SULFATES ON MARS AS MARKERS OF AQUEOUS PROCESSES: AN INTEGRATED MULTI-DISCIPLINARY STUDY OF MINERALS, MARS ANALOG SITES AND RECENT MISSION DATA.

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Recent analyses by the Mars Exploration Rovers (MERs) at Meridiani Planum and Gusev crater and the OMEGA instrument on Mars Express have provided detailed information about the presence of sulfates on Mars. We are evaluating these recent mission data in an integrated multi-disciplinary study of visible/near-infrared (VNIR), mid-IR and Mössbauer spectra of several sulfate minerals and sulfate-rich analog sites.

Recent Results from Martian Missions: Measurements using the APXS on outcrop rocks at Meridiani Planum suggest the presence of greatly elevated S levels, even as much as 20-40% sulfate [1]. The Mössbauer instrument identified jarosite as one sulfate-bearing mineral present at Meridiani [2], and geochemical modeling [1] and spectral analyses [3,4] suggest that other sulfate minerals are present as well. Recent analyses of the Mini-Thermal Emission Spectrometer (Mini-TES) data include spectral models using a mixture of hydrous and anhydrous sulfates to reproduce spectra of these outcrop rocks at Meridiani [5]. The presence of jarosite at Meridiani implies a highly acidic (pH <3) formation environment [6] and the sedimentary character of the jarosite-bearing sulfur-rich outcrops there is consistent with aqueous processes.

Diagnostic NIR absorptions of the sulfate minerals kieserite and gypsum have been identified in data from the OMEGA instrument in several locations on Mars [7,8,9]. The deposits range from small, light-toned outcrops in Valles Marineris to regional sulfate-rich layers in the Meridiani region. Sulfates here are attributed to aqueous alteration. The Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) on board the Mars Reconnaissance Orbiter will evaluate these sulfate-bearing sites at even smaller spots sizes on the surface [10], and may enable identification of specific sulfate minerals.

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 [3]. Our continued analyses suggest that ferrous sulfates may account for the Mössbauer features attributed to olivine [11] and that the mid-IR features attributed to a combination of bound water and carbonate [12,13] may be explained by hydrated iron sulfates. Spectral analyses including novel statistical modeling techniques are underway for detection of sulfates on Mars by OMEGA and CRISM, and for groundtruthing these VNIR hyperspectral datasets using MER results. Recent processing and calibration of MER Mössbauer data is enabling further analyses of that dataset as well.

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 [4]. Minerals such as jarosite, szomolnokite and rozenite form under acidic conditions. Others that contain ferrihydrite and gypsum formed under more neutral conditions. Our results imply that (i) sulfate minerals formed in Martian soils via chemical weathering, perhaps over very long time periods, and (ii) 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 [14]. In addition, tephra altered near cinder cones in the Haleakala crater, Maui, contain alunite-jarosite in a silica/clay/iron oxide/oxyhydroxide matrix [15].

Summary: Our analyses of sulfate minerals, analog sites, and Martian spectra and spectral images is focused on characterization of the Martian surface and in particular identification of aqueous processes there.

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