MICROBIAL SILICIFICATION TRENDS IN ALKALINE HOT SPRINGS, YELLOWSTONE NATIONAL PARK, USA

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ABSTRACT/RESUME

Thermophilic microbial communities that thrive in the geysers and hot springs of Yellowstone National Park represent analogs of some of Earth's earliest inhabitants. We report here on the mineralization of microorganisms observed in alkaline silica-depositing hot springs located in Yellowstone National Park. Analytical scanning electron microscopy of microbial streamers revealed that fossilization results from the aggregation of opal-A colloids. Patterns of deposition strongly suggest at least two distinct modes of formation for the colloids: homogeneous precipitation from supersaturated hydrothermal fluids that build up inside cells, and heterogeneous precipitation and flocculation from supersaturated solutions in the sheaths of the bacterium and on microbial cell surfaces.

1. INTRODUCTION

The recognition of morphological biosignatures in ancient terrestrial or extraterrestrial rocks requires an integrated approach across a range of spatial scales. We have conducted fieldwork and used various types of microscopy and chemical analysis to investigate the earliest stages of silicification of different types of microbial mat streamer communities in alkaline hot springs and geysers of Yellowstone National Park. When first deposited, sinter from such waters consists of opal-A, an X-ray amorphous hydrated silica phase. In a previous paper we reported that distinctive submicroscopic morphological biosignatures of microbial streamers are preserved in alkaline hot spring environments, and that these biosignatures can be recognized in modern fossilized hydrothermal deposits [1]. In all of the samples analysed, fossilization results from the formation and accumulation of opal-A colloids. Here we present scanning electron microscope (SEM) evidence that provides important clues regarding the mode of formation of the colloids that occur in association with thermophiles.

2. MATERIALS AND METHODS

Samples for this study were collected during July, 1998, from two alkaline silica-depositing hot springs in Yellowstone National Park: Queen's Laundry, located in Sentinel Meadows, and Pool C, located in the White Creek area. The samples, collected using sterilized tweezers, were fixed in the field with a 2.5-3% (v/v) solution of aqueous glutaraldehyde prepared with filtered (0.7µm) thermal spring water. At the end of each day the samples were stored in a refrigerator at 4°C. The samples were transported on ice approximately one week after collection to the Space Sciences Microscopy Laboratory at NASA Ames Research Center.

For microscopy analysis the fixative solution was replaced with an 0.1M cacodylate buffer and specimens were dehydrated in successive baths of increasing organic solvent concentration (acetone or ethanol) and critical point dried (Pelco CPD2). The specimens were attached to aluminum stubs using either colloidal graphite or silver paste. To increase conductivity a thin (10nm) coating of chromium was sputtered under vacuum onto each SEM specimen using an ion beam sputter coater (Gatan TMS200S). Observations were made using an Hitachi S-4000 scanning electron microscope and photographs were taken using Polaroid Type 52 film (black and white, 400 ASA). Qualitative chemical analyses at precise locations on the samples were obtained using an energy dispersive X-ray spectrometer attached to the SEM.

3. RESULTS AND CONCLUSIONS

Samples from Queen's Laundry showed filamentous cells (~5µm diameter) filled with opal-A colloids (~0.25µm diameter) (Fig. 1). The close packing of the colloids inside the cells is indicative of homogeneous precipitation from supersaturated hydrothermal fluids, a purely chemical mode of mineral formation (Fig 2).

In contrast, smaller filamentous microfossils collected from Pool C were silicified as a result of the accumulation of colloids (~0.1µm diameter) on the outer surfaces of the microbial cells (Fig. 3). These colloids are neither perfectly symmetrical nor regularly distributed around the cells.

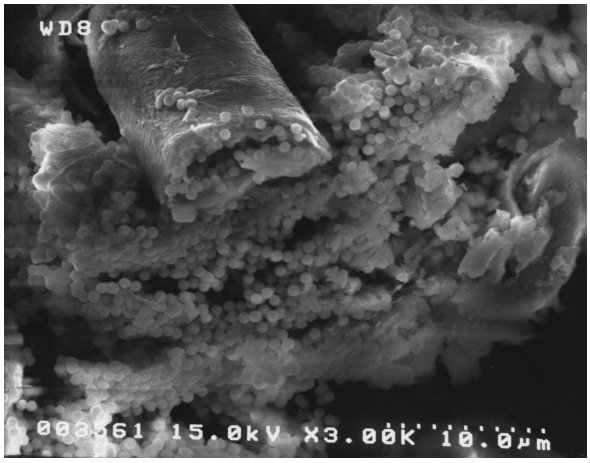

Fig. 1. *Oscillatoria*-like cells from Queen's Laundry

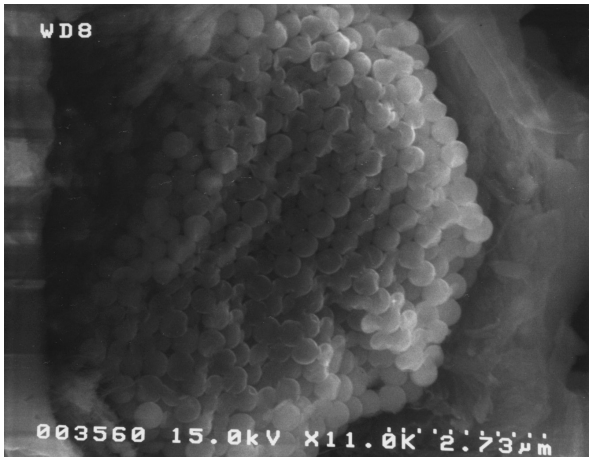

Fig. 2. Regular arrangement of colloids inside a cell

The asymmetrically shaped microfossil shown in Fig. 4 provides insight into this type of colloid formation. At the time of silicification, the left hand side of the cell's extracellular sheath was compressed against a relatively flat surface. In spite of the distortion in cell morphology, the extracellular matrix served as an accumulation site for silica colloids. The cell surface inside the sheath appears to have resisted compression and silica colloids are also associated with the cell surface. The inner diameter of the microfossil (~1µm) is about the same size as *Chloroflexus sp*., the dominant member of the 65°C microbial community in Pool C where the sample was collected. The small, irregular shape of the colloids associated with the filamentous bacteria, their aggregation inside the sheath of the filament, and the close proximity of the colloids to the outer cell membrane strongly suggest that they formed via heterogeneous precipitation and flocculation on the bacteria. We consider this process of fossilization to be mediated by mineral-microbe interactions.

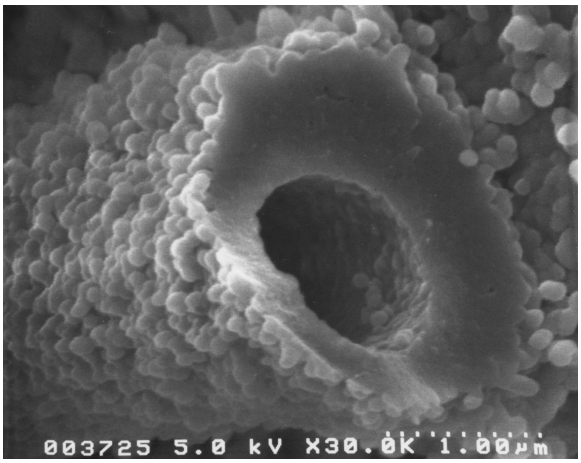

Fig. 3. Silicified bacterial filamentous cell from Pool C

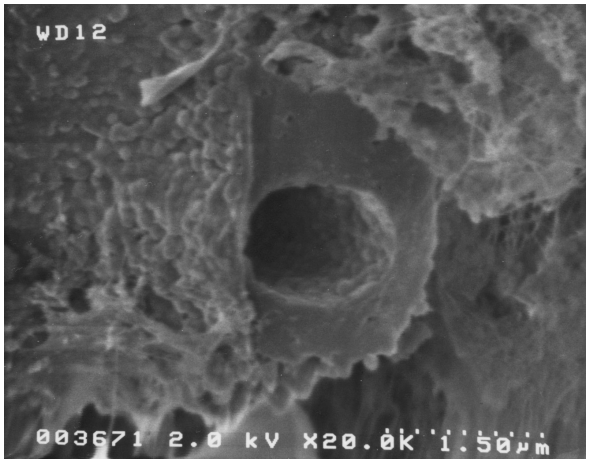

Fig. 4. Asymmetrically silicified cell from Pool C.

4. REFERENCES

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5. ACKNOWLEDGEMENTS

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