

Sulfate Formation on Mars By Volcanic Aerosols: A New Look. D. L. Blaney, Jet Propulsion Laboratory, California Institute of Technology, MS 193-501, 4800 Oak Grove Dr., Pasadena, CA 91109, blaney@kookaburra.jpl.nasa.gov.

Abstract: Sulfur was measured at both Viking Lander sites in abundances of 5-9 wt % SO₃ [1,2]. Because the sulfur was more concentrated in clumps which disintegrated and the general oxidized nature of the Martian soil, these measurements led to the assumption that a sulfate duricrust existed [e.g. 3]. Two types of models for sulfate formation have been proposed. One is a formation by upwardly migrating ground water [3,4]. The other is the formation of sulfates by the precipitation of volcanic aerosols [5]. Most investigators have tended to favor the ground water origin of sulfates on Mars. However, evidence assemble since Viking may point to a volcanic aerosol origin.

The Evidence: 1) *Distribution of Sulfates:* The Viking landing sites in Chryse and Utopia were separated by thousands of kilometers, yet both had evidence of a sulfate duricrust [2,3]. Blaney and McCord [6] found spectroscopic evidence of sulfates at 4.5 μm at a wide variety of locations. These locations included: volcanic regions in Tharsis, a region that included Solis Planum, and a heavily cratered region that included Argyre. Therefore, sulfates occur on Mars in terrains of varying ages and geology. A ground water origin for sulfate formation implies that ALL of these locations have undergone aqueous activity. The volcanic aerosol sulfate model separates the local geology from sulfate formation allowing for different geologic evolutions and sulfates.

2) *Recent Volcanism:* Mars has undergone widespread volcanism throughout it's history. The igneous crystallization ages of shergottites of ~ 180 my are young by Mars standards [e.g. 7]. This evidence of recent volcanism provides a mechanism to form duricrust in the current epoch without invoking global aqueous activity needed to form sulfates at such disparate locations as discussed above. A single eruption is capable of depositing a sulfate layer globally.

3) *Lack of Carbonates:* Sulfate formation by aerosol may also account for the lack of readily detected carbonate in the Martian soil. Carbonates are expected to be plentiful on Mars as weathering products and have been found in many SNC meteorites [8]. However, spectroscopic detections of carbonates have not located abundant carbonates in the optical surface [e.g. 9]. Volcanic aerosol formation of sulfates provides a mechanism to strip carbonates out of the optical surface that is measured by spacecraft and groundbased spectroscopy. Sulfate aerosols would precipitate and react with carbonates in the soil releasing CO₂ and bonding with the carbonate cation. This is a near surface process limited by the diffusion of the sulfate aerosol into the soil. Formation of sulfates from stratospheric aerosols occurs on Earth in the interior portions of Antarctica [10]. The fine grained eolian material would be constantly overturned. Volcanic eruptions over geologic time might totally deplete them of carbonates. Even large carbonate outcrops could be covered by a sulfate film making them difficult to detect spectroscopically.

4) *Viking XRD Elemental Pattern:* The Viking X-Ray Fluorescence experiment showed a lack of correlation of sulfur content with any specific cation. Additionally the elemental pattern was roughly isochemical with basalt, indicating that the Martian fines were formed with relatively low ion mobility [2]. Sulfate formation by volcanic aerosols decouples the sulfate abundance from the composition of the fines measured. This contrast with sulfate formation in an aqueous environment where there should be clear indications of ion mobility and correlations with various elemental

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abundances.

The Implications: 1) Sulfate duricrust formation is a secondary modification of the Martian soil. The formation of iron oxides and potential clay minerals occurred in the absence of sulfate containing liquids, perhaps even under non-aqueous conditions.

2) The low abundance / absence of carbonates cannot be used to constrain the weathering environment that formed the Martian fines. Carbonate abundances equivalent to the sulfate abundances detected could have been present. Carbonates at depth may be abundant.

3). Measurement of the distribution and abundance of sulfate minerals on Mars if formed by volcanic aerosols may be critical in understanding Martian climate evolution. Postawko and Fanale [11] point out that SO₂ may be an important green house gas enabling higher surface temperatures. Yung et al. [12] suggested that SO₂ in smaller amounts may serve to warm the atmosphere by preventing the condensation of CO₂ clouds. Therefore, the amount of sulfate in the soil might constrain Mars's climate evolution.

The Tests: 1). *Sulfates will be common, even in volcanic regions where there is no evidence for aqueous activity:* The aerosol formation model predicts that sulfates should be distributed world wide, spread by a complicated pattern of global circulation, location of eruption, and magnitude of eruption. Therefore, sulfates should be found in locations which make widespread aqueous activity unlikely. The Thermal Emission Spectrometer (TES) on Mars Surveyor should detect sulfates in locations where the geologic context of the site rule out an aqueous origin.

2). *Carbonates will be found in localized deposits:* Volcanism may have depleted the near surface, and over geologic time the fines of carbonates. However, given the readiness that carbonates form on Mars, massive carbonate deposits should form, perhaps in standing bodies of water or in hydrothermal systems. With higher spatial resolution it should be possible to detect carbonates exposed by erosion or by fresh impact craters subsequent to sulfate deposition. Mars Surveyor TES will be able to look at high spatial resolution for localized carbonate deposits.

3). *Sulfur abundance globally will not correlate with other elements and will be inversely correlated with carbon:* Since the sulfur is added in a secondary process to the existing rocks and soils of a region, there should be no correlation of sulfur abundance with other elements as would be expected for aqueous formation. As sulfate aerosols break down carbonates, there should be in general an inverse correlation of sulfur with carbon. This can be tested by the Gamma Ray Spectrometer if flown on the Mars Surveyor Orbiter in 2001.

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