CAN SHORELINE PROCESSES ON MARS CONSTRAIN ITS PAST CLIMATE? E. R. Kraal[1] , E. I. Asphaug[1] and R. D. Lorenz[2], [1]Department of Earth Science – University of California Santa Cruz (1156 High Street, Santa Cruz, California 95064, ekraal@es.ucsc.edu), [2]Lunar and Planetary Laboratory, (1629 E. University Blvd, Tucson, AZ, 85721).

Introduction: Significant past efforts have been devoted to the mapping of shorelines in Martian crater basins [e. g.1, 2-4] and the use of shoreline morphology to interpret the past Martian climate and hydrologic cycle[5-7]. If lacustrine geomorphology persists on Mars, it is a rich key to the Martian past. Yet, despite the wealth of imagery and increasing data return from THEMIS on Mars Odyssey, the interpretation of surface morphology lacks insight from a linked quantitative model. In this spirit, we propose to explore the geomorphic system of a crater lake on Mars and how it would respond to climate perturbations (from occasional filling to persistent lake levels and ice cover), keeping in mind the unique initial conditions of an impact structure to the extent that the initial lake bedrock, breccia and layered deposits can be modeled. *Our ultimate goal is to understand how shorelines might preserve a quantitative record of Martian climate.*

Methods: Shore erosion is a function of wave energy reaching the shore and the erodability of shoreline material. Wave energy is a function of climatic variables such as wind speed and variability as well as air pressure. While resistance of shore erosion is a function of bedrock. Through the use of geomorphic modeling, it may be possible to tease out these two variables and begin to understand the climate conditions present during the formation of possible shorelines.

For instance, a shoreline bench of height h and width w might turn out to be correlated to a lake drainage of h over a duration T with significant wave height A. In this example h and w are directly measured, and A is a proxy for wind speed and atmospheric pressure. The intensity and duration of climatic events may be recorded in crater lacustrine deposits and erosional forms. A primary goal of our forward modeling effort is, therefore, to determine whether Mars climate history is clearly captured in these erosional and depositional forms.

The modeling is separated into two parts. First, is the generation of waves. Second is the interaction of those waves with the shoreline.

Wave Formation. The general wave equations predict expected wave behavior. The velocity of a wave scales with gravity while wave height scales with the inverse of gravity. Therefore, waves produced in the lower gravity of Mars can be expected to grow taller but travel slower.

The energy of a wave is expressed by $E=1/8\rho gH$, where ρ is the fluid density (gm/cm^3), g is planetary gravity (m/s^2), and H is wave height (m). In order to estimate the amount of energy in the system over time, it is also important to know the wave period.

Empirical equations have been developed for the earth to calculate significant wave height (h_s), the average height of waves in the upper one-third of the wave energy spectrum, and the average frequency (f_m) of the significant waves. The two empirical relations are the Pierson-Moskowitz(PM) equation, which is only a function of wind speed, and the JONSWAP equation which is a function of wind speed and fetch [8]. This abstract will use the PM equation, which assumes a fully developed sea [9]. The PM equation for significant wave height is:

$$_{PM}h_s = \frac{0.447 g\sqrt{\alpha}}{\pi^2 f_m{}^2}$$

Where g is planetary gravity in m/s^2, alpha is an empirical constant equal to 8×10^{-3}, and f_m is the peak frequency. Peak frequency is a function of gravity and the wind velocity, u, in m/s

$$_{PM}f_m = 0.8772\left(\frac{g}{2\pi u}\right)$$

Peak period (t_m) is $1/f_m$. Using these equations it is possible estimate wave energy arriving at Martian shorelines and to compare is to energies at equivalent conditions on Earth.

Shoreline Development. From our wave generation model we shall compute the amount of force available to erode a wave cut platform under Martian conditions. Waves provide mechanical energy to erode coastlines by water hammer, abrasion, and quarrying [10]. The highest pressures and erosive power are generally found at the mean water surface [11]. On Earth, the mean water surface is controlled by tides, while on Mars tides are negligible. Trenhaile [12] modeled formation of wave cut terraces on Earth and this method will be closely followed with consideration to Martian conditions.

The wave force (F_b) at the point where the wave begins to break is defined as $F_b = 0.5\ \rho_w h_b$ (4), where ρ_w is the density of water and h_b is the breaking wave depth. F_b has units of kg/m^2. The wave height (H_b) is related to h_b by the critical ratio $H_b = 0.78\ h_b$ (5), which occurs when the water particle velocity at the crest is equal to the wave phase velocity. Combining Eqs. (4) and (5) gives the force at the breakers related to wave height. This wave force at the breakers must be distributed over the width of the surf zone (W_s). Assuming a linearly sloped surf zone $W_s = h_b / \tan$ □ (6) where □ is the slope of the surf zone, the surf force (S_f) reaching the water line may be approximated using a decay function $S_f = 0.5$□$_w(H_b/0.78)\ e^{-kW_s}$ (7). The attenuation rate of energy is represented by the constant k and is related to the roughness of the bottom. Even in some terrestrial situations this constant can be unknown. However, Trenhaile (2000) showed that a range of 0.1 to 0.01 was ample to model high and low surf attenuation. The wave platform is eroded using this wave force.

Results: As anticipated by the basic wave equations, waves produced by the same wind speed are taller on Mars than on Earth. Waves are slower on Mars than on Earth, arriving 3 times less frequently. While gravity varies between the planets, fluid density is assumed to be that of water (1000 g/cm^3) in both cases. Because of the larger wave height, a given wind speed produces more energetic waves on Mars. Even though this relationship is slightly mitigated by the loss of gravitational potential energy on Mars, average energy per Martian wave is almost 3 times larger than terrestrial waves. However, once the wave period (t_m) is converted to number of waves per hour and multiplied by energy per wave, the time averaged energy per wind speed is similar on both planets[13].

Empirical relationships developed on Earth indicate that, given similar wind speeds, the average energy arriving at a Martian shoreline could be comparable to terrestrial wave energy. This conclusion may, however, not be entirely accurate as a 1 bar atmosphere is implicit in the empirical relationship; lower atmospheric density on Mars would make energy transfer from wind to water less efficient. At present, wind wave generation theory based solely on first principles does not exist. It is, therefore, necessary to apply the available tools to make first-order quantitative assessments of the energy available for lacustrine erosion on Mars. Future research will focus on constraining the effects of different planetary conditions on wave field generation, e. g. how atmospheric pressure could be decoupled and thus made explicit for the purpose of general planetary conditions.

The wave fields estimated for various climate conditions (ie wind speed) will be an important input into the geomorphic model of shoreline erosion.

Conclusions: By applying terrestrial wave field models, to first order, wave energy on Mars and Earth may be similar. This would especially be true in an early ~1 bar epoch on Mars, when open water might have existed. The presence of open water and a relatively dense atmosphere could provide conditions necessary to form lacustrine geomorphic features. However, more research on the influence of differing planetary conditions and modeling the lacustrine geomorphic processes associated with wave action is necessary and in progress.

This modeling is highly relevant to understanding Mars' water cycle, climate history and geology. Specifically, some aspects of the geologic history of Mars are uncertain because, due to the small size of the impact craters, and the especially small size of potential shoreline features, age dating via crater counting is difficult and controversial (e.g. Hartmann 2002). Although the age of impact crater lakes have been estimated, the error is significant because of their small surface area [6]. Though this model will not result in absolute ages of geomorphic features due to the estimated parameters (e. g. rock hardness and wind speed) we may gain insight into the time of formation; are the observed features likely formed in tens, thousands, or millions of years? The geologic history is inextricably linked to the climate history. The geomorphic modeling of lacustrine features may offer clues to the duration of 'warm, wet' periods.

References: [1] Cabrol, N.A. and E.A. Grin, *Distribution, classification, and ages of Martian impact crater lakes.* Icarus, 1999. **142**: p. 160-172. [2] Ori, G., L. Marinangeli, and A. Baliva, *Terraces and gilbert-type deltas in crater lakes in Ismenius Lacus and Memnonia (Mars).* JGR, 2000. **105**(E7): p. 17629-17641. [3] Moore, J.M. and D.E. Wilhelms, *Hellas as a possible site of ancient ice-covered lakes on Mars.* Icarus, 2001. **154**(2): p. 258-276. [4] Irwin, R., et al., *A large paleolake basin a the head of Ma'adim Vallis, Mars.* Science, 2002. **296**(5576): p. 2209-2212. [5] Cabrol, N.A., et al., *Duration of the Ma'adim Vallis/Gusev Crater hydrogeologic system, Mars.* Icarus, 1998. **133**: p. 98-108. [6] Cabrol, N.A. and E.A. Grin, *The evolution of lacustrine environments on Mars: Is Mars only hydrologically dormant?* Icarus, 2001. **149**: p. 291-328. [7] Cabrol, N.A., E.A. Grin, and R. Landheim, *Ma'adim Vallis evolution: Geometry and models of discharge rate.* Icars, 1998. **132**: p. 362-377. [8] Carter, D.J.T., *Predictions of wave height and period for a constant wind velocity using the JONSWAP results.* Ocean Engineering, 1982. **9**(1): p. 17-33. [9] Pierson, W.J. and L. Moskowitz, *A proposed spectal for for fully developed seas.* JGR, 1964. **69**: p. 5181-5190. [10] Sunamura, T., *Geomorphology of Rocky Coasts*. 1992, New York: J. Wiley. [11] Trenhaile, A.S., *The Geomorphology of Rock Coasts*. 1987, Oxford: Clarendon Press. 384. [12] Trenhaile, A.S., *Modeling the development of wave-cut shore platforms.* Marine Geology, 2000. **166**: p. 163-178. [13] Kraal, E.R., E.A. Asphaug, and R.D. Lorenz. *Wave energy on Mars and Earth: Considering lacustrine erosion.* in *34th LPSC.* 2003. League City, Texas.