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Spectral and thermodynamic constraints on the existence of gypsum at the Juventae Chasma on Mars

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ABSTRACT

The spectral imaging of the Mars obtained with the Mars Express/OMEGA experiment demonstrates that a majority of the sulfates-rich regions are associated with the interior light-toned layered deposits within the canyon system in the equatorial zone of the planet. While all sulfates-rich deposits inside the canyons are characterized by the presence of the kieserite and hydrated magnesium sulfates, the spectral features of gypsum were detected only in the Juventae Chasma and the Iani Chaos. The detection of gypsum in the upper part of the layered deposits, stacking the erosional remnant on the floor of the Juventae Chasma (above the spectral signature of the kieserite and polyhydrated sulfates detected on the flanks of the remnant) represents a more intriguing case. To clarify the question of the presence of gypsum in the Juventae Chasma, we present reanalyzed OMEGA spectra within that area and performed the chemical equilibrium modelling of sulfates precipitation sequence at the freezing and the evaporation of a hypothetical aqueous solution which could have existed within the Chasma in the past. Our results did not confirm the presence of distinct spectral signatures of gypsum. The results of equilibrium modelling also exclude significant precipitation of gypsum during the latest stage of the aqueous sedimentation, responsible for the formation of the upper part of the erosional remnant.

1. Introduction

There are reliable evidences that sulfates are presence in the surficial Martian regolith at the landing sites of the Viking 1 and 2 (Clark et al., 1982), of Mars Pathfinder (Reider et al., 1997; Wänke et al., 2001; Foley et al., 2003), of MERA and MERB (Gellert et al., 2006; Wang et al., 2006). The following OMEGA/ Mars-Express experiment reveal detected several sulfates-rich regions in the equatorial Valles Marineris canyon system (Bibring et al., 2005; Gendrin et al., 2005) and in the Northern polar area (Langevin et al., 2005; Fishbaugh et al., 2007). The majority of the sulfates-rich regions in the equatorial zone are associated with the light-toned layered deposits within the canyon system and the chaotic terrains (Bibring et al., 2005; Gendrin et al., 2005; Quantin et al., 2006). Among several hypothesis about the genesis of the light layered deposits (see overview in (Catling et al., 2006) their aqueous origin due to sedimentation within closed water reservoirs (in the Late Noachian-Early Hesperian period) appears most likely (McCauley, 1978; Nedell et al., 1987; Komatsu et al., 1993; Malin and Edgett, 2000; Catling et al., 2006). Morphologic and stratigraphic relationships of the layered sedimentary deposits with bedrocks indicate that the deposits were formed inside the canyon long before the Hesperian lava flows covered the surrounding plateau (Catling et al., 2006).

Three main types of sulfate minerals were detected in OMEGA spectra of the layered deposits: kieserite, polyhydrated magnesium sulfates and gypsum. The presence of the kieserite and polyhydrated sulfates in sulfates-rich deposits was detected in all the canyons, but the gypsum's spectrum was detected only within the Juventae Chasma and the Iani Chaos (Bibring et al., 2005; Gendrin et al., 2005). The detection of spectral features of gypsum in the Juventae Chasma represents presents an intriguing case. The point is that according to (Bibring et al., 2005; Gendrin et al., 2005), the spectral features of gypsum are is associated with the upper section of the light layered deposits, stacking the more southern erosional remnant on the floor of the Chasma (Fig. 1), while the spectral signature of kieserite and polyhydrated sulfates was found on the lower flanks of the deposits. However, the presence of gypsum within the upper suite of the layered deposits represents in an essential contradiction from the points of view both geology and the concept of solubility of sulfates. To clarify the question of that gypsum location, we reanalyzed OMEGA

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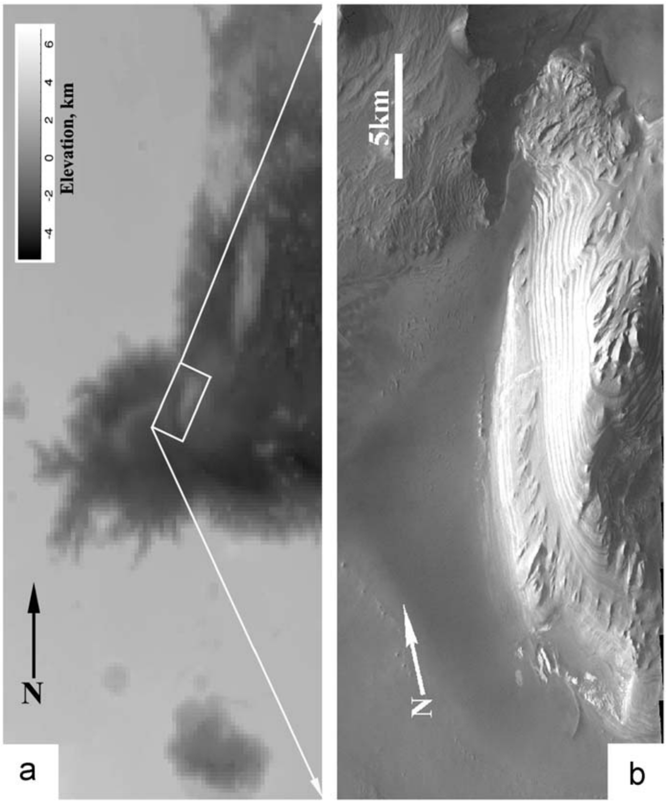

Fig. 1. The MOLA topography of the Juventae Chasma within the footprint of OMEGA spectral cub ORB0482_2 (a) and the THEMIS VIS frame (b) of the southern erosional remnant stacked of the light-toned layered deposits.

spectra of the area and conducted chemical thermodynamic equilibrium modelling of salts precipitation sequence at both freezing and evaporation of a hypothetical initial solution which could have existed within the Juventae Chasma.

2. Analysis of the OMEGA data

To analyze the near-infrared reflectance surface spectra of the Juventae Chasma we used OMEGA spectral cub ORB0482_2. The data were subjected to comprehensive atmospheric corrections in order to exclude contributions of the gaseous absorption bands. Synthetic atmosphere transmittance has been calculated for each spectrum of the OMEGA image taking into account the observation geometry, atmospheric temperature profiles and surface pressures. The temperature-pressure information was taken from the European Mars Climate Database (Forget et al., 1999). Because the spatial grid of the European Mars Climate Database is very rare ($5.675^\circ \times 3.75^\circ$), the surface pressure was recalculated taking into account the MOLA topography (Smith et al., 2001) with a resolution of 16 pixel/deg. Because the atmosphere of Mars has a low density, we ignored the Rayleigh scattering for the spectral range of the OMEGA detector C (0.96–2.67 μm). Aerosol scattering has not been taken into account as well. We assume that the atmospheric optical depth depends only on the gaseous absorption. Therefore, the absorption of the main gaseous component (CO_2) and the minor component (H_2O) has been taken into account. Despite the low-density atmosphere there are some distinct CO_2 bands inside the OMEGA detector C range: 1.43, 1.57, 1.6, 2.0, and 2.7 μm. This range also includes some important water vapor bands: 1.15, 1.38, 1.87 and 2.56 μm. In contrast to CO_2, the water vapor mixing ratio in the Martian atmosphere varies from ~0 to 1000 ppm. To account for this, the seasonal variation of the water abundance was taken from the thermal infrared observations by the TES on the Mars-Global-Serveyor (Smith, 2004). The zonally variable scale height of H_2O was simulated using the GFDL's MGCM Preston model (Rodin and Wilson, 2006). The CO band located near 2.3 μm and the O_2 emission at 1.27 μm has influence on our spectral analysis and has been excluded from calculations of atmospheric transmittance. The parameters of molecular vibration-rotational bands for the CO_2 and the H_2O were taken from the HITRAN-2004 database (Rothman et al., 2005). To calculate absorption coefficients, the 'line-by-line' procedure has been used with the Foight profile for H_2O and CO_2 lines and the form-factor derived by Burch et al. (1969) for CO_2 far wings. To shorten the calculation time, the CO_2 and H_2O absorption cross-sections have been considered on a fixed grid: 10 pressure values for the range from 10^{-9} to 20 mbar and 11 temperature values for the range from 110 to 320 K. The broadening coefficient for water vapor lines in the CO_2 atmosphere of 1.5 has been taken from Gamache et al. (1995). Calculated transmittance spectra have been convolved with the Point Spread Function of the spectrometer (spectral resolution ~13 nm). Based on corrected OMEGA spectra, several spectral indexes have been constructed using the main adsorption bands for gypsum (1.75, 1.93 and 2.2 μm), for kieserite (2.07 and 2.4 μm) and for polyhydrated sulfates (1.93 μm). The detection threshold values of the used spectral indexes (see Table 1) have been defined taking into account such sources of the errors as the instrument noise, the uncertainty of the photometric function, the theoretical solar spectral error and the errors due to atmospheric correction (wavelength depending).

The results of index mapping are presented in Fig. 2. As can be seen from Fig. 2, the maximum values index of the 1.93 μm band correspond to the erosional remnant summit (bright area on Fig. 2b) and the spectral characteristics of the area are consistent with the spectra of polyhydrated sulfates, but not with the presence of gypsum (see Fig. 3a). At that, the maximum index values of the 2.07 and 2.4 μm bands are related to the erosional remnant flanks (bright area on Fig. 2d and e) and their spectral characteristics are consistent with the kieserite spectrum (see Fig. 3b). Moreover, the correlation between the indexes maps for the two main absorption bands used for the detection of gypsum (1.93 and 2.2 μm) is not observed within the erosional remnant. As can be seen from Fig. 2b and c, the summit of the erosional remnant is characterized by a distinctive presence of the 1.93 μm band while the feature at 2.2 μm band here is completely absent. In addition, the other band of 1.75 μm, typical for gypsum, is not detectable in the studied area because of its depth is lower than the spectral noise level, whereas the bands typical for kieserite indexes (2.07 and 2.4 μm) are present mostly on the remnant's flanks (see Fig. 2d and e).

The spectral ratios for the summit and flanks of the erosional remnant (with library spectra of polyhydrated Mg sulfates and gypsum) are presented in Fig. 3. As can well be seen in Fig. 3a and b, the spectral ratio of the summit part of the erosional remnants is consistent with the spectrum of polyhydrated sulfates (like pentahydrite), but not with the gypsum spectrum, whereas the spectral ratio of remnant flanks shows notable similarity with the kieserite spectra. It is notably that no distinct spectral signature of the gypsum has been observed within the other light-toned layered deposits outcrops in the Juventae Chasma, according to the high resolution spectral data, obtained recently with the imaging spectrometer CRISM aboard the Mars Reconnaissance Orbiter (Bishop et al., 2007, 2008). In the same time, the presence of kieserite and polyhydrated Mg sulfates has been also confirmed based on the data. Recently conducted analysis of the OMEGA spectra from the Iani Chaos (Noe Dobrea et al., 2008) also