THE HYDROTHERMAL SYSTEM AT HOME PLATE IN GUSEV CRATER, MARS: FORMATION OF HIGH SILICA MATERIAL BY ACID-SULFATE ALTERATION OF BASALT. R. V. Morris, D. W. Ming, R. Gellert, A. Yen, B. C. Clark, T. G. Graff, R. E. Arvidson, S. W. Squyres, and the Athena and CRISM Science Teams, 1ARES, NASA Johnson Space Center, Houston, TX 77058 (richard.v.morris@nasa.gov). 2University of Guelph, Guelph, N1G2W1, Ontario, Canada. 3Jet Propulsion Laboratory, Pasadena, CA 91109. 4Lockheed Martin Corporation, Littleton, CO 80127. 5Arizona State University, Tempe, AZ 85287. 6Washington University in St. Louis, St. Louis, MO 63130. 7Cornell University, Ithaca, NY 14853.

Introduction: The Alpha Particle X-ray Spectrometer (APXS) instrument on the Mars Exploration Rover (MER) Spirit measured three targets on or adjacent to Home Plate in Gusev Crater that have unusually high SiO2 concentrations (68% to 91%), unusually low FeO concentrations (1% to 7%, with total Fe as FeO), and unusually high TiO2/FeO ratios (0.2 to 1.2 by weight) [1]. Two targets (Kenosha Comets and Lefty Ganote) are located on high albedo soil (Gertrude Weise) that was exposed by the rover wheels, and one target is a float rock called Fuzzy Smith. Kenosha Comets has the highest SiO2 concentration, lowest FeO concentration, and highest TiO2/FeO ratio. Mineralogical evidence from the MER Miniature Thermal Emission Spectrometer (Mini-TES) suggests that the SiO2 is present as amorphous (non-crystalline) SiO2 at Gertrude Weise and nearby targets [2,3]. Mini-TES data were not acquired for Fuzzy Smith.

Home Plate is considered to have an explosive volcanic origin, resulting when basaltic magma came into contact with ground water or ice [4]. Within ~50 m to 1 km of Home Plate are sulfate rich soil deposits (Paso Robles class soils with 22-35% SO3) which are considered to be probable fumarolic and/or hydrothermal deposits associated with the volcanism [5]. We develop the model here, suggested by [5], that the high-silica materials are another manifestation of acid-sulfate processes associated with fumarolic and hydrothermal activity at Home Plate. This is done by analogy with basaltic materials altered by acid sulfate processes on the Island of Hawaii.

Acid sulfate alteration: TiO2 is considered to be virtually immobile with respect to leaching during weathering in the terrestrial environment. In Fig. 1, we show a TiO2-SiO2 diagram (data from [6,7]) for basaltic tephra and rock altered in palagonitic, steam vent, and acid sulfate environments. Palagonitic alteration occurs under ambient conditions, and steam vent and acid sulfate alteration are hydrothermal. For the palagonitic and steam vent alteration, SiO2 is leached and the concentration of TiO2 increases through passive enrichment. For alteration under acid sulfate conditions, both SiO2 and TiO2 are passively enriched. The red squares are from a single basaltic rock (HWSB820) that was sampled from its acid-sulfate altered exterior surface region to its relatively unaltered interior in ~1 cm thick increments [7]. The tan squares are for porous, particulate tephra altered under acid sulfate conditions.

In Fig. 2 we show the TiO2-SiO2 diagram for Home Plate samples. Comparison with Fig. 1 shows that the data for the high-SiO2 rocks and soils at Home Plate are consistent with acid-sulfate alteration of basaltic precursor rock and tephra. The relatively unaltered rocks have SiO2 ~ 46% and variable TiO2 contents from ~0.4% to 1.2%. The blue shaded region corresponds to permitted values of TiO2 and SiO2 by acid sulfate alteration of the precursor rocks. The lines, drawn through the origin and the extreme TiO2 values of unaltered rocks, assume that both TiO2 and...
SiO$_2$ are completely immobile during the acid sulfate leaching. This assumption is at least approximately valid as shown in Fig. 1. All of the high-SiO$_2$ samples fall within or near the shaded region (Fig. 2). In addition to the three samples with the highest SiO$_2$ concentrations (FS, LG, and KC), there are a number of rocks (GQ, IBy, NL, EM, and NW) and one soil (ED) that also have elevated SiO$_2$ concentrations in comparison to the relatively unaltered basalts. Our interpretation is that acid sulfate alteration has simply progressed to variable extents, perhaps in response to variable temperatures and supplies of acid-sulfate solutions/vapors. A similar range, in a single rock (HWSB820), is shown in Fig. 1. We suggest, for example, that Everett (Ev), Innocent Bystander (IBy), and Kenosha Comets (KC) are members of an acid-sulfate alteration sequence from relative unaltered Ev to mildly altered IBy to heavily altered KC. (Ev and IBy are both high MgO rocks).

Mineralogy and thermal emission spectra: The Mini-TES evidence for amorphous SiO$_2$ includes deep emissivity minima near 9 and 21 microns [3]. Amorphous SiO$_2$ is typically characterized by a shoulder near 8 microns, but the Gertrude Weise spectra are instead characterized by a well-defined emissivity minimum, and the difference is attributed to scattering and/or geometric effects [3]. As shown in Fig. 3, a slab and coarse and fine powders from the most altered region of HWSB820 also have a well-defined emissivity minimum near 8 µm. X-ray diffraction data show that the mineralogical composition is opal-A plus anatase (TiO$_2$) [5].

The CRISM/OMEGA connection: The CRISM VNIR instrument has obtained spectral evidence at several locations on the Martian surface in the form of spectral features near 1.39 and 2.21 µm from Si-OH [8]. We obtained the VNIR fingerprint of our acid-sulfate analogue and other high-SiO$_2$ samples to probe the extent that the Martian spectra can be related to acid sulfate leaching (Fig. 4).

Milky quartz contains molecular H$_2$O bands (~1.46 and 1.95 µm) and no detectable Si-OH feature. Wood opal, sedimentary silica, and “acid-sulfate” silica all have opal-A and spectral features potentially Mars-like. Unfortunately, opal-A is not pathway specific, except in the sense that aqueous processes of some sort are implied. The silica gel spectra show that hydration influences the position and shape of the Si-OH spectral features, so that it will be necessary to acquire laboratory VNIR spectra under dry conditions.

Conclusion: Acid sulfate leaching of Ti-bearing basaltic rock/tephra resulting in passive enrichment of SiO$_2$ and TiO$_2$ and in-place formation of opal-A and anatase can account for the properties of the high-SiO$_2$ material at Home Plate, although the depth of the 8 µm feature for our analogue is reduced compared to Mini-TES spectra. An alternate pathway to form high-SiO$_2$ materials is sinter formation in a spring environment. Whether this process can accommodate the chemical data and the observations of unaltered, moderately, and fully altered basalt is unknown. In either case, aqueous alteration under hydrothermal conditions and formation of opal-A are implicated.