Crater Lakes on Mars: Development of Quantitative Thermal and Geomorphic Models. C. J. Barnhart[1], S. Tulaczyk[1], E. Asphaug[1], E. R. Kraal[1], J. Moore[2], [1](Department of Earth Sciences, University of California Santa Cruz, 1156 High Street, Santa Cruz, California, 95064, barnhart@es.ucsc.edu, asphaug@es.ucsc.edu), [2](NASA Ames Research Center, MS 245-3, Moffet Field, CA 94035-1000, jeff.moore@nasa.gov).

Introduction: Impact craters on Mars have served as catchments for channel-eroding surface fluids, and hundreds of examples of candidate paleolakes are documented [1,2] (see Figure 1). Because these features show similarity to terrestrial shorelines, wave action has been hypothesized as the geomorphic agent responsible for the generation of these features [3]. Recent efforts have examined the potential for shoreline formation by wind-driven waves, in order to turn an important but controversial idea into a quantitative, falsifiable hypothesis. These studies have concluded that significant wave-action shorelines are unlikely to have formed commonly within craters on Mars, barring Earth-like weather for ~1000 years [4,5,6].

Ice as Protagonist: A different mechanism is required to explain these features. Our efforts are therefore devoted to understanding the geomorphic effects of thick (glacial) ice cover under martian conditions [7]. Terrestrial analogs are not trivially adapted to martian conditions, and thus a number of studies have examined from first principles the thermal evolution and residence time of liquid water and ice cover in martian environments [8,9,10]. However, the linked geomorphic evolution of such a system has yet to be adequately characterized.

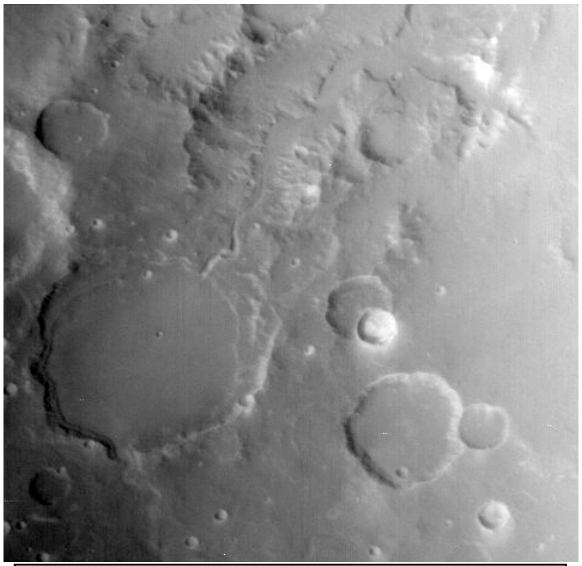

Figure 1: Wide angle image from Mars Global Surveyor, MOC R10-05145 (Malin Space Science Systems). Image is centered on 174.63W 14.51S and width is 120 km.

Possible Scenarios: We have begun to develop detailed models to test specific scenarios for ice-covered lakes (ice battering, thermal expansion, subsidence, burial and exhumation, etc.) exploring their ability to produce shoreline-type features (see Figure 2). In this abstract we describe the preliminary modeling approach for one such scenario, where a lake with thick ice cover experiences volumetric strain from ice/water/brine density variations. This is one of five candidate scenarios to be described during our presentation.

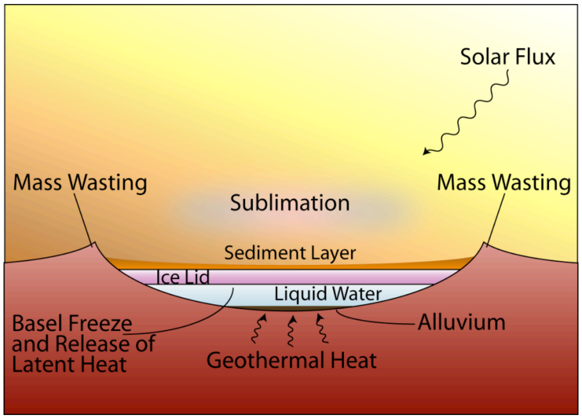

Figure 2: Ice-lake schematic. Mass and energy fluxes involved in our models are indicated. Adapted from McKay et al. (1985).

A lake with thick ice cover is likely to experience volumetric strain in response to extreme temperature changes, for instance the collapse of greenhouse or other severe climate cycling. Thermal expansion and freeze-out leads to strain accommodation and slip, resulting in mass wasting and erosional deformation at the ice margin. The mechanism could repeat with climate cycles if water or brine persist.

Our model, currently under development, begins with a 1D thermodynamical lake model describing energy and sediment inputs and brine-ice interactions. The model is governed by an equation that balances incoming and outgoing energy in the center column of a crater lake. The model provides time scales for the persistence of liquid water/brine and for ice lid longevity. 1D results will be adopted for 2D modified finite element models of ice evolution within evolving crater lake boundary and thermal condiditions, coupled to models for margin deformation and erosion.

Energy Balance: Through energy balance equations it has been shown that ice-covered lakes can exist for up to 700 million years on Mars after the mean global temperature drops below freezing [9,11].

Subsequent research has progressed into the thermodynamics of such systems including: (1) the contribution of crater-formation heating on the persistence of liquid water, and the evolution of ice cover thickness [12], (2) the fate of flood waters emptying into the northern plains [8], (3) the use of detailed thermal and atmospheric models to calculate the lifetime of water and the evolution of ice cover thicknesses [10].

Equation 1 balances the upward conduction of heat at a given depth in the ice cover with the energy input below that level in the ice [9]. A steady state condition is assumed and fluxes are averaged over the year to obtain

$$k\frac{dT}{dz} = S(z) + L + F_g \qquad (1)$$

where k is the thermal conductivity of ice, dT/dz is the gradient of annual mean temperature (T) with depth (z) in the ice, S(z) is the annual mean flux of solar energy absorbed below z and Fg is the geothermal heat flux. As model complexity increases, so will our description of the balance of energy and mass fluxes.

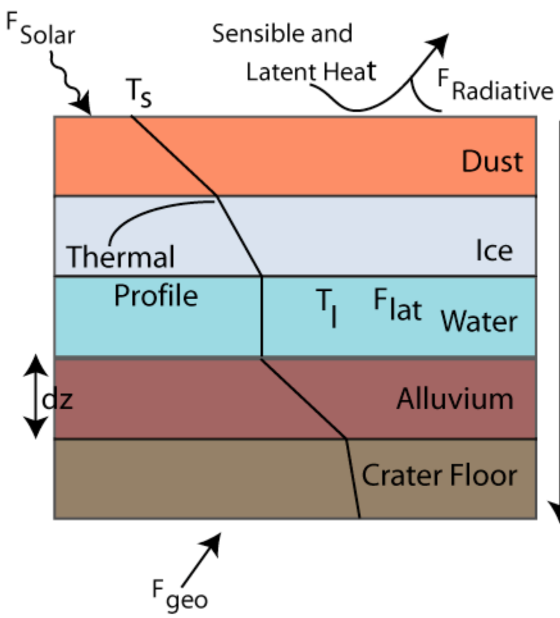

Figure 4: Schematic of a 1D thermodynamic model for an ice-lake. Arrows describe the energy flux, the solid line is a qualitative temperature profile where T_s and T_l are the surface and eutectic temperatures respectively. Model design is motivated by McKay et al. (1985) and Duguay et al. (2003).

Model evolution will include energy balance at discrete layers throughout a one-dimensional column. The speed of this model will facilitate probing consequences of climatic variables and atmospheric forcing on ice-lake longevity and thermodynamic response. Our overall technique will be based on the one-dimensional unsteady heat conduction equation with penetrating solar radiation. The unsteady heat equation is of particular utility, because it describes energy transport and diffusion at depth between different materials; water, ice, dust, alluvium, and bedrock.

Astrobiological Discussion: The exploration of potential sites of astrobiological interest on Mars is one of NASA's main directives. Our model argues that, by comparison to an intracrater ice plug, lacustrine systems on Mars are rather transitory. It is more probable, then, that life would have a greater opportunity to proliferate in an aqueous environment under an ice plug rather than in ephemeral lakes exposed to the myriad hostilities of Mars' surface: UV radiation, sub-arctic temperatures, and the extreme, oxidizing nature of surface chemistries [13].

Conclusion: The glacial geomorphology of crater features is a rich key to the Martian past, yet, despite the wealth of imagery, the interpretation of surface morphology lacks the insight and definition that a quantitative model would provide. Our models explore geomorphic scenarios that posit ice plugs as the formation mechanism for shoreline features. The development of a quantitative model that describes this system will provide new insights—climatic, hydrological, astrobiological—into Mars' history.

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