GUSEV-STYLE ALTERATION: UNIQUE OR UBIQUITOUS ON MARS? Steven W. Ruff[1], [1]School of Earth and Space Exploration, Arizona State University, Tempe, AZ 85287-6305, steve.ruff@asu.edu.

Introduction: Evidence for hydrous alteration on Mars has in recent years become unequivocal. The identification by a combination of orbital and landed instruments of water-derived hematite, sulfates, phyllosilicates, Fe-oxides, and hydrated silica is robust. Even carbonates are now recognized [1, 2]. In some cases, it is possible to ascertain an environmental context for the alteration.

Gusev Crater, which is still being explored by the *Spirit* rover more than five years after its arrival, displays a range of altered materials and secondary phases. Sulfates, Fe-oxides, phosphates, and hydrated silica have been identified using a combination of measurements from the Alpha Particle X-ray Spectrometer (APXS), Mössbauer spectrometer (MB), and Miniature Thermal Emission Spectrometer (Mini-TES). No phyllosilicates have been identified definitively. Most enigmatic is a phase or phases that resemble an amorphous silicate of basaltic composition [3]. No terrestrial analog has been identified for this material.

Despite a powerful payload and a capable rover platform, the environmental conditions that have produced the range of alteration present in Gusev Crater are not well understood. From this lack of understanding comes an opportunity for modeling. Investigating the conditions that could produce the style of alteration observed in Gusev will lead to a better understanding of the range of hydrous environments across Mars.

Alteration on the Plains: The rocks encountered by *Spirit* on the traverse across the plains to the Columbia Hills are only lightly altered in most cases. The Adirondack-class basalts are the dominant rock type. Their primary mineralogy is that of a picritic basalt, with olivine (Fo_{50-60}) clearly evident in the spectra from Mini-TES and MB [e.g., 4, 5].

Sulfur enrichment identified by the APXS that decreases with depth in the rocks [e.g., 6] recently has been characterized using Mini-TES spectra as a sulfate phase that most resembles kieserite [7]. This sulfate phase is a persistent spectral component among all Adirondack-class basalts observed with Mini-TES across the plains. Twenty-seven examples of these rocks have been identified as "exotics" in the Columbia Hills, likely lofted there by meteorite impacts onto the plains. The exotics also display the same sulfate phase. Combined with the observation that many Adirondack-class rocks have a ventifact morphology indicative of aeolian abrasion, the presence of sulfate at the surface of these rocks may represent an active alteration process that outpaces erosion.

The only unequivocal rock coating on Mars is found on a large (~1 m long) Adirondack-class rock called Mazatzal. A smooth, dark-toned coating is present underneath a layer of loose airfall dust [e.g., 8] (Fig. 1). The coating is spectrally thick to Mini-TES, completely obscuring the substrate. Its spectral features resemble no known terrestrial rock coating [e.g., 9] (Fig. 2). Spectral deconvolution indicates a dominant phase that most resembles basaltic glass [7], i.e., an amorphous silicate of basaltic composition. Remarkably, this unusual coating is formed on a surface clearly "fluted" by aeolian abrasion, an indication that it formed well after the Adirondack basalts were emplaced, broken up, and eroded.

Alteration in the Columbia Hills: Massive and layered outcrops known as Clovis class display clear evidence of alteration. Enrichments in S, Cl, and Br relative to the Adirondack basalts observed by the APXS along with highly oxidized iron (avg. $Fe^{3+}/Fe_T \cong 0.8$) and the presence of goethite identified by the MB [e.g., 10] represent an alteration style unique among the measured Gusev rocks. Mini-TES identified no unambiguous alteration phases. Instead, like the Mazatzal coating, the spectra of these rocks are dominated by an amorphous phase(s) of basaltic composition that departs from recognized basaltic alteration (Fig. 3).

On the north flank of Husband Hill, a large (~5 m long) outcrop spectrally matches the adjacent float rock called Watchtower, which displays an enrichment of P, Al, and Ti relative to Adirondack class and also is highly oxidized and contains goethite [e.g., 10]. Mini-TES spectra again are dominated by an amorphous basaltic phase(s).

In contrast to the Mazatzal coating and altered Columbia Hills rocks is the opaline silica phase identified with Mini-TES and APXS data in many eroded outcrop and soil exposures surrounding the Home Plate feature [11]. This is a readily recognized alteration phase consistent with several terrestrial analog environments.

Summary: Except for the opaline silica occurrences adjacent to Home Plate, the alteration of various rocks and outcrops along *Spirit's* traverse appears to have no recognized terrestrial analog. Mini-TES spectra reveal a dominant phase that most resembles an amorphous silicate of basaltic composition. Perhaps very low water-to-rock alteration over geologic times-

cales is responsible. It is noteworthy that the spectral characteristics of this alteration have not been recognized in global mapping using the Mars Global Surveyor Thermal Emission Spectrometer. But without a dedicated search, it is premature to conclude that such alteration is limited to Gusev Crater.

References: [1] Bandfield, J.L., et al., (2003) *Science, 301* 1084-1086. [2] Ehlmann, B.L., et al., (2008) *Science, 322* 1828-1832. [3] Ruff, S.W., et al., (2006) *J. Geophys. Res., 111*(E12S18) doi: 10.1029/2006JE002747. [4] Morris, R.V., et al., (2004) *Science, 305* 833-836. [5] McSween, H.Y., Jr., et al., (2006) *J. Geophys. Res., 111*(E02S10) doi:10.1029/2005JE002477. [6] Gellert, R., et al., (2004) *Science, 305* 829-832. [7] Hamilton, V.E. and S.W. Ruff, (2009) *Lunar Planet. Sci., XL*([CD-ROM]) abstract #1418. [8] Haskin, L.A., et al., (2005) *Nature, 436* 66-69. [9] Hamilton, V.E., et al., (2008) *J. Geophys. Res., 113*(E12S43) doi:10.1029/2007JE003049. [10] Ming, D.W., et al., (2006) *J. Geophys. Res., 111*(E02S12) doi:10.1029/2005JE002560. [11] Squyres, S.W., et al., (2008) *Science, 320* 1063-1067.

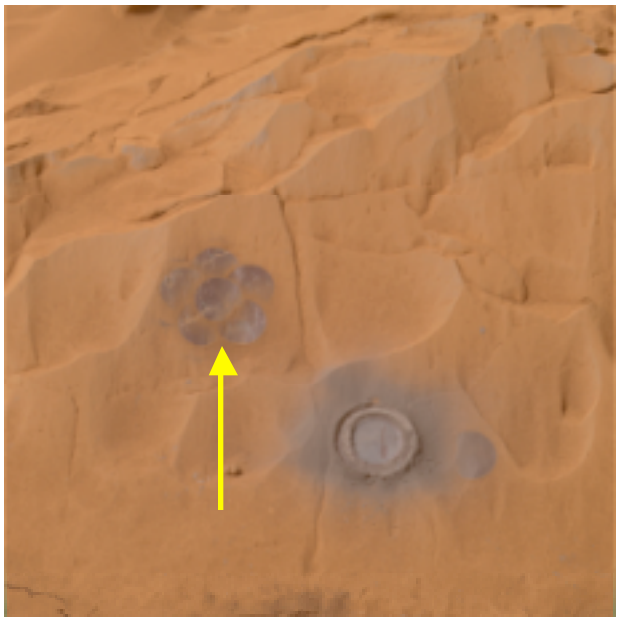

Figure 1. The dark-toned coating on the brushed surface of the rock Mazatzal is the only unequivocal example of a rock coating on Mars.

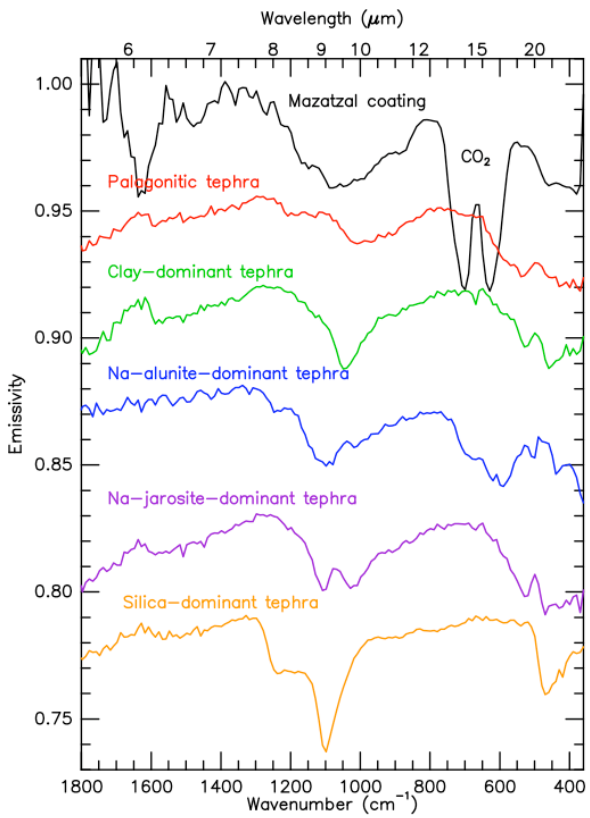

Figure 2. The Mini-TES spectrum of the Mazatzal coating does not match alteration typical of basaltic materials.

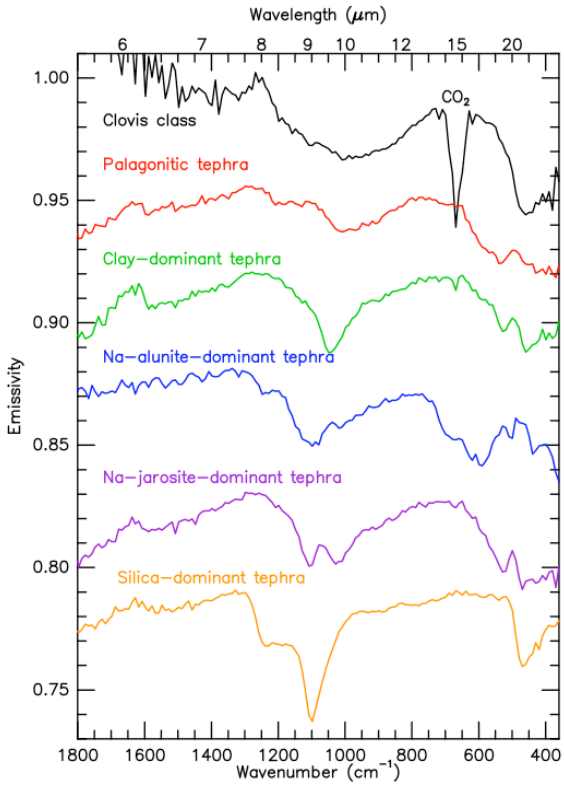

Figure 3. The Mini-TES spectrum of Clovis class rocks does not match alteration typical of basaltic materials.