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Remarkable habitability of a low water, low organic matter environment fueled by perchlorate

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Understanding of the limits of habitability is changing constantly as more extreme environments are investigated and further laboratory experiments are made. We explored a location in Israel, which is the site of a former ammonium perchlorate factory but is also in some respects a Mars analogue. The presence of perchlorate on Mars was determined by the Phoenix mission [1] and engendered speculation about its possible utilization as an energy source there, as it is for microbial populations on Earth. The site was investigated originally because of its potential for dangerous environmental pollution in both groundwater and the unsaturated zone. Nevertheless it has yielded invaluable insights into the viability of microbial processes in a hostile environment (which also is of value in planning possible remediation). The analogue site contains both perchlorate and chloride.

The element chlorine has been detected by all landed missions to Mars but its chemical speciation only determined by the Wet Chemistry Lab (WCL) component, part of the MECA instrument of Phoenix. This opened the question of speciation of the rest of the chlorine detected on Mars and in the absence a process whereby perchlorate is reduced (microbially driven on Earth), there is scope for large amounts of perchlorate in regolith also in lower latitudes than the Phoenix polar landing site. In the Israeli analogue site the unsaturated zone consists of 40 m of sands with sandy clay and clay layers. Unsaturated zone sediment samples contain not only perchlorate and chloride but also nitrate. DNA analysis gives evidence of the presence of both perchlorate reducing and nitrate reducing bacteria. This is surprising for many reasons. Microbial perchlorate reduction is an anaerobic process while the unsaturated zone should be aerobic. Also, there is very little moisture and very little organic matter, both of which are needed by the bacteria. We used chlorine stable isotope analyses to prove and then to quantify the extent of microbial perchlorate reduction.

We detected the microbial perchlorate reduction because imposes a very large isotopic fractionation, producing chloride with δ^{37}Cl values $\sim$15‰ more negative than the perchlorate [2]. Our results show that at some depths up to 10% of the perchlorate present in the unsaturated zone has been reduced. Since inorganic perchlorate reduction is kinetically inhibited, the process must be microbial as indicated by the DNA evidence. The extent of reduction is not correlated simply with depth, amount of clay present (a possible source of organic matter), or water content. Given the generally aerobic environment we infer that there must be anaerobic micro-environments in which the bacteria operate. This site resulted from anthropogenic pollution but like another contaminated area, Rio Tinto, offers extraordinary insights relevant to habitability of Mars. Active microbial processes in an environment where nutrients are extremely limited opens the possibility of similar occurrences on Mars either at greater depth in the polar regions (Phoenix landing site) or in other, warmer areas at low latitudes.

[1] Hecht et al. 2009 Science vol 325, 64.

[2] Coleman et al. 2003 Appl. Env. Microbiology vol 69, 4997.