LIFE AND DEATH ON MARS AND EARTH. K. Zahnle[1] and N. H. Sleep[2], [1]Mail Stop 245-3, NASA Ames Research Center, Moffett Field CA 94035, USA (kzahnle@mail.arc.nasa.gov), [2]Department of Geophysics, Stanford University, Stanford CA 94305, USA.

Failure to discover life on Mars has led a great many experts to conclude that it must be hiding. Where? The likeliest hiding places are deep beneath the surface, where geothermal heat could permit liquid water. In this the search for life on Mars parallels the search for water on Mars. Liquid water has been, at least on occasion, a geologically significant presence on the surface. Channels were cut and plains dissected. This water is now hidden, in all likelihood having drained to the base of the porous regolith, where it fills possibly frozen aquifers. Presumably any surviving biota has followed the water from the surface to its hiding places in the deep.

Accordingly, we have extended our environmental impact assessment of the environmental hazards posed by large asteroid and comet impacts to Mars, and compare its case to Earth's. In particular, we address the continuous habitability of surface and subsurface environments. The chief danger comes from globally distributed ejecta, which for very large impacts take the form of transient thick rock vapor atmospheres; both planets suffered such impacts repeatedly. Exposed surfaces are sterilized. On Earth much of the thermal radiation from the atmosphere is absorbed by the ocean, the surface of which boils. Shallow water quickly evaporates. Any surviving life lives either in deep water or well below the surface. On Earth, global thermal excursions are buffered by the heat capacity of the oceans, especially the latent heat of condensation. But when impacts are large enough to vaporize the oceans ($>10^{35}$ J), thermal buffering serves only to prolong the disaster: very high surface temperatures are maintained for the thousands of years it takes to condense and rain out 270 atmospheres of water vapor.

Mars presents several differences. Without oceans thermal buffering does not occur; therefore relatively small impacts (1033 erg) frequently heat the surface everywhere to near the melting point. However, owing to the low martian escape velocity, the most energetic ejecta (including much of the rock vapor) more easily escape to space, while massive quantities of less energetic ejecta are globally distributed. Martian rock vapor atmospheres do form when ejecta reenter the atmosphere, but the energy density is lower than for Earth. Obviously, survival in open water is more likely on Earth, where the energy required to boil the oceans is enormous. But survival in deep subsurface environments appears more likely on Mars because (i) Mars's lower background heat flow and lower gravity (the latter permitting open porosity at greater depths) allow deeper colonies, and (ii) the thermal heat pulse from a major impact is briefer, and so penetrates less deeply. A third factor that favors ultimate survival on Mars rather than Earth is that the bigger planet statistically experiences more and bigger impacts. Impacts on the order of 10^{34} ergs are known to have occurred on the Moon (S. Pole-Aitken) and Mars (Hellas), and 10^{35} erg impacts are likely on Earth. A 10^{35} erg impact on Mars would sterilize only the upper few hundred meters of the subsurface, while a similar impact on Earth would boil the oceans and sterilize the subsurface to 1 km depth.

An additional refuge that is poorly understood is ejection of weakly shocked material to space by impacts and its return to its home planet or transfer to a neighboring planet. It is clear that such transfer is plausible from Mars to Earth (Gladman et al. 1995), and it is not unlikely that such transfer can go from Earth to Mars. The huge number of impact events on early Earth and Mars opens the possibility that we descend from an ancestral race of inadvertant spacefarers. This view of the solar system has gone from speculation to truism in less than five years (Davies, 1999). Overall, early Mars may have been safer from impact sterilization than early Earth and probably was habitable before the Earth-Moon system formed.

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