WAVE ENERGY ON MARS AND EARTH: CONSIDERING LACUSTRINE EROSION. E. R. Kraal[1], E. I. Asphaug[1] and R. D. Lorenz[2], [1]University of California Santa Cruz (Department of Earth Science, 1156 High Street, Santa Cruz, CA 95064; ekraal@es.ucsc.edu), [2]Lunar and Planetary Laboratory, (1629 E. University Blvd, Tucson, AZ, 85721).

Introduction: Many researchers have identified lacustrine features on Mars[1]; this interpretation has important implications for the climate history of Mars and selection of future landing sites. It is, however, unclear if wave conditions on the Martian surface would be adequate to produce lacustrine features. Wave spectrums have been considered on Titan [2, 3], but not on Mars. This abstract outlines a quantitative assessment of wave energy available for lacustrine erosion on Mars and finds that time averaged wave energy on Mars might be similar to time averaged wave energy on Earth.

Background: Shoreline erosion is a function of wave energy reaching the shore and the erodability of shoreline material. Wave energy is a function of wave height and period.

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 [4]. This abstract will use the PM equation, which assumes a fully developed sea [5]. 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 $8\text{x}10^{-3}$, 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.

Results: As anticipated by the basic wave equations, waves produced by the same wind speed are taller on Mars than on Earth (Plot A). Waves are slower on Mars than on Earth, arriving 3 times less frequently (Plot B). 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 (Plot C). 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.

Discussion: 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.

In addition, this analysis does not consider differences in wind speeds between the planets. The mechanical work produced in the Martian atmosphere by horizontal heat transport ('trade winds') is larger than that on Earth, although vertical heat transport (associated with e.g. hurricanes) is less. Wind speed and, therefore, wave energy, might be significantly less on Mars. (These differences would be smaller for thicker Martian atmospheres.)

Conclusion: 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.

References: [1] Cabrol and Grin, *Distribution, classification, and ages of Martian impact crater lakes.* Icarus, 1999. **142**: p. 160-172. [2] Ghafoor, N., et al., *Wind-driven waves on Titan.* JGR, 2000. **105**(E5): p. 12077-12091. [3] Ori, G.G., et al., *Fluid dynamics of liquids on Titan's surface.* Planetary Space Science, 1998. **46**(9/10): p. 1417-1421. [4] 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. [5] Pierson and Moskowitz, *A proposed spectral for fully developed seas.* JGR, 1964. **69**: p. 5181-5190.

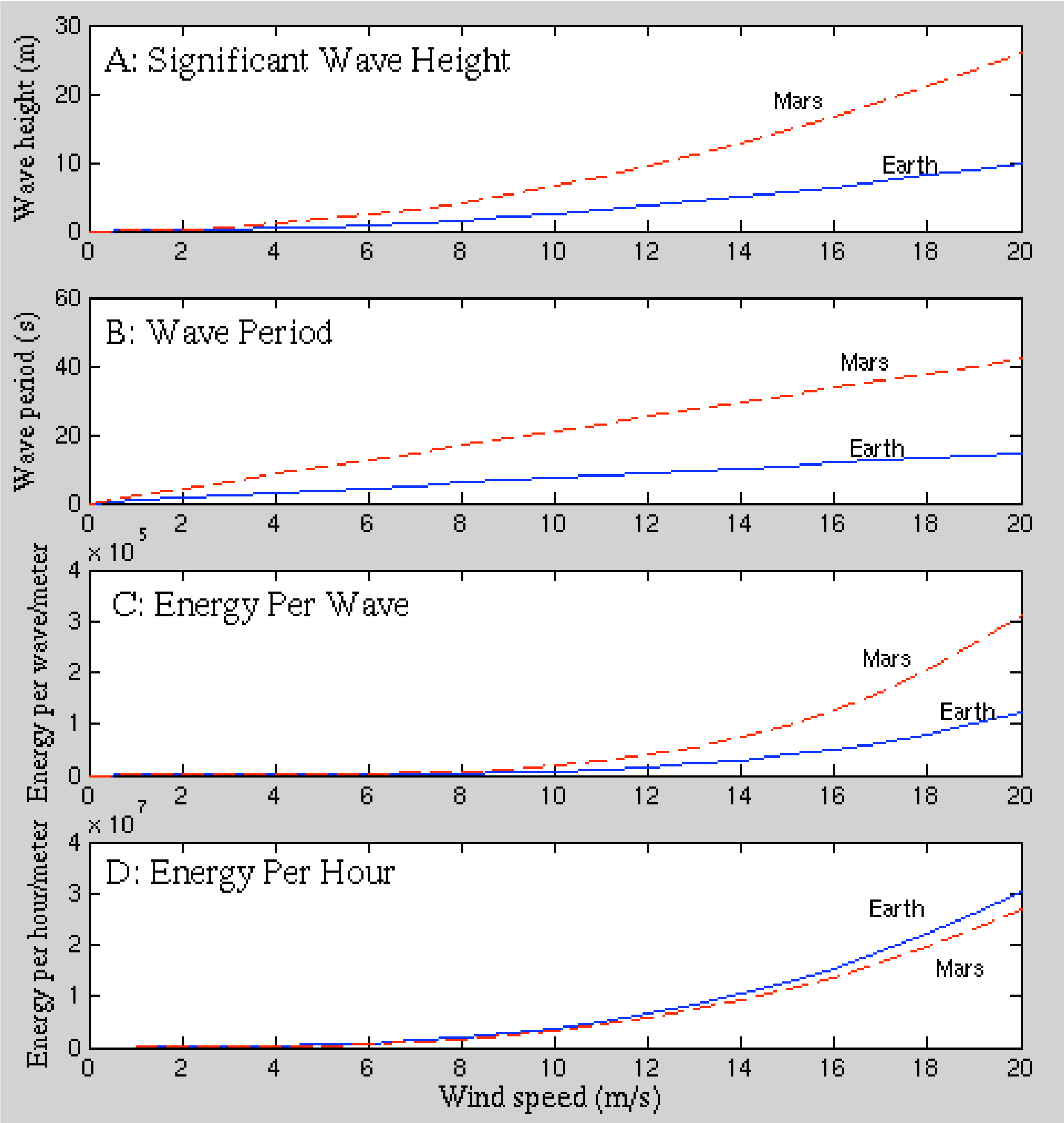

Figure 1: Wave energy on Mars and Earth. For a given wind speed, waves are taller on Mars than Earth (A). Though taller, waves on Mars are significantly slower, arriving less frequently (B). Taller waves produce more energy per individual wave per meter of wavelength on Mars (C). However, the slower period on Mars compensates and therefore the wave energy over time per meter of wavelength for a given wind speed is comparable between the two planets (D).