COMPARATIVE PLANETOLOGY OF THE TERRESTRIAL INNER PLANETS: IMPLICATIONS FOR ASTROBIOLOGY.
D. Schulze-Makuch[1], J.M. Dohm[2], A.G. Fairén[3], V.R. Baker[2,4], and R. Strom[4]
[1]Dept. of Geological Sciences, University of Texas at El Paso (dirksm@geo.utep.edu), [2]Dept. of Hydrology and Water Resources, University of Arizona, [3]Centro de Biología Molecular, Universidad Autónoma de Madrid, 28049 Cantoblanco, Madrid, Spain, [4]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ.

Although all inner terrestrial planets originated from very similar material of the planetary nebula, the worlds that developed after 4.6 billion years of solar system history are very different (Table 1). Mercury and the Moon are today inactive planetary bodies. Only Mercury's inner core appears to be still active, producing a significant geomagnetic field. On both planetary bodies, signs of surface activity include the emplacement of lava flows several billions of years ago. Mercury may have had some liquid water on its surface for a relatively short time period during its earliest stage of formation, and both planetary bodies appear to have some frozen water within impact basins near their poles. However, since Mercury and the Moon are without a protecting atmosphere and without significant amounts of liquid water, they are unlikely to ever have harbored life. The terrestrial planets Venus, Earth, and Mars, on the other hand, show many signs of dynamic activities still occurring today (Table 1). Dynamic features on the Venusian surface include coronae, igneous plateaus, large volcanoes, ridge and fracture belts, tesserae, and other volcanic and structural features. Earth is a dynamic, water-enriched planet where high erosion rates, magmatic-driven activity, and plate tectonism modify its surface over relatively short time periods. Earth transports heat through two primary modes, plate tectonism and plumes of diverse dimensions and origins ranging from superplumes [1,2] to mantle plumes [3]. Mars is primarily cold and dry, but these conditions are punctuated by volcanic eruptions that appear to have occurred until very recently and probably still occur [4]. Episodic endogenic-driven activity also resulted in flooding in the northern plains and short-lived hydrological cycles [5-7]. Orbital parameters such as changes in obliquity also are important factors concerning the surface modification of Mars [8,9].

Venus, Earth, and Mars likely had a similar atmospheric composition early in the history of the solar system derived by volcanic emissions containing mostly CO_2. However, Venus experienced a run-away greenhouse effect [10] developing an extremely thick atmosphere and high surface temperatures that eliminated all water from its surface. Earth's atmosphere became oxygen-rich due to successful organisms that used photosynthesis as a metabolic strategy. Due to its smaller size, Mars retained only a thin atmosphere with liquid water only being stable on the Martian surface at very low surface elevations. Early in solar system history though, life may have originated independently on Venus, Earth, and Mars, or may have been transplanted by "impact transpermia"[11] between these planets during time periods when liquid water was stable on their surfaces. The surfaces of all three planets might have been partially covered with oceans or lakes, and therefore provided suitable habitats for life at that time. This is no longer the case for both Venus and Mars. Surface conditions on Venus are extremely hot and desiccating, and on Mars very oxidizing and desiccating accompanied with high fluxes of UV radiation. If life ever gained a foothold on Mars and Venus as it did on Earth, subsequent climatic and geological changes could have driven it to search for protective niches into the subsurface in the case of Mars and into the atmosphere in the case of Venus. In the case of Mars subterranean voids may provide environments suitable for life to thrive [12] until environmental conditions improve such as when nutrients and energy are injected into the system, for example accompanied by a pulse of Tharsis magmatic-driven hydrothermal activity [7,13]. On Venus, a case has been made for life residing in the atmosphere [14,15]. On Earth, life is known to exist in both subsurface and surface environments, and at least transiently in the atmosphere. Through the investigation of extreme environments it has been learned that species can adapt by directional selection to environmental conditions that have been regarded prohibitive for life just a few years ago. It appears that as long as water can stay in the liquid phase, life can adapt. If so, life could exist in the Venusian atmosphere under relatively benign environmental conditions [15] and certainly in the Martian subsurface. Microbial organisms may have adapted from living in surface water pools to living in ecological niches of Venus and Mars. The presence of life on Venus and Mars can be argued upon, however it is certainly not as pervasive as it is on Earth, and therefore future missions will have to be specifically designed to optimally search these potentially life-containing terrestrial planets for possible microhabitats of life.

References: [1] Maruyama, S. (1994) *Journ. Geol. Soc. of Japan*, 100, 24-49. [2] Larson, R.L. (1991) *Geology*

19, 963-966. [3] Mege, D., and Ernst, R.E. (2001) *GSA Spec. Pap. 352*, 103-140. [4] Hartmann, W.K. and Berman, D.C. (2000) *J. Geophys. Res.*, 105, 15,011-15,025. [5] Baker, V.R. et al. (2002) *Geosciences* 7, (<http://lin.springer.de/service/journals/10069/free/conferen/superplu/. [6] Dohm J.M. et al. (2001) *J. Geophys. Res.* 106, 32,943-32,958. [7] Fairén, A.G. et al. (2003) *Icarus 165*, 53-67. [8] Touma, J. and Wisdom, J. (1993) *Science*, 259, 1294-1296. [9] Head, J.W. et al. (2003). *Nature* 426, 797–802. [10] Rasool, S.I. and de Bergh, C. (1970) *Nature*, 226, 1037-1039. [11] Melosh H.J. (1988) *Nature, 332*, 687-688. [12] Boston, P.J. et al. (1992) *Icarus* 95, 300-308. [13] Dohm, J.M. et al. (2000), *Lunar Planet. Sci. Conf.* [CD-ROM], XXXI, Abstract 1632. [14] Schulze-Makuch, D.. and Irwin, L.N. (2002) *Astrobiology, 2,* 197-202 [15] Schulze-Makuch, D. and Irwin, L.N. (2004) *Life in the Universe: Expectations and Constraints*, Springer.

Table 1. Terrestrial Planet's Characteristics

Process or Property	***Mercury***	***Venus***	***Earth***	***Moon***	***Mars***
Impact Crater Abundance	Large	Small	Very small	Large	Duality large/small
Surface Age	Very old, recording the early history of the Solar System	Young, recording only the last ~600 m.y.	Very young	Very old, recording the early history of the Solar System	Very diverse, the only planet that records the whole history of the Solar System
Present Geologic State	Inactive	Globally active	Globally very active	Inactive	Local and temporally active
Volcanic Features	Probably flood basalts; intercrater plains and smooth plains	Flood basalts; regional plains; lava flow fields; shield volcanoes; some viscous extrusions such as lava domes	Flood basalts; lava flow fields; wide-ranging types of volcanic constructs, which include composite, shield, cinder, and silicic-rich lava domes; hot spots	Flood basalts; intercrater plains and smooth plains	Flood basalts; intercrater plains and smooth plains; lava flow fields: mostly shield volcanoes; some putative viscous extrusions
Magmatism	Probably flood basalt volcanism as well as impact-induced volcanism (?)	From oldest to youngest: (1) global resurfacing event, (2) stagnant-lid, episodic (pulse-like) magmatism that results in regional to local uplifts and downdwellings and regional plains development; magmatic-driven tectonic activity and regional plains development transitions into centralized volcanism and more local tectonism	Mostly efficient internal heat release during plate tectonism with major pulses of paleomagmatic activity	Flood basalt volcanism; impact-induced volcanism	Putative early earth-like conditions that transitions into a stagnant-lid regime with episodic (pulse-like) magmatism such as observed at Tharsis and in the development of the regional plains; magmatic-driven tectonic activity and regional plains development transitions into centralized volcanism and more local tectonism
Tectonism	Global; early expansion (tension); late contrac-tion (compres-sion)	Possible early global plate tectonics (?) followed by stagnant-lid activity, which includes localized extension and contraction	Global to local; plate tectonics; extensional and contractional deformation related to both plate tectonics and magmatic-driven vertical tectonism	Local; basin subsidence; mainly tension	Early global plate tectonics (?) followed by stagnant-lid activity, which includes localized extension and contraction; regional and local magmatic-driven uplift; an order of magnitude difference is recorded in fault density and fault-length density at Tharsis when comparing the Noachian with the late Hesperian period
Hydro sphere	No	No, but some liquid water in the atmosphere	Yes	No	Early oceans and ice sheets (?); presently none, but probably ice and liquid water in subsurface
Weathering	No	Very little, if any	Extensive	No	Moderate (heightened erosion during endogenetic-driven climatic perturbations)
Atmosphere	No	Thick CO_2 (90 bars)	Moderate N_2, O_2 (1 bar)	No	Thin CO_2 (~8 mbars)
Polar Ice Deposits	Yes, ice (cometary ?) at poles	No	Yes, ice sheets and glaciers	Very little ice at poles	Past: larger ice bodies, present: polar caps with CO_2 and H_2O