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Discovery of jarosite within the Mawrth Vallis region of Mars: Implications for the geologic history of the region

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ABSTRACT

Analysis of visible to near infrared reflectance data from the MRO CRISM hyperspectral imager has revealed the presence of an ovoid-shaped landform, approximately 3 by 5 km in size, within the layered terrains surrounding the Mawrth Vallis outflow channel. This feature has spectral absorption features consistent with the presence of the ferric sulfate mineral jarosite, specifically a K-bearing jarosite ($KFe_3(SO_4)_2(OH)_6$). Terrestrial jarosite is formed through the oxidation of iron sulfides in acidic environments or from basaltic precursor minerals with the addition of sulfur. Previously identified phyllosilicates in the Mawrth Vallis layered terrains include a basal sequence of layers containing Fe–Mg smectites and an upper set of layers of hydrated silica and aluminous phyllosilicates. In terms of its fine scale morphology revealed by MRO HiRISE imagery, the jarosite-bearing unit has fracture patterns very similar to that observed in Fe–Mg smectite-bearing layers, but unlike that observed in the Al-bearing phyllosilicate unit. The ovoid-shaped landform is situated in an east–west bowl-shaped depression superposed on a north sloping surface. Spectra of the ovoid-shaped jarosite-bearing landform also display an anomalously high 600 nm shoulder, which may be consistent with the presence of goethite and a 1.92 μm absorption which could indicate the presence of ferrihydrite. Goethite, jarosite, and ferrihydrite can be co-precipitated and/or form through transformation of schwertmannite, both processes generally occurring under low pH conditions (pH 2–4). To date, this location appears to be unique in the Mawrth Vallis region and could represent precipitation of jarosite in acidic, sulfur-rich ponded water during the waning stages of drying.

1. Introduction

Exposures of light-toned layered rocks surrounding the Mawrth Vallis outflow channel were noted by Malin and Edgett (2000). Later observations with the Mars Express Observatoire pour la Minéralogie, l'Eau, les Glaces et l'Activité (OMEGA) imaging spectrometer indicated that these rocks contained widespread occurrences of phyllosilicate minerals (Bibring et al., 2005; Poulet et al., 2005; Loizeau et al., 2007). Higher spatial resolution observations with the Mars Reconnaissance Orbiter (MRO) Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) have revealed that there are several varieties of phyllosilicate minerals present at Mawrth Vallis (Bishop et al., 2008). Reflectance spectra of these minerals can be used to determine a "spectral stratigraphy" for the region. A simplified spectral stratigraphy consists of a basal sequence of Fe–Mg smectites with a distinctive 2.29–2.3 μm absorption overlain by a unit displaying an absorption at 2.2 μm. Variations in the shape and width of the 2.2 μm absorption indicate the presence of different phases including hydrated silica, montmorillonite and kaolinite (Bishop et al., 2008). While acknowledging that it also contains hydrated silica, we henceforth refer to the latter unit as the "Al phyllosilicate" unit. At a number of locations, but not everywhere in the region, there is between the lower Fe–Mg smectites unit and the overlying Al phyllosilicate unit spectral evidence of a phase with a positive spectral slope in the near infrared (NIR) with a change in slope to a flat spectral response at approximately 2 μm. Bishop et al. (2008) interpreted this phase as a ferrous mica but allowed for the possibility of different interpretations. To reflect the ambiguous interpretation of the identity of this phase, we henceforth refer to it as the "Fe2M" phase. Wray et al. (2008) suggested that the Al phyllosilicate layers were draped over the Mawrth Vallis outflow channel topography. However, they were not able to establish whether the underlying Fe–Mg smectite-bearing unit was draped over the pre-existing topography thus leaving open the possibility that the channel was incised through these layers with the Al phyllosilicate layers being deposited later in time. Thus, there is potentially a profound

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unconformity between the Fe–Mg smectite – bearing unit and the overlying Al phyllosilicate layers.

Mawrth Vallis is the oldest recognized outflow channel emptying into Chryse Planitia. It occurs in northwest Arabia Terra at the transition from the highlands to the lowlands (with elevations ranging roughly from −1500 m to −3500 m). The channel carves through Noachian-aged ancient cratered terrain and it is the only large outflow channel that does not originate from chaos terrain although Parker (2000) suggested that source chaos region might have been buried by ejecta from the crater Trouvelot.

Bibring et al. (2006) suggested that ancient terrains that show spectral features indicating the presence of phyllosilicate minerals could have formed under environmental conditions where surface and subsurface waters were more alkaline and that a period of global environmental change generated acidic groundwater conditions leading to the deposition of sulfate minerals observed in Terra Meridiani, Valles Marineris and elsewhere (e.g., Gendrin et al., 2005). Here we examine the discovery of a localized deposit in the northern part of the Mawrth Vallis region, present within a single CRISM scene (Fig. 1), that has spectral features of the ferric sulfate mineral jarosite [$(Na, K)Fe_3(SO_4)_2(OH)_6$] that would indicate acidic ground or surface waters in the Mawrth Vallis region.

2. Data

Numerous CRISM HRL and FRT scenes have been collected over the Mawrth Vallis region to evaluate its viability as a possible Mars Science Laboratory landing site (Grotzinger, 2009). The CRISM instrument is described more fully in Murchie et al. (2007), but briefly it utilizes two spectrometers, an "S" spectrometer covering the wavelength region from 0.36 to 1.05 μm, and an "L" spectrometer covering the wavelength region from 1.0 to 3.9 μm. Spectral resolution is approximately 6.55 nm/channel and spatial resolution in its "full resolution targeted" or FRT mode is 15–19 m/pixel. In order to avoid effects from thermal emission in the "L" spectrometer data, here we utilize only channels below 2.65 μm. While there is also information to be derived from "S" spectrometer data, atmospheric dust has a greater influence at these shorter wavelengths. Mars also has inherently low reflectance, and thus provides low signal, at short wavelengths (less then ∼450 nm). CRISM also has a flaw, discussed in more detail in Murchie et al. (2007) caused by a scattered light mask in the VNIR focal plane assembly that results in low response from approximately 610–710 nm, thus except for spectral parameter images calculated from the "S" spectrometer (using methods from Pelkey et al., 2007), we restrict our spectral analysis to the "L" spectrometer data.

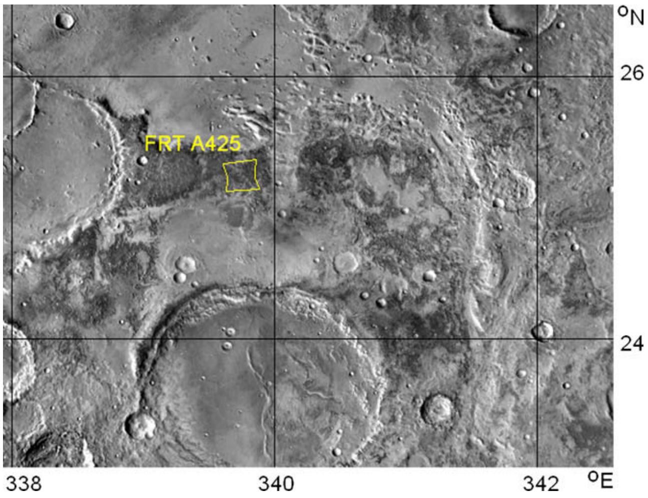

Fig. 1. Mawrth Vallis region shown on a composite of THEMIS day IR images. Location of the CRISM scene referenced in the text is shown.

CRISM "L" spectrometer data were converted to apparent surface reflectance and to surface Lambert albedo using two different approaches in order to compare and contrast the results. Data were converted to apparent surface reflectance using a "volcano scan" approach (Langevin et al., 2005; Mustard et al., 2008) implemented in the IDL-based CRISM Analysis Tool (CAT) (Murchie et al., 2007). The data have also been converted to surface Lambert albedo using look-up table values calculated from forward modeling of the scene parameters using the DISORT (Stamnes et al., 1988) radiative transfer model. A description of this approach for the derivation of surface Lambert albedo from CRISM multispectral mapping data was provided by McGuire et al. (2008). Results were generally comparable from the two approaches although the DISORT correction can retain residual atmospheric features, particularly the 2 μm CO_2 feature. Except where noted, the volcano scan corrected data were used here. For later stages of this work we were also able to utilize the denoising approaches in a later release of CAT (Parente, 2008). To help mitigate instrumental effects and to diminish residual atmospheric effects, the data over the region of interest were also divided by a set of pixels with essentially spectrally flat responses drawn from columns in the data over the same range of columns that include the region of interest.

Georeferenced forms of the CRISM imagery were derived by application of latitude and longitude information provided in accompanying CRISM "DDR" (derived data record) files and utilization of the commercial ENVI software.

Various processing approaches were applied to the CRISM data including calculation of a set of standard spectral mapping parameters (Pelkey et al., 2007) and also application of a linear spectral mixture model (Adams et al., 1993) in which averages of spectra from regions of interest taken to best exemplify spectral "endmember" materials were used to derive fraction images (wherein data values ideally go from zero to one with pixels filled with the endmember material having data values of one and pixels devoid of the endmember material having data values of zero) for each endmember.

3. Results

As part of a broader examination of the Mawrth Vallis region, we have examined numerous CRISM and OMEGA scenes over this area (Table 1), but in this paper focus on a single CRISM scene,

Table 1
CRISM and OMEGA scenes examined in the conduct of this overall study. Only in the FRT A425 scene have we found spectral evidence of the mineral jarosite.

CRISM scenes	OMEGA scenes
HRL0000285A	Orb0353_3
HRL000043EC	Orb0912_5
HRL00009A5F	Orb0923_5
FRT00003BFB	Orb0934_5
FRT00004ECA	Orb0954_5
FRT0000672C	Orb0967_5
FRT0000863E	Orb0978_5
FRT00008838	Orb0989_5
FRT00009326	Orb1293_0
FRT0000A2C2	Orb1326_1
FRT0000A12A	Orb1337_1
FRT0000A425	
FRT0000A600	
FRT0000A955	
FRT0000AA7D	
FRT0000B3B6	
FRT0000B141	
FRT0000B506	
FRT0000B643	
FRT0000BF57	