EXTRATERRESTRIAL CAVES AS ARCHIVES OF LIFE. M. N. Spilde[1], P. J. Boston[2], L. A. Melim[3] D. E. Northup[4]. [1]Inst. Meteoritics, Univ. New Mexico, Albuquerque, NM 87131, mspilde@unm.edu; [2]Dept. of Earth & Environmental Sci., NM Tech, Socorro, NM, 87801 and National Cave & Karst Research Institute, Carlsbad, NM; [3]Geology Department, Western Illinois University, Macomb, Illinois. 61455; [4]Biology Dept, UNM, Albuquerque, NM 87131.

Introduction: Microorganisms exist in the subsurface of Earth, living within open spaces in the rock. The void space represents a continuum of micro- to macroporosity, from voids that exist as intergranular pore space all the way to cave-sized voids that humans can enter. Caves provide a window into the near subsurface and can shelter organisms from harsh surface conditions. They can act as a permanent refuge, since water and favorable living conditions may exist there when such conditions are not present at the surface. Caves hold extant life and preserve evidence of past life here on Earth. Extraterrestrial caves may also harbor extant life or at least preserve evidence of past life. Lava tubes are known to be present on Mars, and high resolution imaging of the surface of Mars has revealed several likely cave openings [1]. Such caves may be important targets for future astrobiological missions.

Caves on Earth and other planets can be classified into several different types: 1) solution caves, such as those in carbonate or sulfate substrates; 2) erosional and suffosional caves, such as sea caves and soil sapping caves; 3) caves formed by phase transitions, including lava tubes and ice caves; or 4) tectonic caves, expressed as large cracks or fractures. However, significant questions surround the ability to look for life on other planets beyond the Earth. How will we know if there is or was life present? What should we look for? Regardless of the style of cave formation, certain fundamental principles should apply when we look for evidence of life. However, several questions must be considered before we can effectively commence such a search: 1) How long will direct evidence of microbes persist? and 2) If direct evidence is not present, are there other means by which we can reliably determine the past presence of microbes?

Persistence: How long will evidence of microbial involvement persist? In hot springs environments such as in Yellowstone, microbes are rapidly coated and destroyed by precipitates but frequently leave distinctive mineral fabrics [2]. Caves may preserve the organic remains of microbes much better than other environments because there is no weathering in the usual sense of the term, there are stable temperatures within limits, there are few higher order grazers, and no destructive ultraviolet radiation (e. g. sunlight). Thus, original organic material, including organic carbon, proteins, DNA, etc. degrade slowly or little at all, and may persist over geologically significant time periods. However, little is known about the limits of actual preservation or its duration.

Biopatterns: Can we look for other evidence of biological involvement if the microbial organic material doesn't survive? In our previous work, we have shown that there is a suite of unique carbonate features present in some caves that may help identify the presence of microbial precipitation [3, 4]. Features such as pool fingers and pool precipitates provide this evidence, and their unique morphology forms a type of biopattern. In addition, the precipitation of calcite that makes up these features traps exopolysaccharides and microbial bodies or filaments, providing further evidence of microbial involvement. The existence of microbial casts is common in biogenic minerals and is noted by many workers. These casts can be thought of as another style of biopatterning. Yet another type of biological remnant is a self-organizing, macro-scale repetitive form (Fig. 1) recognized on cave walls and other protected or sheltered environments [5]. This type of biopattern is created by the influence of gravity and fluid movement on microbial colonies. It is preserved in the biofilm by the incorporation of clays and detrital minerals, leading to long-term preservation via lithification after the biofilm has dried or decomposed.

Mineral Biosignatures: On Earth, microorganisms that live in the subsurface can survive on energy derived from organic materials from the surface or on chemical energy available in the rock itself (chemolithotrophy). However, even where no surface biota is available to provide organic material, organisms can thrive on inorganic energy sources. Even in this circumstance, it is not necessary for every organism to be chemolithotrophic, and we have shown that subsurface communities exist as consortia [6] with microorganisms as specialists, certain ones providing energy and others, such as nitrogen-cycling bacteria, providing other necessary nutrients.

Manganese and iron oxidizing microorganisms are abundant in some caves where metal oxidation may provide an energy source for the microbial communities. The deposits of intimately associated Fe- and Mn-oxides found on the walls, ceilings and floors of the caves are known as ferromanganese deposits (Fig. 2)[7]. The types of oxides in these deposits, such as the Mn-oxide todorokite, can alone be indicative of microbial activity. Indeed the mere presence of these metal oxides, out of equilibrium with the surrounding environment, may be enough to suggest microbial deposition.

One apparent misunderstanding that persists in our current knowledge of microbial minerals is the question of which species are responsible for producing the observed biominerals. Mineral deposition is not necessarily limited to only those microbes that have been identified as carbonate or oxide producers. Genes for mineral production may exist in many species or may be passed between species. However, it may not be expressed as precipitation behavior in circumstances outside of the cave environment that are less favorable. A study in 1973 showed that carbonate precipitation was an exceedingly common phenomenon among soil bacteria [8]. Therefore mineral deposition may not be limited to known or identified carbonate or oxide producers and may be ubiquitous among cave microorganisms.

Discussion and Conclusion: Caves are a stable environment and usually contain some level of water that is required for life to survive. This may also be the case even on an arid planet like Mars. Although caves are usually low energy environments, niche-filling microorganisms in terrestrial caves have taken advantage of this situation because of a lack of competition with other faster-growing organisms that require higher energy levels.

Because of their high potential for life preservation, extraterrestrial caves should make good targets for life-detecting exploration and a robust understanding of the biopatterns and biosignatures that life leaves behind will be essential to such future missions.

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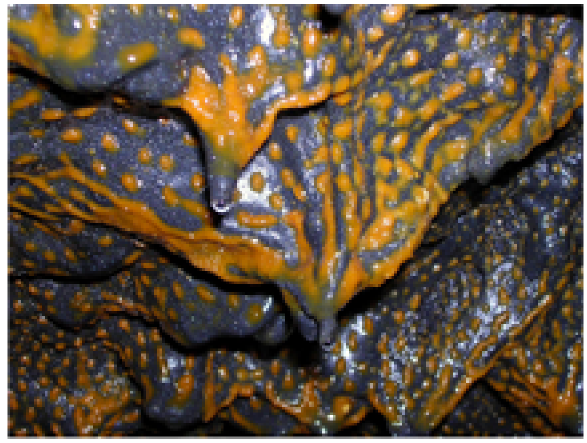

Figure 1. Example of a biopattern on the wall of a lava tube in the Azores. Bright orange areas are biofilm. Width of photo is approximately 4 cm. Photo by Stefan Kempe.

Figure 2. Sampling ferromanganese deposits in Lechuguilla Cave, New Mexico. Image courtesy of Val Hildreth-Werker