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Introduction: Lava tubes, pit craters and skylights observed by Mars-orbiting spacecraft provide strong evidence of caves on Mars. Likewise similar features have been spotted on the Moon. Caves, modified into underground Moon or Mars bases, would provide shelter from radiation for human habitation. On Mars at least, lava caves may provide locations where water or ice are present, along with protection from radiation, conditions suitable for extant or past life.

For more than a decade, we have investigated the idea that the subsurface of Mars is the most likely place to find life or its traces. We have conducted extensive geomicrobiological, mineralogical, and geological fieldwork in a variety of lava caves in tropical to arid conditions. All the caves that we have sampled show evidence of microbially induced or precipitated minerals through SEM examination and DNA analysis [1]. Many microbial communities we have sampled are unique to the subsurface and represent countless novel strains [2].

Minerals in phase change caves (lava caves).

Cu and V minerals. Ephemeral minerals may be present in lava caves, largely related to fumarolic activity, including Cu-V oxides such as mcbirneyite [$Cu_3(VO_4)_2$] or ziestite [$Cu_2V_2O_7$] [3]. We have observed yellow and golden yellow V-bearing minerals in two cold, high altitude caves on Mauna Loa, Hawaii. SEM-EDS analysis revealed microbial evidence in the form of filaments, carbon-rich biofilm and putative cells closely associated with these minerals. We have observed other Cu minerals in lava caves in both Hawaii and New Mexico, also closely associated with evidence of microbial activity. These include reticulated filaments intermingled with Cu-Al silicate identified as chrysocolla by XRD in Maelstrom Cave on the flank of Mauna Loa. Unidentified Bi minerals associated with putative microbial cells in a greenish mineral coating were also found in this cave (Figure 1). Other, as yet unidentified, blue-green mineral deposits are present in lava caves at El Malpias National Monument in New Mexico.

Bismuth and V exhibit moderate volatility in volcanic systems. As fumarolic sublimates, Bi and V fall more or less midrange between volatile (e.g. S) and non-volatile elements (e.g. U) in fumarole deposition experiments [4]. Copper occurs slightly more toward the volatile side, similar to Zn in order of sublimation. Thus Cu-Bi-V minerals may be present as the result of degassing of the lava and crystallization after the tube drains. However, all the sites that we have examined show evidence of microbial filaments, slime, and cells within the minerals. This microbial evidence poses a question: are these unusual mineral deposits the result of abiotic sublimation which are then utilized by microbial communities or are they biotic in nature and the microbial community has enriched low levels of metals from the lava as a result of life processes.

Sulfates and carbonates. Both calcite and gypsum are common in lava caves as crusts, protrusions, and stalactites. These minerals may be present as moonmilk, a coagulation of disordered micro-sized individual crystals, plastic in nature, and containing up to 80% water as a paste (or as a crust when dry). Moonmilk may be of biogenic origin, chemogenic or of mixed origin [5].

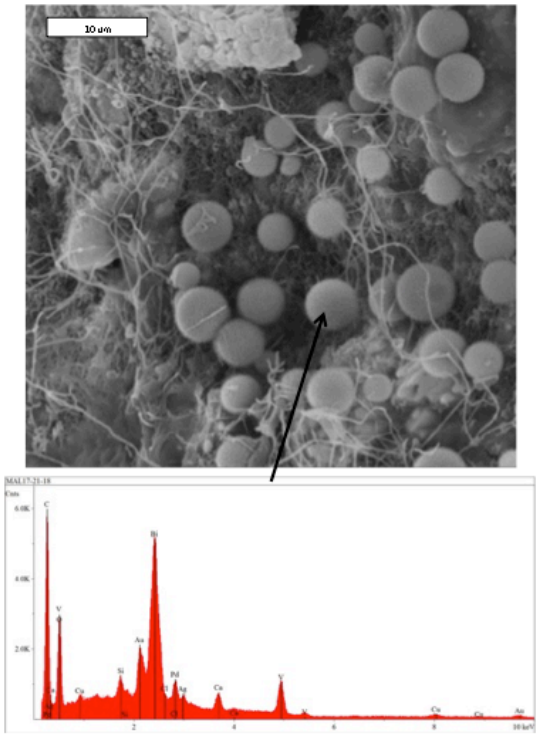

Fig. 1. Bismuth-vanadium oxide associated with microbial filaments and putative cells from a greenish mineral crust in a Hawaiian lava cave.

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