Acid Sulfate Alteration in Gusev Crater, Mars

Morris, R. V., Ming, D. W., and Catalano, J. G.

NASA Johnson Space Center, Houston, TX, 77058, USA
Washington University in St. Louis, St. Louis, MO, 63130, USA

The Mars Exploration Rover (MER) Spirit landed on the Gusev Crater plains west of the Columbia Hills in January, 2004, during the martian summer (sol 0; sol = 1 martian day = 24 hr 40 min). Spirit explored the Columbia Hills of Gusev Crater in the vicinity of Home Plate at the onset of its second winter (sol ~900) until the onset of its fourth winter (sol ~2170). At that time, Spirit became mired in a deposit of fine-grained and sulfate-rich soil with dust-covered solar panels and unfavorable pointing of the solar arrays toward the sun. Spirit has not communicated with the Earth since sol 2210 (January, 2011) [1]. Like its twin rover Opportunity, which landed on the opposite side of Mars at Meridiani Planum, Spirit has an Alpha Particle X-Ray Spectrometer (APXS) instrument for chemical analyses and a Mössbauer spectrometer (MB) for measurement of iron redox state, mineralogical speciation, and quantitative distribution among oxidation (Fe³⁺/ΣFe) and coordination (octahedral versus tetrahedral) states and mineralogical speciation (e.g., olivine, pyroxene, ilmenite, carbonate, and sulfate) [2].

The concentration of SO₃ in Gusev rocks and soils varies from ~1 to ~34 wt% (Fig. 1a) [3,4,5]. Because the APXS instrument does not detect low atomic number elements (e.g., H and C), major-element oxide concentrations are normalized to sum to 100 wt%, i.e., contributions of H₂O, CO₂, NO₂, etc. to the bulk composition are not considered. The majority of Gusev samples have ~6 ± 5 wt% SO₃, but there is a group of samples with high SO₃ concentrations (~30 wt%) and high total iron concentrations (~20 wt%). There is also a group with low total Fe and SO₃ concentrations that is also characterized by high SiO₂ concentrations (>70 wt%) (Fig. 1a). The trend labeled “Basaltic Soil” is interpreted as mixtures in variable proportions between unaltered igneous material and oxidized and SO₃-rich basaltic dust. The Mössbauer parameters are not definitive for mineralogical speciation (other than octahedrally-coordinated Fe³⁺) but are consistent with a schwertmannite-like phase (i.e., a nanophase ferric oxide).

The high oxidation state (Fig. 1b) and values of Mössbauer parameters (center shift and quadrupole splitting) for the high-SO₃ samples imply ferric sulfate (i.e., oxidized sulfur), although the hydration state cannot be constrained. In no case is there an excess of SO₃ over available cations (i.e., no evidence for elemental sulfur), and Fe sulfide (pyrite) has been detected in only one Gusev sample. The presence of both high-SiO₂ (and low total iron and SO₃) and high SO₃ (and high total iron as ferric sulfate) can be accommodated by a two-step geochemical model developed with the Geochemist’s Workbench. (1) Step 1 is anoxic acid sulfate leaching of martian basalt at high water-to rock ratios (>70). The result is a high-SiO₂ residue (Fig 1a), and anoxic conditions are required to solubilize Fe as Fe²⁺. (2) Step 2 is the oxic precipitation of sulfate salts from the leachate. Oxic conditions are required to produce the high concentrations of ferric sulfate with minor Mg-sulfates and no detectable Fe²⁺-sulfates.