

OPPORTUNITIES FOR LIFE IN ACIDIC MARTIAN PALEOENVIRONMENTS

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A CO₂-dominated atmosphere in early Mars rendered an ocean mildly acidic [1] by releasing free protons in the sequence $\text{H}_2\text{O} + \text{CO}_2(\text{g}) \leftrightarrow \text{H}_2\text{CO}_3 \leftrightarrow \text{H}^+ + \text{HCO}_3^-$. The addition of iron contributed even more to oceanic acidification: hydrolysis of ferrous ion generates free protons by the equilibrium $\text{Fe}^{2+} + 2\text{H}_2\text{O} \leftrightarrow \text{Fe}(\text{OH})_2 + 2\text{H}^+$, and the process is much more effective if the iron is in the form of ferric ion $\text{Fe}^{3+} + 3\text{H}_2\text{O} \leftrightarrow \text{Fe}(\text{OH})_3 + 3\text{H}^+$. Moreover, jarosite minerals, as well as evaporite deposits containing magnesium sulphate salts, a typical sublimation residue, have been detected by the MER Opportunity in the sediments deposited at Meridiani Planum. The amount of salts detected, up to 40% in the outcrop [2], leads us to expect that sulphate levels in ancient martian oceans were at least at the same order of magnitude as those derived from weathered ultramafic rocks on Earth. Following the Opportunity results, however, we assume a Fe³⁺-enriched solution in equilibrium with jarosite at least locally and/or temporarily, so potentially displaying sulphate levels up to 13.5 mM.

For the Noachian oceans, aqueous thermodynamic calculations [1] considering such a solution enriched in iron hydroxides and sulphate result in a pH between 5.3 and 6.2 for the siderite-Fe²⁺ equilibrium; and if the ferrous iron was photolytically oxidized to ferric, the final pH was between 1.9 and 2.1 for the siderite-Fe³⁺ equilibrium. The subsequent evolution of the acidic environment over time results in Fe³⁺-sulphatetic species dominating the chemistry of the oceans.

A well-characterized terrestrial analogue to the acidic martian paleoenvironments are the headwaters of the Tinto River system (in the southwest of Spain), an extreme acidic environment controlled by iron biogeochemistry which produces ferric iron-enriched sediments dominated by sulfate and oxihydroxide parageneses, resulting in goethite, hematite and jarosite, analogous to the minerals found in Meridiani [3]. In the living Tinto River system, the values of pH, redox potential, and Fe³⁺ and sulphate concentration remain constant in different years under variable rain regimes. Life is highly diverse in the Tinto system, allowing us to suggest comparable ancient acidic aquatic habitats hosting a putative early biosphere on Mars. In fact, if biological inhabitation of early Mars is considered plausible, moderate acidic oceans represent the closest terrestrial analogue for a biogenic environment, similar to that where life originated on the Hadean-Early Archaean Earth [4,5]. In the Tinto River system, the remobilization of iron and its subsequent precipitation as ferric minerals preserves biological remains sometimes in remarkable detail, suggesting an analogue record in the rock exposures derived from the acidic martian early environments.

References

- [1] Fairén et al (2004) Nature in press. [2] Moore, J. M. Nature 428, 711-712 (2004). [3] Fernández-Remolar, D., et al. Planet. Space Sci. 52, 239-248 (2003). [4] Russell, M. J. & Hall, A. J. J. Geol. Soc. 154, 377-402 (1997). [5] Schaefer, M. W. Geochim. Cosmochim. Acta 57, 4619-4625 (1993).