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Astrobiology and the Exploration of Gusev Crater by the Mars Exploration Rover Spirit

David J. Des Marais[1] and the Athena Science Team

We assess the availability of nutrient elements, energy and liquid water on the plains surrounding Columbia Memorial Station by evaluating data from Spirit in the context of previous Mars missions, Earth-based studies of martian meteorites and studies of microbial communities on Earth that represent potential analogs of martian biota.

The compositions of Gusev basalts resemble those of olivine basalts beneath the seabed on Earth that deep drilling has shown to support life. Of particular relevance to biology, phosphate abundances are much greater in Gusev basalts (0.84 ± 0.07 wt. % P_2O_5) than in oceanic basalts (typically 0.06 wt. %).

Habitable environments must provide, at least intermittently, sources of energy to fuel metabolism and self-replication, and repair cellular constituents. Within Gusev crater, impacts and aeolian activity have reworked ancient basalts in a surface environment that has been dominated by dry and desiccating conditions for billions of years. In the absence of light, chemoautotrophic microorganisms can exploit oxidation-reduction reactions (e.g., of Fe^{2+}, Mn^{2+} and S species) to obtain energy. These reduced species and their oxidized alteration products have been documented in martian meteorites. On Earth, subsurface communities dominated by methanogenic archea obtain their energy and reducing power from H_2 and CO_2 generated by hydrothermal activity. The aqueous alteration of ultramafic rocks produces H_2, a near-universal source of energy and reducing power for microorganisms. Martian igneous rocks exhibit a broad range of silica and olivine abundances that broadly overlap compositions of mafic and ultramafic rocks on Earth, including rocks that have been shown to sustain subsurface microbial communities. Three Gusev basalts have olivine abundances that lie near middle of this range of abundances. Gusev basalts also contain magnetite and show evidence of at least limited chemical alteration. Although magnetite can occur solely from igneous processes, it also might indicate that olivine was altered to form serpentine, magnetite and H_2.

The minimum water activity that is necessary to sustain microbial processes is ~0.75 for haloarchea in NaCl brines and ~0.61 for fungi in high sugar media (distilled water has an activity of 1.00). Evidence for the former presence of liquid water has emerged from analyses of materials in the basaltic plains. Laguna Hollow is a shallow impact crater that has been filled relatively recently with fine-grained deposits. A trench revealed a mixture of silicate and soluble salt constituents that are uniform with depth. Percolating water would have preferentially mobilized soluble salts and created abundance variations with depth. Habitable conditions very likely never developed within this fill since it and perhaps other such deposits were emplaced in Gusev. Spirit excavated two trenches ("Big Hole" and "The Boroughs") in flat terrane that was remote from larger craters and thus developed over longer periods than soils in ejecta blankets and small impact-generated hollows. Abundances of S, Mg, Cl and Br varied with depth in these trenches, indicating that water probably percolated through these soils. Given the great age inferred for the Gusev plains landscape, these basalts might have formed 10^8 to10^9 years ago. Water might have weathered rock surfaces and deposited minerals in vugs and cracks. But the bulk elemental abundances of these rocks resemble those of unaltered olivine basalts. Thus water/rock values were low, fluid movements were minor, thus it seems unlikely that these rock interiors could have sustained life. A few rocks on the Gusev plains exhibited exfoliation and case hardening, features indicating extensive chemical alteration. The compositions of these rocks were not determined because they were found in images retrieved from Spirit after it had departed the area.

The dry and cold climate of Mars is due in part to the planet's current obliquity of 25.19°. This is far from 41.80°, which the most probable value over the long term. Dramatic increases in summer insolation can create dynamical instabilities in the polar caps that can drive atmospheric humidity levels to as much as 50 times the present level. Quick disappearance of polar caps over some obliquity cycles can create surface ice in equatorial areas. During earlier periods when the obliquity of Mars was high, basal melting of snow/ice deposits might have recharged subsurface aquifers in Gusev crater. Also, transient increases in atmospheric density associated with large, sustained volcanic eruptions may have permitted liquid water to be stable near the surface. Aquifers that were periodically recharged might have sustained habitable conditions for geologically long periods of time. Because mafic and ultramafic terrains exhibit the potential to sustain chemosynthetic microorganisms in subsurface environments, these terrains merit closer scrutiny in future orbital and landed missions.