L**INKING HYDRATED SILICA TO HABITABILITY AND PRESERVATION POTENTIAL ON MARS: LESSONS LEARNED.** Steven W. Ruff, 1 Arizona State University, School of Earth and Space Exploration, Tempe, AZ, 85287-6305, steve.ruff@asu.edu.

**Introduction:** On Earth, volcanic hydrothermal systems are known to produce habitable environments that typically become inhabited by diverse microbial communities. Hot springs and geysers are manifestations of such hydrothermal systems that, through precipitation of opaline silica (hydrated amorphous SiO₂), produce deposits known as sinter that commonly preserve in the rock record textural, morphological, and geochemical evidence of microbial activity. For these reasons, sinter deposits on Mars have long been an exploration target in the search for ancient life there[1].

Hydrated silica occurrences have been identified in situ by rovers on Mars, and by orbiting spacecraft in many locations across the planet. However, the presence of hydrated silica does not uniquely represent a habitable environment with preservation potential. There are multiple processes known to produce hydrated silica on Earth, but on Mars the most likely relevant to astrobiology is sinter deposition from hot springs/geysers. Therefore, making the connection between hydrated silica and sinter deposits is key in the search for ancient life on Mars.

Given that obvious geomorphic features of ancient hot springs/geysers may not be preserved (holes in the ground tend to get filled over time), I highlight the following observations to help inform current and future exploration of hydrated silica on Mars. Some of these are detailed in a recent publication [2].

**Composition:** Volcanic hydrothermal systems on Earth that manifest hot springs and/or geysers typically include other manifestations, like fumaroles, which emit magmatically derived sulfur-rich gases (SO₂ and H₂S) leading to S precipitates and sulfuric acid condensates with consequent acid-sulfate leaching. Therefore, the co-occurrence of sulfur-rich materials and hydrated silica rocks is a hallmark of volcanic hydrothermal systems. Although this combination was documented by the Spirit rover in the Columbia Hills (Fig. 1) and attributed to volcanic hydrothermal activity [3], the likelihood of both fumarolic and hot spring activity was not fully appreciated [2]. In Gale crater, S-rich materials were not observed among the silica-rich rocks identified by the Curiosity rover, diminishing the likelihood of an origin in a volcanic hydrothermal system [4].

Silica sinter deposits are produced following cooling and evaporation of hydrothermal silica-rich fluids, which commonly include chlorine compounds like halite (NaCl). Consequently, halite occurs as a persistent residue on silica sinter produced in arid environments on Earth and is evident among the silica deposits in the Columbia Hills [5]. Thus, the co-occurrence of hydrated silica and halite is a possible indicator of silica sinter.

![Figure 1. Co-located silica outcrops and sulfur-rich materials in the Columbia Hills (top, “McMurdo” Pancam mosaic) and Roosevelt Hot Springs, Utah (bottom) indicative of a volcanic hydrothermal system.](image)

Infrared spectra of hydrated silica contain multiple identifying features that have been recognized on Mars in both orbital and in situ observations. However, a feature near 1 µm in multi-spectral Pancam observations of opaline silica materials in the Columbia Hills has remained enigmatic. It does not appear in a range of natural hydrated silica materials but is present in some synthetic forms [6]. I now have observed this feature in aged silica sinter (~1900 years old; [7]) that has experienced incipient diagenesis (Fig. 2). On Earth, opaline silica transitions from its amorphous, hydrated form (opal-A), through paracrystalline forms (Opal-C/CT), to a fully crystalline, anhydrous quartz via extended exposure to water. Opal-A persists on Mars presumably due to its extreme aridity, but perhaps the ~ 1 µm feature is evidence for incipient diagenesis. At this point, it has only been observed in aged sinter, so perhaps is another identifying feature.
Figure 2. Near/shortwave infrared laboratory spectra (ASU Mars Space Flight Facility) of ~1900 year old silica sinter from Opal Mound, Utah and fresh silica sinter from El Tatio, Chile. Incipient diagenesis results in a strong feature near 1 µm in the aged sinter that is absent in fresh sinter and other hydrated silica spectra, but is evident in Spirit Pancam spectra [6].

**Morphology and Texture:** Sinter deposits on Earth display a wide range of morphologic and textural characteristics. One of the most common and areally extensive sinter textures is a breccia, produced from disaggregated and re-cemented earlier generations of sinter. Evidence for sinter breccia is found among the silica outcrops in the Columbia Hills [2], but has not been documented among silica-rich rocks at other rover sites. Nodular silica outcrops are a morphologic feature of sinter deposits on Earth, and also have been found in the Columbia Hills [2]. Likewise for digitate (finger-like) silica structures, which on Earth arise from passive biomediation [5]. This suite of features has only been recognized in silica sinter deposits, and is evident in the Columbia Hills.

**Landscape Expression:** Extensive, layered sinter aprons are features of large, long-lived volcanic hydrothermal systems like in Yellowstone National Park (USA), but much smaller and unlayered examples are more common. However, in all cases the sinter conforms to the local pre-hot spring topography, producing a stratiform expression of outcrops, which may or may not be continuous depending on the nature of deposition and erosion. The discontinuous nodular silica outcrops identified in the Columbia Hills display a stratiform expression consistent with sinter deposits (Fig. 1)[2]. Although hot spring pools and geyser vents are rarely preserved due to infill (example in Fig. 1, bottom), in some cases they build mounds of sinter that can be preserved. A possible vent mound has been identified in the Columbia Hills (Fig. 3)[2] and, based on orbital images, perhaps in Nili Patera [8].

**Jezero Crater:** NASA’s Mars 2020 rover mission will focus exploration efforts on the delta in Jezero crater, but spectral evidence from orbital observations of hydrated silica adjacent to the delta adds another potential exploration target [9]. At this time, the origin of this hydrated silica material is ambiguous, with hydrated volcanic glass as one of several possible explanations.

**Conclusions:** Hydrated silica occurrences on Mars represent another of its water related features. However, the most astrobiologically relevant occurrences are those associated with volcanic hydrothermal systems hosting hot spring/geyser sinter deposits. A suite of observables, as partially outlined above, can be used to disambiguate among the different possible origins for hydrated silica on Mars. The opaline silica occurrence in the Columbia Hills displays all of these features, which is most consistent with a sinter deposit there. The hydrated silica occurrence in Jezero crater represents the first time such an orbital identification has been made in advance of a mission. This offers the opportunity to investigate it using a well informed exploration model.