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Discussion

A comment on tectonics and the future of terrestrial life—reply

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In our recent paper (Lindsay and Brasier, 2002) we evaluated stable carbon isotope data from 474 samples of platform carbonates collected from the Late Archaean and early Paleoproterozoic Hamersley Basin and associated basins of Western Australia. The data are consistent and compare well with data from rocks of similar age on other major ancient continental blocks (cf. Karhu and Holland, 1996; Bau et al., 1999). The data clearly reflect a global signal, which has been attributed to the oxygenation of earth's atmosphere and hydrosphere. The conspicuously bimodal nature of the secular carbon curve suggests that the global reduced carbon reservoir has grown episodically (see Knoll and Canfield, 1998 for a summary). This in turn has been taken to suggest that the atmosphere was oxygenated in a stepwise fashion (Des Marais et al., 1992) as a result of episodic burial of carbon during large scale tectonic cycles (supercontinent cycles; Des Marais, 1994; Lindsay and Brasier, 2000, 2002). When viewed in the larger context of earth history, there are several converging lines of evidence that suggest that carbon burial and oxygenation are linked to planetary evolution and that this in turn could have driven biospheric evolution. Not only is oxygenation an important component in the evolution of complex life but the recycling of biolimiting nutrients, especially phosphorus, is also important (Brasier and Lindsay, 1998). Without this driving mechanism we conjecture that the biosphere would enter a prolonged stasis and ultimately face extinction.

Gerstell and Yung (2002) raise a number of interesting and provocative points concerning the future of the earth and its biosphere but we point out that the focus of our conclusions (Lindsay and Brasier, 2002) was not the future of life on earth as they imply, but the early history of life on earth or even on smaller planets such as Mars. A planet with the mass of the Earth has the ability to retain a significant atmosphere and, with it, a hydrosphere, together with enough endogenic energy resources to maintain an active plate tectonic regime. The earth's plate tectonics regime has been sustained and prolonged by the role of water in lowering solidus temperatures (Hodder, 1986). Crustal evolution requires the formation of vast volumes of granite, which in turn is dependent upon the subduction of hydrated oceanic crust (Campbell and Taylor, 1983).

Mars is considerably smaller than earth and maintains only a thin atmosphere and, early in its history, a limited hydrosphere. It has been argued that Mars is more moon-like than earth-like with high cratering densities on the older highland regions, while the northern lowlands with their lower density of impact craters could be regarded

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as giant impact basins (Wilhelms and Squyres, 1984; Frey and Schultz, 1988). It is, however, difficult to explain this crustal dichotomy and the concentration of younger volcanism into localised province along the boundary between the two crustal provinces. Sleep (1994) has argued for limited early plate activity, suggesting that the northern lowlands of Mars were formed following subduction of thick older highland crust during the Late Noachian (ca. 3.85–3.50 Ga) or Early Hesperian (ca. 3.50–3.10 Ga) and its replacement by thinner crust formed at one or more spreading centres. McGill and Dimitriou (1990) further argued that the lowlands were due to crustal thinning in response to a mantle plume. Recently acquired evidence indicating a periodically reversing magnetic field on Mars supports an argument for the operation of plate tectonics for perhaps the first 500 million years (Nimmo and Stevenson, 2000). The evidence is by no means conclusive (McKenzie, 1999). Responding to the Sleep (1994) plate model Pruis and Tanaka (1995) analysed the distribution of volcanism on the surface of Mars and argued that his conclusions were not plausible. Thus, even though volcanic activity may have continued well beyond early crustal evolution, there is little evidence to suggest that the endogenic energy of the planet was able to drive a plate tectonic system for more than 500 million years. The small volumes of water present early in Martian history were probably not sufficient to induce the formation of granites and hence, sialic crust (Campbell and Taylor, 1983). In short, it matters little whether or not a plate system had begun to evolve on Mars since the planet would not have been dynamic enough, nor was the process of sufficient duration to drive any primitive biosphere forward towards greater biological complexity, as has arguably happened on earth.

While life may have begun to emerge early on in Mars history, particularly as planetary surface temperatures fell within a suitable range (ca. 0–100 °C), it seems that the planet's energy resources were rapidly exhausted, implying that any biosphere would have been forced into a prolonged stasis and possibly extinction. This suggests to us that the search for life on Mars should focus upon the early fossil record and, in particular, upon evidence for extremely simple organisms. The search for the earliest life on Mars will not be easy, however (cf. McKay et al., 1996; Brasier et al., 2002). A biogeochemical approach may be the best way forward for recognising pre-existing extraterrestrial life on small planets (e.g. McKay et al., 2000; Maule et al., 2002).

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