SILICEOUS SHRUBS IN YELLOWSTONE'S HOT SPRINGS: IMPLICATIONS FOR EXOBIOLOGICAL INVESTIGATIONS. S. A. Guidry[1, 2] and H. S. Chafetz[2], [1]ExxonMobil Production Co., 800 Bell St., Houston, TX 77002 (sean.a.guidry@exxonmobil.com), [2]University of Houston, Department of Geosciences, Houston, TX 77204-5007.

Introduction: Potential relict hot springs have been identified on Mars and, using the Earth as an analog, Martian hot springs are postulated to be an optimal locality for recognizing preserved evidence of extraterrestrial life [1]. Distinctive organic and inorganic biomarkers are necessary to recognize preserved evidence of life in terrestrial and extraterrestrial hot spring accumulations. Hot springs in Yellowstone National Park, Wyoming, U.S.A., contain a wealth of information about primitive microbial life and associated biosignatures that may be useful for future exobiological investigations.

Numerous siliceous hot springs in Yellowstone contain abundant, centimeter-scale, spinose precipitates of opaline silica (opal-A). Although areally extensive in siliceous hot spring discharge channel facies, these spinose forms have largely escaped attention. These precipitates referred to as "shrubs", consist of porous aggregates of spinose opaline silica that superficially resemble miniature woody plants, i.e., the term shrubs. Shrubs in carbonate precipitating systems have received considerable attention [2], and represent naturally occurring biotically induced precipitates. As such, shrubs have great potential as hot spring environmental indicators and, more importantly, proxies for pre-existing microbial life.

Observations: At Cistern Spring, a siliceous terraced mound accumulation, shrubby precipitates are evident in approximately 1900m^2 of the deposit. Siliceous shrubs occupy shallow terracettes (1-20cm deep) and can be observed throughout most of the 20m of Cistern's flowpath. The shrubs constitute a major precipitate style associated with discharge channel/flowpath facies of siliceous terraces, and are found in siliceous spring waters ranging in temperature from 76.4 to 16.2 ^{o}C and pH from 6.0 to 7.4. Whereas adjacent rimstone dams tend to be characterized by smooth walls of opaline precipitates, pool bottoms tend to be bumpy and irregular and are characterized by the shrubby siliceous precipitates. Shrubs have a radiating or arborescent form, consisting of aggregates of bladed opal-A (1-5cm high). Even at the macroscale, mucilaginous microbial colonies occupy the bladed precipitate edge and vary in color from brownish-grey (higher temperature) to orange or green (lower temperature).

At the thin-section scale, shrubby horizons from Cistern Spring exhibit different assemblages of microbes associated with the precipitates. At higher temperatures, microbial filaments lacking pigmentation in transmitted light are predominant. These filaments are generally 4μm in width and 80μm long, and lack a readily apparent sheath. In contrast, shrubs from lower temperature environments generally exhibit sheathed filamentous microbial remains with faint orange or green pigmentation in transmitted light. Lower temperature filamentous microbes associated with shrubs are about 2.5μm wide and highly variable in length (up to 100 μm) with sheaths approximately 0.75μm wide. Clear, isopachous opal surrounds the filaments, producing tubular forms. Although the predominant shrub-building microbes vary over the length of Cistern Spring's flowpath, some communities of microbes are ubiquitous. For example, dark curved or straight rods 1 micron in length are common in shrubs from both environmental settings. Similar to travertine shrubs, siliceous shrubs were observed to fluoresce under 420nm wavelength fluorescent light, an indication of the presence of light hydrocarbons.

Perhaps the most revealing perspective of siliceous shrubs can be gleaned from 3D microscopy. Shrubs consist of dense "tangles" of filamentous microbial remains and associated polymeric substances in various stages of silicification. These tangles of microbial material are the framework of the siliceous shrub. Where silicification is readily apparent, silica appears to form regular, isopachous coats around the filament, i.e., evidence for subaqueous precipitation of the silica. Silica is also associated with some of the external polymeric substances (mucilage) that surrounds the microbial community.

SEM images reveal that the surface of the shrub is smooth opal-A. The architecture of the precipitate consists of a myriad of silicified strands that have a superficial resemblance to fiberglass. The precipitates envelope these strands in an equal coating: no great variations in the thickness of precipitates were observed over the length of an individual strand or filament. Where this surface is broken, filaments are readily apparent and some strands were observed to desiccate under the electron beam. These silicified filaments commonly are 1 μm wide, and often exhibit division septae. Silicified extracellular polymeric substances (EPS), or biofilms, are very abundant. Some filaments appear to be smooth, whereas others have a thick coating of opaline spheres 100-200nm in diameter.

Discussion: The biologic affinity of shrubs in siliceous systems has been debated, however, much work has been done in the travertine systems to indicate that the shrubs are indeed bacterial in origin [2]. Similar shrubs have also been documented in Fe- and Mn-precipitating systems, and a wide variety of bacterial forms have been observed within the shrubby precipitates (e.g., straight and slightly curved rods, chains of coccoidal bacterial cells) [3]. Shrubs in travertine and Mn- and Fe-precipitating systems are thought to be the product of bacterially induced carbonate precipitation, and by analogy siliceous shrubs may result from similar processes. Thus, it is our interpretation that the bacterially induced shrubby precipitate form extends beyond carbonate and manganese precipitating systems and is common in hot spring opaline systems.

Siliceous shrubs in Yellowstone's hot springs reflect a strong biotic influence on the precipitate fabric. The observation of bacterial colonies on the blades of siliceous shrubs further substantiates a strong biotic influence on the framework of the precipitates. In petrographic thin-section, silica has an intimate association with the bacterial remains (e.g., filaments and biofilms). At any given locale, a variety of bacterial taxa are present (e.g., curved rods, filaments), thereby providing evidence that shrubs are the products of a complex and taxonomically diverse microbial community. Thus, the shrubs are the product of a bacterial community and the community members evolve with changes in temperature. Therefore, shrubs are the product of these diverse communities in silica-rich systems just as other communities produce shrubs in carbonate and Mn- and Fe-rich systems.

Siliceous shrubs are a reasonably good facies indicator of a discharge channel/flowpath setting, and may be the most volumetrically significant precipitate style associated with silicified terraced deposits. The case for siliceous shrubs as potential microbial biomarkers is substantiated by observations at numerous levels. At the outcrop level, shrubs are widespread and have a distinctive form. In thin-section and SEM, shrubs contain abundant evidence of well preserved morphological remains encapsulated within the silica. Coupled with the preserved morphological remains, preserved organic remains are abundant and distinctive of bacteria. Thus, siliceous shrubs are good environmental indicators and potential candidates for exobiological microbial biomarkers.

Conclusions: Siliceous "shrubs" are composed of bladed aggregates of opal-A with an arborescent or branching pattern, and have strong morphological similarities to shrubs from carbonate precipitating hot springs. They occupy an areally significant portion of the discharge channel/flowpath facies of siliceous terraced mound accumulations. At Cistern Spring, shrubs are evident along most of the 20m of flowpath, and become more robust downflow.

At every scale, siliceous shrubs contain abundant evidence of microbial life in the form of bacterial body fossils and extracellular polymeric substances (EPS). Shrubs consist of dense "tangles" of these biological materials and resemble a "fiberglass" texture. Mucilagenous microbial colonies can be seen occupying the blades of the shrubby precipitates. Silica is intimately linked to biological remains. The presence of relict biochemical constituents and bacterial morphological fossils indicate that the shrub fabric and architecture are dominated by bacteria. Precipitation of opal in siliceous shrubs is very likely the result of either active bacterially induced precipitation or passive mediation through organic templates. In either case, organic material is a requisite to the precipitation process.

Shrubs are widespread, have a distinctive morphology and, thus, are good hot spring environmental indicators. On a larger scale, siliceous shrubs contain abundant evidence of former microbial activity in hot springs, thus they also could be good microbial biomarkers. Future exobiological studies may be able to utilize these features as reliable indicators of preexisting microbial life.

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