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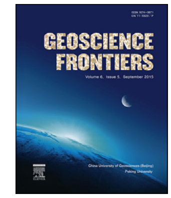

Research paper

Mineral abundances and different levels of alteration around Mawrth Vallis, Mars

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Spectral indices from OMEGA hyperspectral data show that there are two main phyllosilicates exposed in and around Mawrth Vallis: Al phyllosilicates and Fe/Mg phyllosilicates. Detailed analysis of CRISM spectra shows that Al phyllosilicates such as montmorillonite, hydrated silica, kaolinite; Fe/Mg phyllosilicates such as nontronite, saponite, serpentine are widespread on the light-toned outcrops. Though similar stratigraphical sequences, morphologies and textures are observed on both sides of Mawrth Vallis from HiRISE images, suggesting that the geological processes that formed these units must have operated at a regional scale; the multiple endmember spectral mixture analysis (MESMA) derived mineral abundance indicates that there is a higher level of alteration in the western side relative to the eastern side. We suggest that the observed phyllosilicates, stratigraphical sequences and different levels of alteration might have been caused by sedimentary deposition processes in which the composition of the external source sediment or the local solution was different, or by a pedogenic process closely related to the leaching of abundant liquid water with different chemical properties.

1. Introduction

Mawrth Vallis outflow channel, centred at approximately 25°N, 20°W, is located at the dichotomy boundary of the southern highlands and the northern lowlands (Fig. 1). The highly cratered Noachian plateaus around Mawrth Vallis have one of the largest contiguous exposures of phyllosilicates on Mars, which extend as large as approximately 1000 km × 1000 km (Noe Dobrea et al., 2010). The spectrometer Observatoire pour la Minéralogie, l'Eau, les Glaces et l'Activité (OMEGA) onboard Mars Express (MEX) has firstly detected phyllosilicate-rich outcrops in and around this outflow channel with a spatial resolution of hundreds of metres per pixel (Poulet et al., 2005; Bibring et al., 2006). The existence of these minerals has been subsequently confirmed and finely classified by another imaging spectrometer, Compact Reconnaissance Imaging Spectrometer for Mars (CRISM), onboard Mars Reconnaissance Orbiter (MRO) with an increased resolution of approximately tens of metres per pixel (Bishop et al., 2008b). Both of these identifications are based on the spectral absorption bands of Al–OH and Fe/Mg–OH near 2.2 and 2.3 μm, respectively. For example, Loizeau et al. (2007) successfully identified Al–OH smectites and Fe/Mg–OH smectites unit from OMEGA spectra and they are placed exclusively on bright outcrops. McKeown et al. (2009) discriminated definitively nontronite, montmorillonite, kaolinite, saponite and hydrated silica by characterising their specific spectral features on CRISM spectra.

The identified phyllosilicate-bearing units are generally associated with layered and indurated light-toned outcrops with complex spatial and stratigraphical relationships, and further studies of the phyllosilicate-bearing units have shown that there is a typical mineralogical stratigraphical sequence of a Fe/Mg-phyllosilicate-bearing (e.g., nontronite, saponite and vermiculite) unit overlain by an Al-phyllosilicate-bearing (e.g., kaolinite, montmorillonite and hydrated silica) unit, which are in turn overlain by a dark-toned, spectrally unremarkable capping unit (Loizeau et al., 2007; Bishop et al., 2008b; Loizeau et al., 2010; Noe Dobrea et al., 2010). Wray et al. (2008) also suggested that a similar stratigraphical sequence occurs on both sides of the Mawrth Vallis outflow channel and its floor. Loizeau et al. (2012) further studied the chronology of deposition and alteration around Mawrth Vallis region by the cratering model, and they infer the main clay-rich

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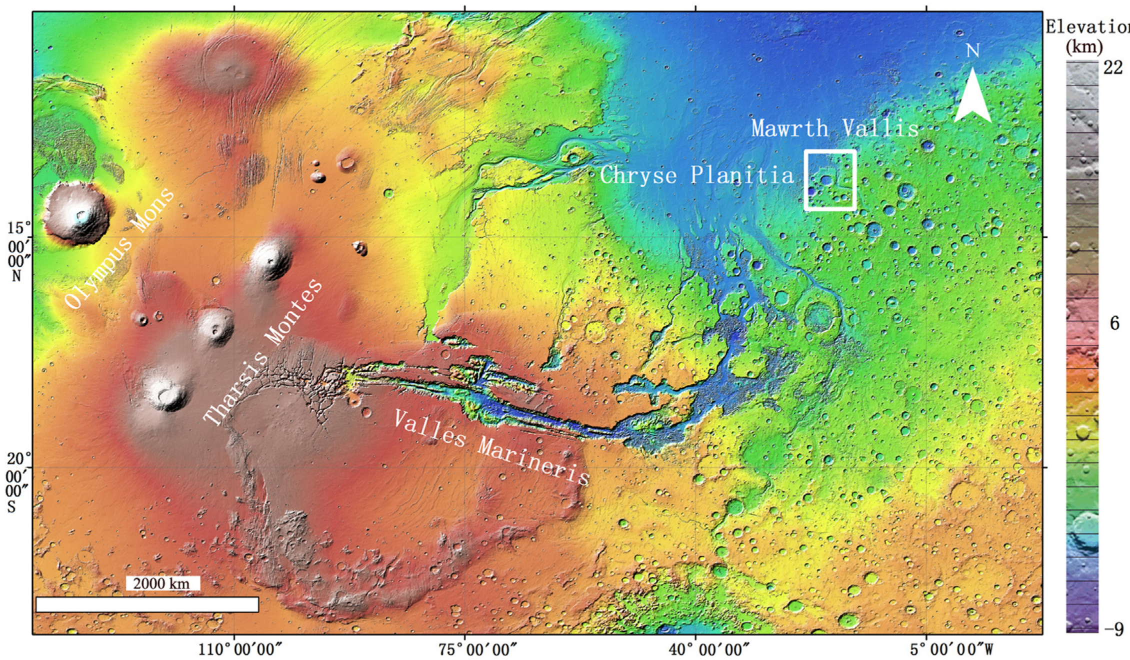

Figure 1. Location of Mawrth Vallis (indicated by the white box) on MOLA elevation data.

layered-unit was deposited in the Noachian period, which is similar to the conclusion from Michalski and Noe Dobrea (2007) that the clay-bearing rocks dated to early–middle Noachian time (estimated as 3.8–4.1 Ga).

Several hypotheses have been proposed for the formation of these phyllosilicate-bearing units. For example, Loizeau et al. (2007) proposed several mechanisms, including deposition of the siliciclastic sediments in an aqueous environment (e.g., an accumulation basin), or the deposition of phyllosilicate-rich aeolian unit; Michalski and Noe Dobrea (2007) interpreted the unconformably deposited, finely layered, lithified phyllosilicate-bearing units to have been formed by pyroclastic or sedimentary processes. Bishop et al. (2008b) suggested that alteration of ashfall-formed basalt, which happened in open water or by groundwater, is the most likely scenario; Noe Dobrea et al. (2008) supposed that the contact between the geological Al-phyllosilicate and Fe/Mg-phyllosilicate units represents an alteration front. Wray et al. (2008) also proposed a similar hypothesis, and further speculated that the Al-phyllosilicate unit may be either sedimentary or pyroclastic in origin. Noe Dobrea et al. (2010) proposed that the layered units may have been deposited at Mawrth Vallis and then subsequently altered to form the hydrated units; the observed Fe/Mg phyllosilicate assemblage is consistent with the products of hydrothermal alteration or pedogenetic processes, and the Al-phyllosilicate unit may have been formed through alteration of felsic material or leaching of basaltic material during pedogenic alteration or in a mildly acidic environment. Based on the existence of Mg–Fe-bearing clays and Mg-carbonates observed at McLaughlin crater around Mawrth Vallis, Michalski et al. (2013) opened up a completely new perspective to explain the mineral formation mechanism that various altered and cemented surface mineral sediments in this region were formed owing to groundwater upwelling, which in turn is of major astrobiological significance and have extremely high preservation potential of a deep biosphere on Mars.

Apart from the qualitative description on the stratigraphy, geomorphology on this region, some quantitative analysis work has been done that try to determine mineral fractions present in various stratigraphic units on Mawrth Vallis. Poulet et al. (2008) applied Shkuratov radiative transfer theory to model OMEGA near-infrared reflectance spectra to derive the modal mineralogy on ten selected phyllosilicate-rich outcrops, which shows as much as 65% phyllosilicates (with an estimated accuracy of about ±10%) may exist in these outcrops of Mawrth Vallis region. The same work has been done on CRSIM spectra to get preliminary estimates for the mineral abundances of the major phyllosilicate-bearing deposits at the final four curiosity candidate landing sites (Poulet et al., 2014). Farrand et al. (2011) also used Shkuratov theory to model CRISM spectra, while Ehlmann et al. (2011) utilized Hapke theory to retrieve mineral abundances from CRISM spectra, both of their results are similar and comparable. Not only the near infrared spectra observed at this region are utilized to derive the modal mineralogy, thermal infrared data are also used. Spectral unmixing of Thermal Emission Spectrometer (TES) data on light-toned units from Michalski and Fergason (2009) showed phyllosilicate abundances are about 10–20%, which is near the TES threshold of detectability. Viviano and Moersch (2013) used multispectral THermal Emission Imaging System (THEMIS) data to derive the phyllosilicate abundance distribution map on light-toned phyllosilicate-bearing materials in Mawrth Vallis, which shows maximum phyllosilicate abundance is about 63%. It is obvious that there are significant discrepancies on the modal mineralogy derived by the visible and near-infrared spectra and by the thermal infrared spectra, the potential factors that may account for this discrepancy (e.g., sub-pixel temperature differences, low absolute phyllosilicate abundance, and surface textures) are described (Michalski and Fergason, 2009) and tested (Viviano and Moersch, 2013) by previous works.

As phyllosilicates can only form in aqueous environments, a quantitative mineral abundance description will help to infer and constrain the aqueous environments that formed these mineral assemblages and even the lasting time of these aqueous activities. Thus, we will better present our unmixing results of average spectra from interested CRISM scenes on a more microscopic scale around both sides of the Mawrth Vallis, and discuss the implications of the unmixing results, which may be used to