

Constraints on the rate of sulfate phase changes in Valles Marineris Interior Layered Deposits. L.H. Roach¹, J.F. Mustard¹, S.L. Murchie², J-P. Bibring³, R.E. Arvidson⁴, J.L. Bishop⁵, R.E. Milliken⁶, F. Seelos², and the CRISM Science Team. ¹Dept. of Geological Sciences, Box 1846, Brown University, Providence, RI 02912 Leah_Roach@brown.edu, ²Johns Hopkins/APL, Laurel, MD 20723, ³Institut d'Astrophysique Spatiale, Orsay Campus, France, ⁴Dept. Earth Planetary Sciences, Washington University, St. Louis, MO 63031, ⁵SETI Institute/NASA-ARC, Mountain View, CA 94043, ⁶JPL, Pasadena, CA 91106.

Introduction: Analysis of OMEGA and CRISM spectral data for sulfate-rich Interior Layered Deposits (ILDs) in Valles Marineris has revealed complex assemblages of iron oxides and multiple sulfates [1-7]. Mono- and polyhydrated sulfates occur together in many ILDs, and can be interpreted as either a multi-sulfate evaporite sequence or a deposit that has undergone recent change in sulfate hydration state from kieserite [$\text{MgSO}_4 \cdot \text{H}_2\text{O}$] to a polyhydrated form. Recent work has shown that kieserite can hydrate to polyhydrated sulfate (PHS) under current martian conditions with 100% relative humidity and is not expected to be stable anywhere water ice is or was present [8]. Thus, we argue the presence of kieserite with PHS in these ILDs may indicate a recent, dynamic hydration by surface-atmosphere interaction or exposure of a diverse sulfate evaporite sequence.

Spectral interpretations of observations over ILDs in Eastern Candor and Tithonium Chasmata are presented, together with geomorphic and topographic arguments for the freshness of sulfate exposure. Understanding the mineralogy present in ILDs and their hydration state and geologic context will enable us to better understand how these features form, and it can provide insight into the rate of hydration/dehydration under current or recent martian conditions. We also present paired OMEGA and CRISM observations of a sulfate-bearing ILD in Eastern Candor Chasma and discuss the possibility of very short-term changes in sulfate hydration.

Datasets: OMEGA is a visible-near infrared hyperspectral imager on the ESA/Mars Express mission [9]. It has a 300m-4.8km spatial sampling, and a 7 to 20 nm spectral resolution in 352 spectral bands over 0.35-5.1 μm . CRISM, a visible-near infrared hyperspectral imager on Mars Reconnaissance Orbiter (MRO), has similar spectral characteristics and takes targeted observations at up to 18m/pixel [10]. The MRO HiRISE camera is capable of acquiring co-aligned imagery with CRISM and can resolve details down to ~ 30 cm/pixel [11].

Background: Kieserite and PHS have been previously identified throughout Valles Marineris with OMEGA data [2,12]. Hydrated sulfates have an absorption near 2.4 μm due to H_2O and OH combinations and sulfate bending overtones [13]. Kieserite is identified by characteristic vibrational absorption features at 1.6 and 2.1 μm . PHS (such as epsomite and copiapite) are identified by absorptions near 1.4 and 1.9 μm due to H_2O . Other sulfates, like gypsum or jarosite, and hydrated minerals, such as phyllosilicates and hydrated silicates, can also be classified by diagnostic absorptions [14].

The sulfates are highly localized, found in many exposed layered terrain but not in neighboring dusty regions

[2]. Deposit locations are indicated on Fig. 1, as are the two ILD study areas. Ferric oxides or ferric sulfates are frequently found in association with the multiple-sulfate assemblages [3,7].

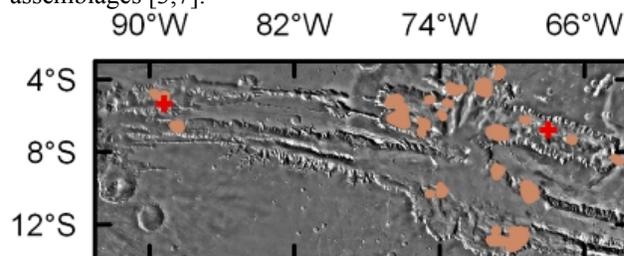


Figure 1. Context map of OMEGA sulfate detections (brown) and CRISM targeted obs in red crosses: FRT0000510D (Tithonium Chasma) and HRS00002FAF (East Candor Chasma).

Mineralogy and Geologic Context in Eastern Candor Chasma ILD:

The East Candor ILD is isolated in the middle of the chasma, with the best layering visible on a bench-like exposure below an E-W trending ridge (Fig 2). Sulfates are not detected on the ridge due to obscuring dust but are found on its flanks. Kieserite, PHS, and another component consistent with gypsum, jarosite, or a hydrated silicate, are found in East Candor [15]. A ferric component is found in overlying, loose, dark material that collects at the base of cliffs and in other topographic depressions [15] (spectra in Fig 3). These findings are consistent with other sulfate-rich ILDs in Valles Marineris [12].

The sulfate-rich layers have alternating hydration states: a HiRISE DEM shows that cliff-forming kieserite-rich layers (which also contain PHS) alternate with slope-forming PHS layers [15]. The mineralogy is consistent within a layer and traceable along the layer's exposure. Additional minerals such as gypsum and hydrated silica also appear associated with layering [7]. The deposit

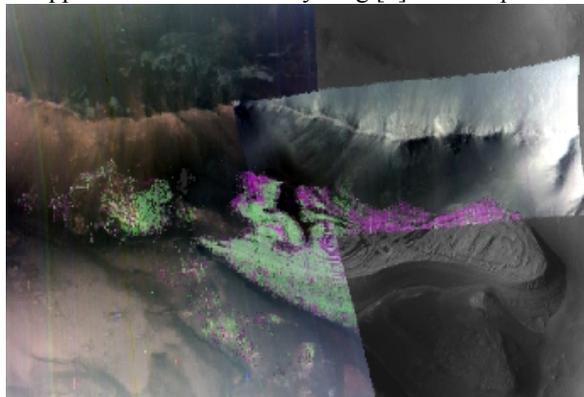


Fig 2. East Candor Chasma ILD in CRISM targets HRS00002FAF and HRL00006844. CRISM parameters indicating kieserite (green) and polyhydrated sulfate (purple) overlain on false color (RGB: 2.33, 1.5, 1.08 μm). ILD is ~ 12 km across.

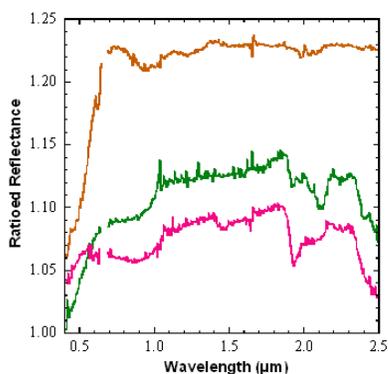


Fig 3. CRISM ratioed spectra from East Candor showing variation across layers in the relative amount of polyhydrated (pink) and monohydrated sulfate (green), and overlying loose ferric component (brown). Spectra from HRS00002FAF and HRL00006844.

could be dominantly kieserite that is hydrating to PHS upon exposure, or a diverse evaporite sequence containing both kieserite and PHS [16]. In either case, fresh kieserite is exposed more rapidly than it can weather to PHS.

Mineralogy and Geologic Context in Tithonium Chasma ILD: A dominantly kieserite-bearing ILD in western Tithonium Chasma stretches ~40 km in length. There is a transition from kieserite to PHS where the ILD is weathering out from underneath a spectrally bland, smooth mantle and abutted by a dark dune field (Fig 4). There is little topographic relief across the transition. Layering is not apparent, but the PHS material appears rougher, darker, and with more dark aeolian material on it. The polyhydrated spectra cannot be explained by intimate or areal mixing of kieserite with the aeolian material. There are several potential explanations for the transition between hydration states. 1) The ILD adjacent to the dunes has a rougher texture and perhaps the greater surface area promotes more rapid hydration than the smoother ILD material above it. 2) Shallow groundwater or collected melt water from interstitial ice in the dune field alters the ILD adjacent to the dunes. 3) Kieserite overlies PHS here from original evaporite deposition or later groundwater alteration and is coincidentally eroded so the PHS-bearing mat-

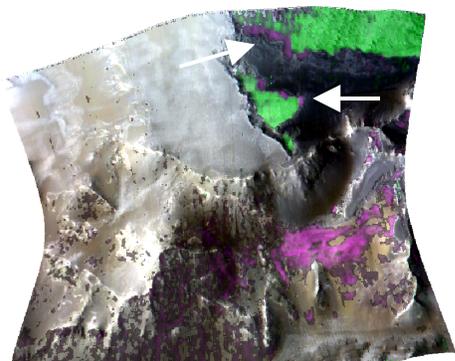


Fig 4. Tithonium Chasma ILD in CRISM target FRT0000510D. CRISM parameters indicating kieserite (green) and PHS (purple) overlain on false color (RGB: 2.33, 1.5, 1.08 μm). Arrows point to hydration state transition. Observation ~10 km across the middle. The first two hypotheses require hydration under current conditions while the third relies on a

coincidence of exhumation. We will test these hypotheses with other CRISM observations of this large ILD.

Paired OMEGA and CRISM observations: OMEGA and CRISM spectra of the East Candor ILD were taken with different viewing geometries and spatial resolution one Mars year apart yet are remarkably similar (Fig 5). OMEGA data were acquired 9/21/2005 and CRISM data on 11/12/2006. A second CRISM observation (not shown) taken 7/6/2007 also shows similar relative amounts of poly- and monohydrated sulfates. Spectra shown are of the same location, but cover 2.8 km^2 with OMEGA, and 7250 m^2 with CRISM. The similarities in the relative band depths of the 1.9 μm and 2.1 μm absorptions indicate the proportionate amounts of PHS and kieserite have not changed over one Mars year. Further OMEGA and CRISM observations over other ILDs will test this. If seasonal changes are not enough to induce hydration, high obliquity events might be needed to provide sufficient conditions [8].

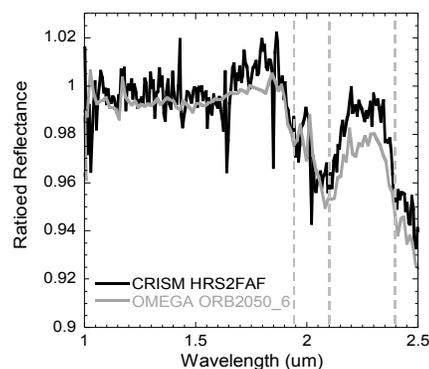


Fig 5. Spectral ratios of OMEGA (gray) and CRISM (black) spectra from same location in East Candor indicating relative amounts of polyhydrated and monohydrated sulfates have remained constant over one Mars year. Dotted lines indicate 1.94, 2.1, and 2.4 μm .

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References: [1] Bibring, J.-P. et al (2007) *Science* 317, 1206-1210. [2] Gendrin, A. et al. (2005) *Science* 307, 1587-1591. [3] Murchie, S.L. et al. (in press) *Nature*. [4] Murchie, S.M. et al. (2007) *AGU Fall Meeting*, Abst P21C-04. [5] Bishop, J.L. et al. (2007) *7th Mars*, Abst #3350. [6] Parente, M. et al. (2007) *AGU Fall Meeting*, Abst P23A-1091. [7] Roach, L.H. et al. (2007) *AGU Fall Meeting*, Abst #2106. [8] Vaniman, D.T., et al. (2006) *LPSC XXXVII*, Abst #1442. [9] Bibring, J.-P. et al. *ESA SP 1240*, 37, 2004. [10] Murchie, S.L. et al. (2007) *JGR 112*, E05S03. [11] McEwen, A.S. et al. (2007) *JGR 112*, E05S02. [12] Bibring, J.-P. et al. (2005) *Science* 307, 1576-1581. [13] Cloutis, E.A. et al. (2006) *Icarus* 184, 121-157. [14] Hunt, G.R., J.W. Salisbury and C.J. Lenhoff (1971) *Modern Geology* 3, 1-14. [15] Roach, L.H. et al. (2007) *7th Mars*, Abst #3223. [16] Roach, L.H. et al. (2007) *LPSC XXXIX*, this issue.