.75 m/s^2 on mars), v stands for the kinematic viscosity of CO_2, $\Delta\rho/\rho$ accounts for the temperature dependent buoyancy of water in the CO_2 atmosphere, ρ_{sat} is the temperature dependent saturation density.

To obtain preliminary results on the amount of remaining liquid solution after freezing, we assume the lake freezes relatively instantaneously to the annual skin-depth (~9 m). Using the Temperature profile across the year for obliquity of 25.2°, we determine the temperature at skin-depth (~205 K). We apply the standard freezing rate equation (assuming the lake was 0.1% salt) and recalculate the solution activity and freezing temperature at every time step.

Results: We have successfully determined the annual temperature for the entire lake and here present the average surface temperature per Ls (Fig. 2).

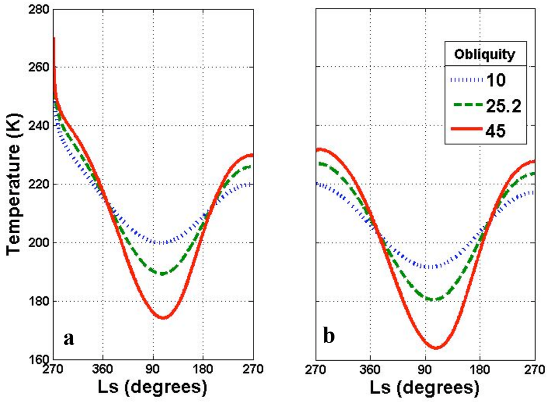

Fig 2: Average surface temperatures of the lake for the (a) 1st and (b) 2nd year.

In oder to determine the lifespan of the lake, we used Temperatures from the second year (Fig. 2b). The change in height over the 2nd year is shown in Fig. 3. Using these values we extrapolate the lifespan of the lake at each obliquity as shown in Table 1.

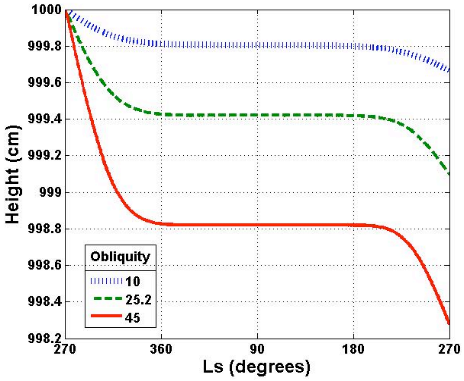

Fig.3: Change in height using Eq. 5 at each time-step.

Obliquity	Change in Ht. (cm/yr)	Lifespan (yrs)
10	0.33	455,000
25.2	0.90	167,000
45	1.70	88,000

Table 1: Extrapolated lifespan of the lake using change in height in second year (debth: 1.5 km).

As you concentrate the solution, the freezing rate approaches zero (Fig. 4b). At this point, we have an activity of 0.4 and a liquid depth of ~1.95 m (Fig. 4a), depressing the freezing point below 205 K. Using the rate of sublimation for Mars at current obliquity, it would take ~0.167Myr for the ice cap to fully sublimate. This provides a lower bound time limit for the liquid solution to remain present neglecting the additional time it would take to evaporate the solution.

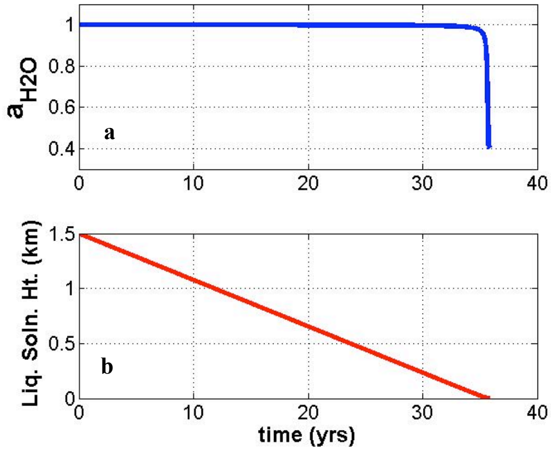

Fig. 4: (a) Activity vs. time (b) height of liquid vs. time.

Conclusion: We have determined the diurnal and annual temperature profile of the paleolake for current, maximum, and minimum obliquities as well as the evaporation rates at the surface. From our model, we estimate that the upper bound lifespan of the lake at current obliquity is ~0.167 Myr as well as the lower bound lifespan of the liquid solution at an activity of 0.4 and temperature of 205 K. Considering Ulrich *et al.* suggested bench mark lower limit temperature for metabolic activity of 253 K, the possibility for life is bleak [13]. Still, our model currently suggests that liquid may have existed in the past on Mars under our studied conditions. We also find that the rate at which the lake freezes is much faster than that of sublimation.

References: [1] Di Achille, G. et al. (2009) *GRL, 36*, L14201. [2] Altheide, T. S. et al. (2009) *Workshop on Modeling Martian Hydrous Environments*, Abstract #4030. [3] Wray, J. J. et al. (2009) *LPS XL*, Abstract # 1896. [4] Barnhart, C. et al. (2006) *LPS XXXVII*, Abstract #2437. [5] Rivera-Valentin, E. G. et al. (2009) *Workshop on Modeling Martian Hydrous Environments*, Abstract #4020. [6] Schmidt, F. et al. (2009) *Icarus,* doi:10.1016. [7] Applebaum, J. et al. (1993) NASA Technical Memorandum 106321. [8] Ulrich, R. et al. (submitted) *Astrobiology*. [9] Paige, D. A. et al. (1994) *JGR, 99*, 25959-25991. [10] Cogley, J. G. (1979) *Monthly Weather Review, 107*, 775-781. [11] Altheide, T. S. et al. (2009) *EPSL, 282*, 69-78 [12] Ingersoll, A. P. (1970) *Science, 168*, 972-973. [13] Ulrich, R. et al. (submitted) *Astrobiology.*