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Spectral identification of hydrated sulfates on Mars and comparison with sulfate-rich terrestrial sites

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We interpret recent spectral data of Mars collected by the Mars Exploration Rovers to contain substantial evidence of sulfate minerals and aqueous processes. We present visible/near-infrared (VNIR), mid-IR and Mössbauer spectra of several iron sulfate minerals and sulfate-rich alteration products. We compare our combined lab data to the recent spectra of Mars: global hyperspectral VNIR spectra from OMEGA on Mars Express [*Bibring*, 2004], multispectral VNIR spectra from Pancam at Gusev crater [*Bell et al.*, 2004a] and Meridiani Planum [*Bell et al.*, 2004b], emission spectra in the mid-IR from the Thermal Emission Spectrometer (TES) [*Christensen et al.*, 2001] and the mini-TES [*Christensen et al.*, 2004a,b], and Mössbauer spectra at Gusev crater [*Morris et al.*, 2004] and Meridiani Planum [*Klingelhöfer et al.*, 2004]. We suggest that the sulfates on Mars are produced via aqueous oxidation of sulfides known to be present on Mars from the martian meteorites or via solfataric alteration of volcanic ash. An initial study of hydrated iron sulfates showed that some of these minerals can explain a number of the Mössbauer, mid-IR and VNIR spectral features observed for the global Martian soil [*Lane et al.*, 2004]. Our continued analyses suggest that ferrous sulfates may account for the Mössbauer features attributed to olivine [*Morris et al.*, 2004] and that the mid-IR features attributed to a combination of bound water and carbonate [*Bandfield et al.*, 2003; *Christensen et al.*, 2004a] may be explained by hydrated iron sulfates. Spectral analyses have been preformed for detection of these sulfate minerals/phases on Mars by OMEGA and for groundtruthing the OMEGA spectra with MER data.

Sulfate precipitation in acidic environments. The sulfate-rich rock outcrops observed in Meridiani Planum may have formed in an acidic environment similar to acid rock drainage environments on Earth [*Bishop et al.*, 2005a]. Minerals such as jarosite, szomolnokite and rozenite form under acidic conditions. Others that contain ferrihydrite and gypsum formed under more neutral conditions. Because microorganisms typically are involved in the oxidation of sulfides to sulfates in terrestrial sites, sulfate-rich rock outcrops on Mars may be a good location to search for evidence of past life on that planet. Whether or not life evolved on Mars, following the trail of sulfate minerals will to lead to aqueous processes and chemical weathering. Our results imply that sulfate minerals formed in martian soils via chemical weathering, perhaps over very long time periods, and that sulfate minerals precipitated following aqueous oxidation of sulfides to form the outcrop rocks at Meridiani Planum.

Solfataric alteration. Solfataric alteration may have played a role in sulfate mineralization on Mars. Fumaroles in the Kilauea caldera, HI, have created a solfataric bank on the south wall of the crater where Keanakakoi ash was deposited forming a combination of jarosite and gypsum in a silica/clay matrix (.)[*Bishop et al.*, 2005b]. Similar processes may have occurred on Mars if hydrothermal processes existed. This would be an explanation for the formation of sulfate minerals and hydrated phases on Mars that does not require long-term aqueous processes.

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