

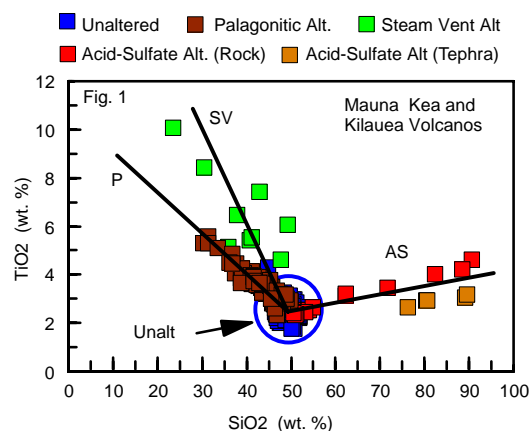
THE HYDROTHERMAL SYSTEM AT HOME PLATE IN GUSEV CRATER, MARS: FORMATION OF HIGH SILICA MATERIAL BY ACID-SULFATE ALTERATION OF BASALT. R. V. Morris, D. W. Ming, R. Gellert, A. Yen, B. C. Clark, T. G. Graff, R. E. Arvidson, S. W. Squyres, and the Athena and CRISM Science Teams, ¹ARES, NASA Johnson Space 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.

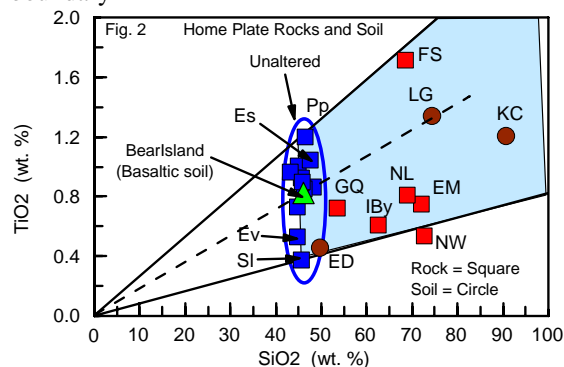
Home Plate is considered to have an explosive volcanic origin, resulting when basaltic magma came into contact with ground water or ice [4]. Within ~50 m to 1 km of Home Plate are sulfate rich soil deposits (Paso Robles class soils with 22-35% SO₃) which are considered to be probable fumarolic and/or 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 boundary



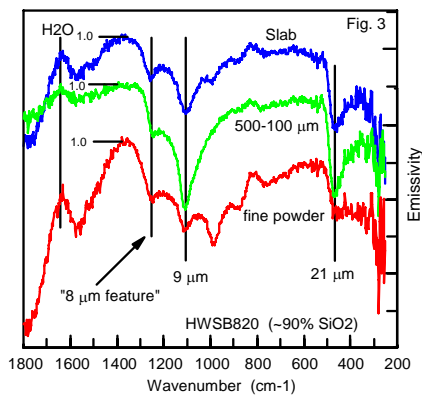
Es = Esperanza Pp = Pesapallo Ev = Everett
 SI = Slide GQ = Good Question ED = Eileen Dean
 FS = Fuzzy Smith NW = Nancy Warren LG = Lefty Ganote
 KC = Kenosha Comets NL = Norma Luker
 IBy = Innocent Bystander

lines, drawn through the origin and the extreme TiO₂ values of unaltered rocks, assume that both TiO₂ and

SiO₂ are completely immobile during the acid sulfate leaching. This assumption is at least approximately valid as shown in Fig. 1. All of the high-SiO₂ samples fall within or near the shaded region (Fig. 2).

In addition to the three samples with the highest SiO₂ 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 SiO₂ 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).

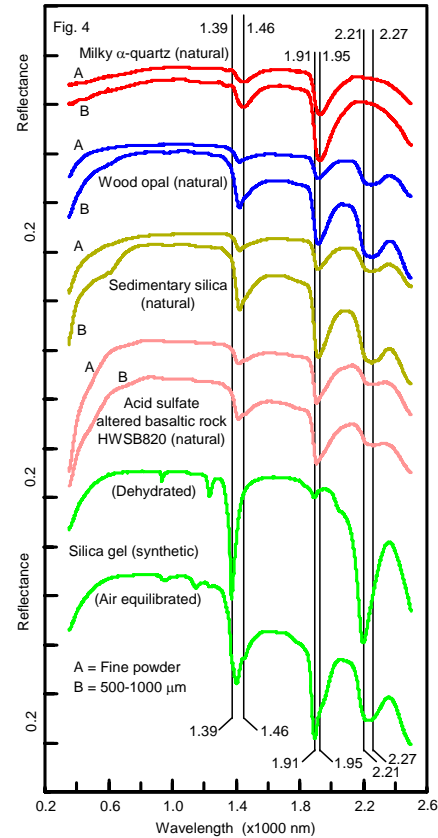
Mineralogy and thermal emission spectra: The Mini-TES evidence for amorphous SiO₂ includes deep emissivity minima near 9 and 21 microns [3]. Amorphous SiO₂ is typically characterized by a shoulder near 8 microns, but the Gertrude Weise spectra are instead characterized by a well-defined emissivity minimum, 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 μ m. X-ray diffraction data show that the mineralogical composition is opal-A plus anatase (TiO₂) [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 μ m from Si-OH [8]. We obtained the VNIR fingerprint of our acid-sulfate analogue and other high-SiO₂ samples to probe the extent that the Martian spectra can be related to acid sulfate leaching (Fig. 4).

Milky quartz contains molecular H₂O bands (~1.46 and 1.95 μ m) 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 SiO₂ and TiO₂ and in-place formation of opal-A and anatase can account for the properties of the high-SiO₂ material at Home Plate, although the depth of the 8 μ m feature for our analogue is reduced compared to Mini-TES spectra. An alternate pathway to form high-SiO₂ 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.

References: [1] Ming, D.W. et al. 2008, *JGR*, to be submitted. [2] Squyres S.W. et al. (2007), *Eos Trans. AGU* 88(52), Fall Mtg., Abs. P21C-01. [3] Ruff S.W. et al., this volume; [4] Squyres S.W. et al. (2007), *Science*, 316, 738. [5] Yen et al. (2008), *JGR*, accepted. [6] Morris R.V. et al. (2000), *JGR*, 105, 1757. [7] Morris R.V. et al. (2000). *LPSC31*, #2014. [8] Milliken R.E. et al., this volume.