SOLFATARA GAS/GAS INTERFACES: A NOVEL HABITABLE MARS ENVIRONMENT?

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The search for near-surface life on Mars is hampered by the limited availability of liquid water reservoirs. We report finding microbial biofilms on rock surfaces in gas:gas interfaces from solfatara environments on Earth, analogues of which may also be found on Mars. This habitat does not require the proximity of liquid water reservoirs (such as subsurface aquifers, springs, ponds or melting ice). At solfatara interfaces liquid water is in the form of thin films on rock and mineral surfaces produced by condensation of water vapors from solfatara emmisions. On Mars, such water films may be maintained in liquid phase even at low temperature and pressure due to high surface salinity and acidity leading to a condensation / evaporation / sublimation equilibrium.

We observed microbial biofilms in a solfatara habitat on Earth (Smelly Cave, Romania). In this area volcanic gas emissions fill subsurface voids to a level where a redox gas:gas interface forms with hydrogen sulfide (H_2S) and carbon dioxide (CO_2) below and atmospheric dioxygen (O_2) on top. Water is only present in thin surface layers but sufficient for the maintenance of microbial biofilms. The dominant secondary minerals are orthorhombic sulfur (S^o), alum ($KAl(SO_4)_2 \bullet 12H_2O$) and gypsum ($CaSO \bullet 2H_2O$). The wall's surface pH is approximately 0.5-1.0, due most likely to sulfur oxidation to sulfuric acid.

Microbial biofilms are abundant on the rock walls at the H_2S/O_2 gas:gas interface. Based on 16S rDNA and metagenomic sequencing, the microbial community is dominated by *Mycobacterium* bacteria and Ferroplasmaceae archaea. The microbial biofilms are most abundant at the gas:gas interface, with a thickness of up to approximately 5 mm and a vertical span of approximately 5 cm. Microbial biofilms are not visible above and below the redox interface, but scanning electron microscopy (SEM) has revealed isolated cells afar from the redox interface that were also detected in low abundance in DNA extracts. SEM images show abundant fiber-like structures resembling nanowires between cells and the orthorhombic sulfur crystals. These fibers are slightly visible at 1,000x magnification and easily visible at 2,500x.

Approximately 10 to 20 cm below the microbial mats, on the cave walls, massive soft deposits of elemental sulfur are present (up to 20 cm thick). These deposits consist of very dense bundles of sulfur fibers (approximately 1 µm in diameter) oriented perpendicularly to the cave wall. Their origin is unclear.

Exinct fumaroles are abundant on Mars, but active fumaroles may also be present. It is expected that some fumaroles on Mars are sulfatara (i.e. fumaroles emmiting reduced sulfur gasses such as hydrogen sulfide). The Tarsis province is a place on Mars where S-rich volcanic emissions have existed in the past. The Home Plate formation at the Gusev Crater is also suspected to be the eroded remains of an ancient and extinct fumarole. Elemental sulfur from solfatara activity may be common on Mars. Sulfur-rich deposis were found by APXS at Gusev, some of which are believed to be elemental sulfur.

We offer an alternative to the precept "*find liquid water reservoirs on Mars in order to find habitable environments*". Based on our work, the strategy we sugest for finding and studying past or extant habitable gas:gas interface sulfatara environments on Mars is:

- remote observations to locate areas where active or fossil solfatara fields exist;
- lander-based visual observation of geomorphology to locate potential (past or present) gas emission zones;
- chemical characterization of rock surfaces by laser-induced breakdown spectroscopy;
- close proximity gas and redox analyses to detect active sulfataras and gas:gas interfaces;
- low resolution imaging and mineralogy analyses;
- detection of water films and quantification of pH on rock surfaces;
- high resolution microscopic observation to search for fossil or active biofilms, cells, sulfur fibers and nanowires; and
- stable isotope analyses.

We propose that this exploration strategy will greatly expand the range of sites to search for habitability, microbial fossils and life on Mars.