BIOPHYSICAL COMPARISON OF THE HABITABLE ZONES ON EARTH AND MARS. A. Méndez, Department of Physics and Chemistry, University of Puerto Rico at Arecibo, Arecibo, PR 00613 (a_mendez@cuta.upr.clu.edu).

Introduction: A planet's habitable zone (HZ) is the spatial and temporal region capable of supporting life. The biosphere (Earth's habitable zone) extends to the near-surface environment (about ±10 km with respect to sea level) including part of the atmosphere, hydrosphere and lithosphere. Its extension is also controlled by temporal variations due to daily and seasonal cycles. Bacteria spores have been collected from the air at several kilometers over sea level [1] and barophilic bacteria have been isolated from a deep of 11 km under sea level [2]. These examples show the broad vertical extension of the biosphere. Life is limited in this region at least by the temporal availability of liquid water, and this is controlled by the environment temperature and pressure as described in a water phase diagram. The planet Mars' near-surface environment oscillates between 140 to 300 K with an average atmospheric pressure of 6.1 mbar [3]. There are no Earth examples of microorganisms adapted to similar low temperature and pressure environments because natural examples of such environments are rare or difficult to study [4].

The purpose of this research is to give a global comparison of Earth's and Mars' habitable zones from a biophysical point of view. This biophysical approach includes the construction of a single pressure-temperature (*PT*-space) diagram combining *Earth's and Mars' near-surface environment*, a *water phase diagram* and *known microbial habitats*. This approach gives a general panorama of the limits of life with respect to temperature and pressure. These two basic environmental variables control the reaction rates, diffusion rates, viscosity, dielectric constant, stresses respond and heat capacities of the cell biochemicals and structures [5].

Earth's and Mars' Near-surface Environment: A *PT*-space profile of the near-surface environment of Earth and Mars was constructed from mean pressure and temperature vertical profiles. The atmosphere mean pressure profile was calculated from the hydrostatic equation for an altitude dependant density according the ideal gas law [6]. The lithosphere and hydrosphere mean pressure profile was calculated from the hydrostatic equation for a constant density [7, 8]. Equation (1) gives the mean pressure profiles for the atmosphere, lithosphere and hydrosphere, respectively.

$$P(z) = \begin{cases} P_s e^{-z/H_e} & z \geq 0 \\ P_s - \rho_c g z & z < 0 \\ P_s - \rho_{sw} g z & z < 0 \end{cases} \quad (1)$$

The atmosphere mean temperature profile was calculated for the adiabatic case [6]. The lithosphere mean temperature profile was calculated from Fourier's Law for a simple radioactive upper crustal layer model [7]. The hydrosphere mean temperature profile was calculated from a simplified model for the mixed layer and thermocline [8] with boundary conditions fitted from empirical data [9]. Equation (2) gives the mean temperature profiles for the atmosphere, lithosphere and hydrosphere, respectively. Parameters for both equations were obtained from various references (see table) and combined in the form *T(P)* for each profile.

$$T(z) = \begin{cases} T_s - \Gamma_s z & z \geq 0 \\ T_s - \frac{z}{k}\left(q_o + \frac{1}{2}Az\right) & z < 0 \\ T_b + \left(T_s - T_b\right)e^{\frac{w}{K}z} & z < 0 \end{cases} \quad (2)$$

Table: Comparison between Earth's and Mars' mean near-surface atmosphere, lithosphere and hydrosphere properties [3, 6, 7, 8, 10, 11].

	Earth	Mars
Atmosphere		
T_s, surface temperature (K)	288	214
P_s, surface pressure (mbars)	1013	5.6
Γ_s, lapse rate (Kkm^{-1})	6.5	2.5
H_e, scale height	8	10.8
Lithosphere		
ρ_c, crust density (gcm^{-3})	2.8	2.9
q_o, surface heat flow (mWm^{-2})	65	30
g, gravity field (ms^{-2})	9.806	3.735
k, thermal conductivity (Wm^{-1}K^{-1})	2.4	2.0
A, heat generation (Wm^{-3})*	4.0x10^{-6}	1.8x10^{-6}
q/k, thermal gradient (Kkm^{-1})	27	12
Hydrosphere		
T_b, deep-sea temperature (K)	275	—
ρ_{sw}, sea water density (gcm^{-3})	1.035	—
w/K, vertical speed and mixing coefficient ratio (m^{-1})	1.37x10^{-3}	—

* Mars' heat generation value was estimated from the surface thermal gradient.

Water Phase Diagram: A water phase diagram was constructed with data from various sources for pure water on a flat surface [12, 13]. This diagram (integrated in the figure) will be updated to show the supercooled water interface, aqueous solutions, and the effects of small curved surfaces relevant to microbial size.

Microbial Habitats: A database of the habitats and laboratory environmental variables in which microorganisms grow such as temperature, pressure, pH, salinity and energy source is under construction. The purpose of this database is to get a general perspective of the conditions for life, especially in terms of *PT*-space. Most of the known microorganisms' habitats are concentrated in a small region in *PT*-space corresponding to a temperature of about 310 K at standard atmospheric pressure (mesophiles). Although much is known about the effects of temperature on microorganisms, little is known about the combined effects of pressures and temperatures [5].

Discussion: A global temperature and pressure diagram of Earth's and Mars' habitable zone was constructed (see figure). This diagram combines a description of the near-surface environment of both planets with a water phase diagram and Earth's known microbial habitats. This type of diagram, a *HZPT*-diagram, gives a general idea of the habitable zones in terms of *PT*-space within a planetary body. A *HZPT*-diagram for Earth and Mars shows that in a global sense, Mars has two possible habitable zones. At 2 meters below its surface, Mars has similar *PT*-space conditions to 11 km above Earth's surface where, thus far, bacteria spores have been collected. More interestingly, at 5 km below Mars' surface the planet has similar *PT*-space conditions to Earth's deep-sea 5 km below. Unfortunately, only Mars' subsurface 2 meters below can be explored in the near future, and not much about life in similar environments is known. Thus, more research on microbial life under low temperature and pressure environments (i.e. high Altitude Mountains) is needed. Experiments to model and measure the microbial growth rate constant [14, 15] as a function of temperature and hydrostatic pressure for various microorganisms are necessary. These experiments might answer the following questions: What are the limits of life within the water liquid phase? How does the combined effect of environment pressure and temperature affect microbial growth?

Future work will include the addition of more details to *HZPT*-diagrams by considering the microscopic scales and temporal variations within the planetary boundary. Research in this field, planetary microbial ecology, might be relevant to the search for life on Mars as a biophysical approach for theoretical predictions of habitable zones.

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References: [1] Imshenetsky AA, Lysenko DV, Kazakov GA (1978). *Appl. and Environm. Microbiol.* **35**: 1-5. [2] Kato C, Li L, Nogi Y, Nakamura Y, Tamaoka J and Horikoshi K (1998). *Appl. and Environ. Microbiol.* **64**: 1510-1513. [3] Kieffer H H, Jakosky B M and Snyder C W (1992). In *Mars*, eds., H H Kieffer, B M Jakosky, C W Snyder and M S Matthews (Tucson: The University of Arizona Press), 31-32. [4] Campbell G S and Norman J M (1998). *An Introduction to Environmental Biophysics, 2nd ed.* (Springer), 185-205. [5] Yayanos A A (1998). In *Extremophiles: Microbial Life in Extreme Environments*, eds., K Horikoshi and D W Grant (New York: Wiley-Liss), 47-92. [6] Seinfeld J H and Pandis S N (1998). *Atmospheric Chemistry and Physics*. (John Wiley & Sons) 777-839. [7] Sleep N H and Fujita K (1997). *Principles of Geophysics*. (Blackwell Science), 134-201. [8] Mellor G L (1996). *Introduction to Physical Oceanography*. (Springer-Verlag). [9] Levitus S and Boyer T P (1994). *World Ocean Atlas 1994 Volume 4: Temperature.* (US Department of Commerce Washington, DC) 117. [10] Boeker E and Van Grondelle R (1995). *Environmental Physics*. (John Wiley & Sons), 31-63. [11] Carr M H (1996). *Water on Mars.* (Oxford University Press), 30-46. [12] CRC (1980). *Handbook of Chemistry and Physics*. (CRC). [13] Granger R A (1997). *Life on Mars*. (Scientific Archives Series in Science) 42-90. [14] Koch A L, Robinson J A and Milliken G A (1998). *Mathematical Modeling in Microbial Ecology*. (Chapman & Hall), 14-31. [15] Pirt S J (1990). In *Microbial Growth Dynamics*, eds., R K Poole, M J Bazin and C W Keevil (Oxford: IRL Press), 1-16.

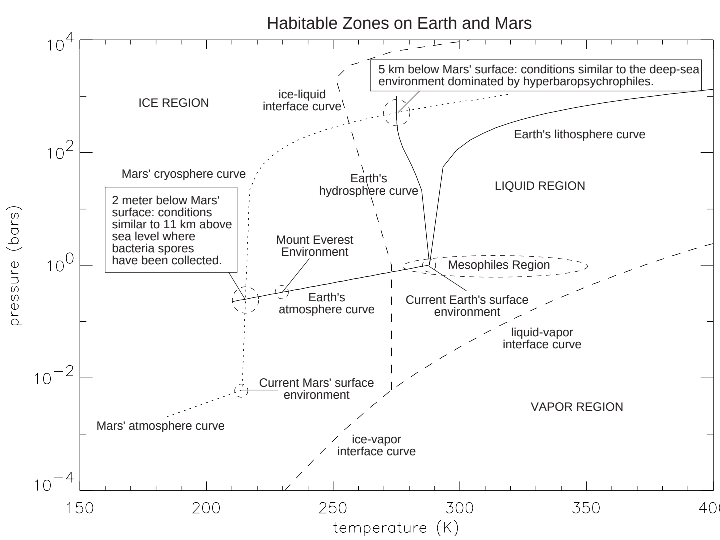

Figure: This diagram compares the mean near-surface macroenvironment of planet Earth and Mars in terms of hydrostatic pressure and temperature. It suggests possible habitable zones within the Martian global environment.