MICROFABRICS IN SILICEOUS HOTSPRINGS: YELLOWSTONE NATIONAL PARK, WYOMING.
S.A. Guidry[1], H.S. Chafetz[1], and F. Westall[2], [1]University of Houston, Dept. of Geosciences, Houston, TX 77204-5503, [2]Lunar and Planetary Institute, 3600 Bay Area Blvd., Houston, TX 77058-1113.

Introduction: Recently, study of hotspring deposits has gathered impetus because of the increasing potential of extraterrestrial exploration and one of its scientific cornerstones: determining whether life arose in other areas of the solar system. Potential relict hotsprings have been identified on Mars [1] and, using the Earth as an analog, the Martian sites are postulated to be the optimal locality for recognizing preserved evidence of extraterrestrial life [2]. Success of any future Mars mission depends on a better understanding of the physical characteristics and processes governing the distribution of hotspring facies on Earth.

Several siliceous hotspring systems in the Norris and Lower Geyser Basins of Yellowstone National Park, Wyoming, were studied in order to gain further insights into depositional facies patterns and associated microfabrics. Cistern, Octopus, Deerbone, and Brock springs are active hotsprings where parameters such as water temperature, pH, and elemental abundances could be coupled with distinct lithofacies. Pork Chop Geyser, an inactive, siliceous deposit, further extends this facies model to a relatively young "rock record" hotspring deposit. Eight hotspring/geyser depositional facies identified are: 1) vent, 2) proximal vent, 3) pool, 4) pool margin, 5) pool eddy, 6) discharge channel, 7) debris apron, and 8) geyser (Fig. 1).

Observations: *Vent Facies (>90 ^oC):* Siliceous hotspring vents are composed of aggregates of dimpled, hemispherical chalcedony crystallites 0.5-0.75cm in diameter with a surface texture similar to a golf ball. In thin-section, they are clear, length-fast, and exhibit occasional dusty bands of radiating fluid inclusions which align with radiating bundle fibers. SEM analyses provide the greatest detail of these crystals, revealing regularly banded chalcedony with a botryoidal surface texture. Even at this scale, there is a sharp contact between the vent chalcedony and the adjacent proximal vent facies.

Proximal Vent Facies (<90 ^oC): Immediately adjacent to the vent are areas greatly influenced by the influx of hot water which extend a short distance downflow (usually <1m). The chalcedonic crystallites are much smaller than those comprising the vent facies (~0.5-1.0mm in width), and are length-slow. This length-slow chalcedony is a marked deviation from the chalcedony lining the vent. Non-oriented, dusty inclusions are only concentrated in zones near the crystal bases. In SEM, two major types of chalcedonic precipitates were observed: chalcedony crusts alternating with bands of opal and discrete chalcedonic isopachous cements. Based on the "patchy" distribution of opal and chalcedony, it is likely that the laminated chalcedony/opal crusts gradually grade into the opaline pool bottom facies.

Pool Facies (~80-90 ^oC): Bottoms of siliceous hotspring pools are best identified from macroscopic flow structures or "rills". Most of the details about the microfabrics were gleaned from precipitates on a series of sterile glass slides immersed in the pool. In petrographic thin-section, these slides exhibit abundant native sulfur and minor amounts of delicate opaline precipitates. Under SEM, the opaline precipitates are very smooth, with abundant native sulfur enmeshed in silicified polymeric substances. The sulfur crystals are euhedral, tetragonal dipyramids ranging in size from 10 to 100μm.

Pool Margin Facies (~80 ^oC): This facies is evident around the margins of the pool, and consists of opaline lilypad stromatolites prograding over the pool facies, forming overhanging ledges. These stromatolites exhibit abundant fenestrate porosity (bird's eye structures) similar to many ancient microbial deposits, alternating with white, siliceous and dark, organic-rich laminae. Each lamination has a "crinkled" appearance. These stromatolites exhibit strong fluorescence under 420nm wavelength light. Several accessory minerals are present including gypsum, hematite, alunite, fluorite, and calcite. Gypsum tends to form enterolithic nodules within the stromatolitic heads. Hematite is only observed as micron-sized blebs enmeshed in relict organic remains. Alunite crystals are approximately 4 μm in diameter, and appear to be restricted in occurrence to this facies. Based on hydrochemical modeling, none of these mineralogical species can be explained by equilibrium precipitation.

Pool Eddy Facies (<80 ^oC): The pool eddy facies is restricted to areas adjacent to lilypad stromatolites of the pool margin, in areas somewhat sheltered from inundation by the hottest springwater. Lack of a winnowing current allows a great deal of debris to accumulate. Despite the presence of hot water, a wide variety of allochems are present in the opaline precipitates. Pollen grains and other plant debris are the most common in petrographic thin-sections, and represent debris that is swept into the deposit. All of these allochems are bound by opaline cements which are weak and very friable.

Discharge Channel Facies (<80 °C-Ambient Temperatures): This facies occurs in areas where springs discharge into a network of anastomosing channels. Degree of mineralization can be highly variable, from unsilicified microbial mat material to thoroughly silicified "shrubby" precipitates. Opaline precipitates consist of porous aggregates of spinose silica 1-5cm in height resembling miniature woody plant shrubs. Pennate diatoms and assorted plant debris are also common, however, green filamentous microbes ~10μm wide are the most striking features.

Debris Apron Facies (Variable Temperatures): Perhaps the most widespread lithofacies associated with modern siliceous hotsprings consists of siliceous intraclasts in various stages of lithification. Clasts are derived from all of the other facies, and are generally 1-2 cm in length (though dimensions range greatly) and commonly very angular. When lithified, individual clasts appear to be coated by a thin, clear isopachous coating of amorphous silica.

Geyser Facies: Many hotsprings in Yellowstone have had a complex history including intermittent episodes of geyser activity. Periodic agitation associated with pool level fluctuations during eruptive geyser activity can produce siliceous oncoids/pisoids. At a microscale, these opaline coated grains tend to have a nucleus of either igneous rock fragments or reworked siliceous sinter. These geyser precipitates are irregularly laminated, and have many features resembling microbial laminae in the oncoid cortices. These laminations were observed to fluoresce under the fluorescent microscope.

Discussion and Conclusions: Siliceous hotspring deposits can be easily discerned based on distinctive facies and their associated microfabrics. Thus, a comprehensive facies model based on these characteristics greatly facilitates their recognition in the terrestrial rock record as well as potential extraterrestrial deposits.

A number of distinctive characteristics can be used to successfully identify relict hotspring deposits or facies. Macroscopic length-fast, chalcedonaic quartz crystals are the best indicator for the vent facies. Laminated opal with incipient length-slow chalcedony indicates the proximal vent facies. Pool bottoms are best identified by outcrop patterns of the "rilled" siliceous sinter, exhibiting some remnants of flow structures. Lilypad stromatolites are the best indicators for the pool margin facies, and may also contain fenestrae or evaporites. Eddy facies are characterized by a hash of plant or eukaryotic remains. Bacterial shrubs and filaments are the best indicators for spring flow facies. Debris apron facies are an admixture of reworked fragments from other facies. Geyser facies may/may not be present, but are indicated by siliceous oncoids/pisoids.

Aside from a conventional facies model for siliceous hotsprings, these microfabrics shed light on the mechanisms governing siliceous sinter precipitation. Precipitates form a natural progression between those that are little influenced by the extant biota to those that have a strong biotic influence on the microfabric. Chalcedony and chalcedonic crusts represent the high-temperature regimes of the siliceous hotsprings, where precipitation is mostly governed by abiotic processes. Moving away from the higher temperature regimes, biotic influence on precipitate fabrics becomes more apparent. The pool margin stromatolites indicate a pronounced biotic influence in the microfabric. Here, mineral species (e.g., hematite, alunite) not predicted by hydrochemical modeling suggest localized disequilibrium conditions and a possible biotically induced mechanism for their formation. Siliceous shrubs represent the biotic end-member precipitate, where biologic activity has the greatest influence on the resulting precipitate.

References: [1] Christensen, P.R., et al., (2000) *JGR, 105,* 9623–9642. [2] *An Exobiology Strategy for Mars Exploration* (1995) NASA SP-530.

Acknowledgements: This research is supported by a NASA-JSC Astrobiology Grant (to HC), SEPM Foundation Robert J. Weimer Grant for Student Research (to SG), GSA Student Grant (#6239-98 to SG), and the Explorers Club-Rocky Mountain Chapter Grant for Student Research (to SG). The National Park Service graciously provided permission to sample.

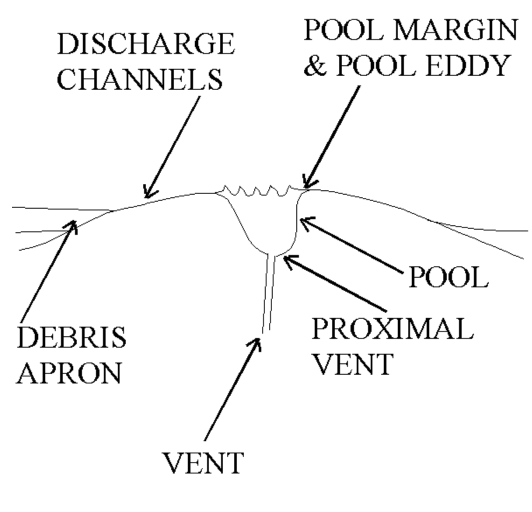

Figure 1: Generalized schematic cross-section through a subaerial hotspring deposit showing major facies.