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Origin of Martian Sulfates and Interior Layered Deposits (ILDs) in the Valles Marineris by atmospherically driven processes

J. Michalski (1,2) and P. B. Niles (3)
(1) Planetary Science Institute, Tucson, USA. michalski@psi.edu (2) Natural History Museum, London, UK, (3) NASA Johnson Space Center, Houston, TX, USA

Abstract

Since the first photogeologic exploration of Mars, vast mounds of layered sediments found within the Valles Marineris canyon system (Interior Layered Deposits or ILDs) have remained unexplained. We use spectroscopic mapping along with geomorphic observations and mass balance calculations to address the origin of sulfate-bearing ILDs. The results suggest that the ILDs in Valles Marineris could not have formed from groundwater upwelling or any "bottom-up" alteration. Instead, the ILDs likely formed by atmospherically driven processes.

1. Introduction

A number of models have been proposed to explain the formation of Martian layered sulfate deposits, including the ILDs. These ideas can be grouped as "bottom-up" or "top-down" models. Bottom-up models involve alteration of (or infusion of) layered surface sediments by groundwater [1] that either has dissolved S from the subsurface or becomes infused with SO_2 as the water emerges at the surface. Acidity of the fluid is achieved by dissolution of sulfides in the subsurface or photo-oxidation of Fe^{II}-rich fluids upon emergence in the surface environment [2]. Top-down models suggest that layered sediments were infused with S-rich volcanogenic vapor (fumarolic fluids) [3] or that masses of ice, volcanogenic aerosols, and sediment were deposited together, and chemical weathering of fine-grained sediments occurred within the ice [4]. In both types of models, the altered mass of sediment undergoes late-stage diagenesis, during which hematite concretions form and a final overprint of evaporite mineral textures is preserved.

2. Methods

In order to evaluate these two scenarios as they apply to the sulfate-bearing ILDs, we performed spectroscopic mapping using OMEGA data and carried out mass balance calculations using a Geographic Information System (GIS). OMEGA data were processed into atmospherically corrected I/F spectra using standard techniques described previously [5]. Each image cube was processed into two types of spectral index map: a 2.1 μm index (BD21) tuned to identify monohydrated sulfates (REF) and a 2.4 μm index (BD24) that identifies polyhydrated sulfates. Both of these spectral index maps were used together to map occurrences of sulfates within Ophir, Candor, and Melas Chasmata and no distinction is made between the two classes of sulfates in this work. Sulfate-bearing units were identified where >5 contiguous pixels (though most include >>5) above the detection limit of either index occur together. Detections were validated by comparison to previous work showing localized sulfate detections [6-13] and by inspection of extracted surface spectra for evidence of sulfate minerals. The area and average elevation of each mapped deposit was calculated in the GIS. A histogram of the elevations at which the 84 detected sulfate deposits occur was created by dividing the area of each deposit by the total area of all of the detected sulfates, and classification within 500 m-bins.

3. Results and Implications

The sulfate deposits occur over an elevation range of ~7.5 km, similar to the overall elevation range of the canyon itself [Figure 1]. Approximately 80% of the sulfate deposit area occurs below an elevation of -1500 m, which we call level-1 (L1). However, ~20% of the deposits are roughly evenly distributed above L1 up to an elevation of 3000 m, which we term level-2 (L2) (Figure 1). Any model to explain the formation of canyon sulfate deposits must account for this wide range of elevations, and must function even at high elevations within the canyon.

The ILDs were emplaced post-Noachian (<3.9 Ga) after the tectonic formation of the Valles Marineris, and were in their current configuration by 3.5 Ga [14]. Therefore any emplacement and erosion mechanisms proposed to explain the ILDs must operate during a window of ~400 My during the Early to Mid Hesperian. At the same time, sulfate- and silica-bearing sediments were deposited on the plains around the canyon (at elevations similar to the rim of the canyon. Therefore, a geological scenario used to explain the ILDs should also be consistent with these additional alteration deposits.

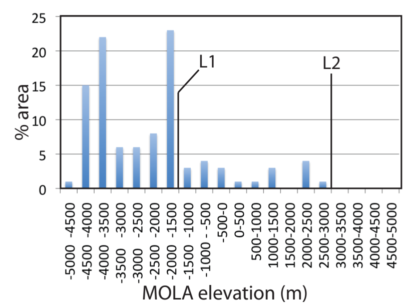
If groundwater produced the sulfates that occur up to the elevation of L2, then either a vast lake must have formed in the canyon system (which is highly unlikely and geochemically inconsistent with the alteration phases observed), or groundwater must have existed within canyon fill sediments that occurred up to this level and have since been eroded. If the canyon was filled with sediment to level L2, then it must be true that 4-7 km of sediment was removed by erosion since the Hesperian when these deposits formed. This implies a minimum erosion rate of 10 um/yr, which is low by terrestrial standards [15], but extremely high for Mars and incompatible with the erosion rates predicted for other Hesperian surfaces. Furthermore, the canyon fill sediments would have contains a significant amount of sulfur (assuming that the sulfur-bearing ILDs are erosional remnants of a vast deposit of similar composition).

To address the question of the origin of sulfur in the putative canyon fill sediments, we performed mass-balance calculations for the Melas-Candor-Ophir chasma system. Two scenarios were considered. The first was carried out assuming that the sulfates detected by OMEGA are simply surface veneers of altered materials averaging ~100 m-thick. The second calculation was carried out assuming that this part of the canyon was filled to L2 with sulfate-bearing sediments. Volumes of material were calculated in the GIS environment by fitting a plane at an elevation 3000 m (L2), and calculating the volume beneath that plane and above the current topography or in the case of veneers, by simply multiplying the area by an average thickness of 100 m.

The results show that the canyon system could never have been filled with sulfur-rich sediments because it would requite the presence of more SO_2 than has ever been outgassed during all of Martian history [13]. By contrast, if the ILDs formed in a configuration similar to their current size and shape, the mass of sulfur required to produce these deposits could easily have been supplied by volcanic outgassing, particularly because the peak outgassing is likely ot have occurred during the Early Hesperian [13], when the ILDs also formed.

The ILDs most likely formed from atmospherically driven processes where SO_2 was supplied by acid snow and/or acid rain fueled by high rates of volcanic outgassing. S-rich sediments on the plains outside the canyon and within the ILDs could have formed from deposits of snow-ice mixed with clastic material and SO_2 that were deposited during periods of high obliquity, when the canyon may have been volatile sink.

Figure 1: Histogram of sulfate occurrences.



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