THE GEOLOGICAL CONTEXT OF WATER-ALTERED MINERALS IN VALLES MARINERIS.

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Introduction: Over 15,000 km^2 of the layered deposits within Valles Marineris (VM) are associated with water-altered minerals, yet their origin and history of alteration remains a mystery. There are numerous competing hypotheses for the formation of the interior layered deposits (ILDs) that have been postulated, including lacustrine [1] and volcanic [2] in origin. Recent spectroscopic data have indicated that water has played a role in their history. TES measurements [3] have revealed significant crystalline hematite deposits (3,000 km^2 total area) within VM, typically related to ILDs. Usually associated with dark material, these hematite deposits are found within steep bedrock exposures, but also downslope in flat, low thermal inertia surfaces where they may be lag deposits. More recently, Mars Express OMEGA data [4] show hydrated sulfates covering some 10,000 km^2 area of VM. Sulfates are found in numerous topographic settings and geologic units, but are typically located along the flanks of ILDs and floor units. In both cases, hematite and sulfates, formation processes require contributions from water.

We investigated hematite and sulfate sites throughout the Valles Marineris complex in order to better understand the correlation between different mineral types (hematite, polyhydrated sulfates and kieserite) and their likely origin. We used discriminate analyses to study the similarities and differences of the groups in terms of their physical properties and geological context. The results indicate a wide range of diversity within individual mineral classes.

Method: We defined polygons from previous TES hematite maps [3] and OMEGA sulfate maps [4] covering VM. The 243 total polygons were then grouped into 43 sites based on their location, geologic setting, proximity of neighboring polygons and the similarity or differences in their properties. A 14 point look-up table was constructed for the mineral sites that included: area, MOLA elevation [5], MOLA roughness [6], MOLA slopes (0.5 km baseline), TES albedo [7], TES thermal inertia [7] and TES dust index [8]. General trends and correlations were sought for each of the three mineral types and also within their occurrences in a particular geologic subunit (Wall, ILD, and Floor). We also examined each deposit with available MOC narrow-angle, THEMIS visible, and HiRISE images. The ultimate goal is to determine the major characteristics of the different water-altered mineral types, assess their similarities and differences, and relate the findings to their origin and history.

Results and Discussion: Figure 1 shows the global histogram of albedo vs. thermal inertia [9] with the VM mineral units overlaid. The majority of water-altered minerals correspond with high thermal inertia (>300 $Jm^{-2}K^{-1}\ s^{-1/2}$ hereafter referred to as "tiu" for thermal inertia units) surfaces. This would be consistent with mineral locations associated with bedrock exposures, yet a wide range of physical properties suggests that the minerals exist in multiple settings. Polyhydrated sulfates appear the most diverse in thermal inertia and albedo with several floor and ILD unit outliers very bright and indurated. Kieserite is the most clustered mineral in Figure 1 and shows a decreasing albedo with increasing thermal inertia trend. Hematite, also thermophysically diverse, is slightly darker in albedo and higher in thermal inertia than the other minerals. When compared to other non-VM deposits (i.e., Meridiani, Aram & eastern VM chaos terrain), both sulfate classes were found to have very similar thermophysical characteristics. The VM hematite contrasts with exposures in Meridiani Planum (Fig. 1); the VM deposits are nearly 0.05 brighter in albedo and ~200 tiu greater in thermal inertia (mean values), suggesting a different formation and/or histories.

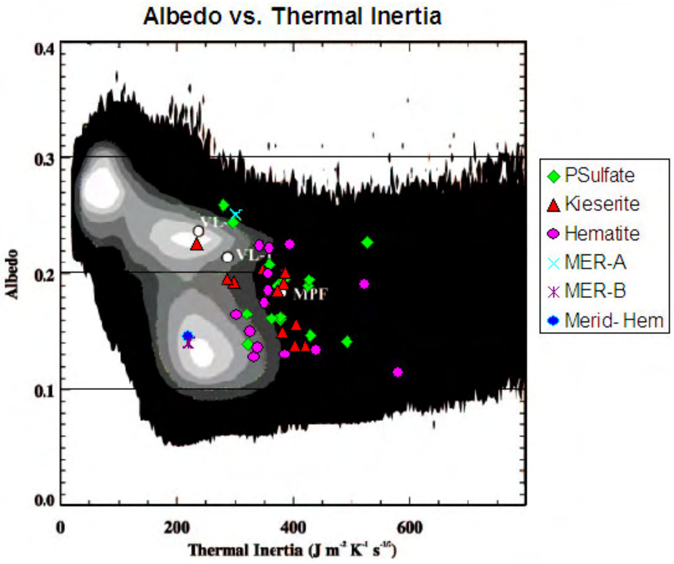

Figure 1. This global histogram Putzig et al. [9] of albedo vs. thermal inertia with VM, MER sites and Meridiani water-altered mineral sites overlaid. Mean values are listed.

Regional comparisons show great diversity between VM chasmatas (Table 1), which also suggests different origins and/or histories. Ophir Chasma's water-altered deposits are primarily located in two very different environments: the topographic low below the southern flank of Ophir Mensa and the central windswept floor.

The later comprises a near homogenous mix of all three types of minerals associated with both steep bedrock exposures and dark (0.14 min albedo), downslope topographic lows. In the hematite case, this location offers a excellent candidate for a lag deposit as observed in-situ at the Opportunity landing site [10]. The mineral site of Ophir's main floor shows some of the highest thermal inertia surfaces (751 tiu) in the whole VM [11], yet counterintuitive, a bright surface with albedo up to 0.27.

Western Candor Chasma possesses the most areally expansive set of water-altered VM deposits detected to date, primarily sulfates along the flanks of Ceti and Candor Mensae. Statistical comparison between characteristics of minerals shows little variability compared to other canyons (Table 1), despite the deposits ~8 km range in elevation. This, along with observations of ill-defined unit boundaries and lack of fresh craters, suggest more erosion is occurring relative to other locations, consistent with the finding of Malin et al. [12]. In eastern Candor Chasma are several large, dusty (1.45 min [8]) and bright (0.25 max albedo) hematite deposits, contrasting with the typical character of both Meridiani and other Valles sites. These deposits are located on lower sections of steep wall remnants and also may represent hematite weathering out and accumulating as a lag deposit.

Far reaching Melas Chasma possesses two major stacks of layered sulfate deposits on the southwest and southeast ends of the chasma with sporadic deposits interspersed. The SW complex shows abundant diversity with sulfates occurring on the flanks and tops of ILDs, in lower sections of wall spurs and in floor deposits; all with a variety of thermophysical characteristics (range of 0.10-0.22 in albedo and 225-550 tiu). Contrastingly, the SE stack of sulfate-bearing ILDs is comprised of repetitive layers with consistently low albedo values (~0.15). The majority of these 10s-100s-m-thick layers can be traced for ~90 km east to west and stay at constant elevation, indicating a large scale depositional environment and little structural deformation since their formation.

Conclusions: Statistical distinctions can be made between deposit types and ongoing qualitative and quantitative studies are placing the water-altered VM deposits in a broader context. Data indicate a wide range of diversity within an individual mineral class, between mineral classes, and also among morphological types. Hematite is typically found in low albedo, high thermal inertia, rough floor units at relatively low elevations. Figure 1 indicates that Valles hematite has a very diverse and different thermophysical character than Meridiani, despite an identical TES spectrum. Polyhydrated sulfate deposits generally have higher albedo, rougher surfaces, and a widespread elevation range. Kieserite is associated with lower slopes and less dusty surfaces and has not been detected on wall units to date. The diversity of mineral deposit characteristics implies that they may have a number of formation mechanisms.

References: [1] Malin, M. C. (1979) *NASA Conf. Publ.*, 2072, 54 pp. [2] Hynek, B. M. et al. (2003) *JGR, 108*, 5111. [3] Christensen, P. R. (2001) *JGR, 106*, 23,873–23,886. [4] Gendrin, A. et al. (2005) *Science, 505*, 1587-1591. [5] Smith, D. E. et al. (2001) *JGR, 106*, 23,689– 23,722. [6] Neumann, G. A. et al. (2003) *Geophys. Res. Lett.*, *30* (11), 1561. [7] Mellon, M. T. et al. (2000) *Icarus*, *148*, 437-455. [8] Ruff, S. and P. Christensen (2002) *JGR, 107*, 5127. [9] Putzig, N. E. et al. (2005) *Icarus, 173,* 325-341. [10] Squyres, S.W. et al. (2004) *Science, 306*, 1709-1714. [11] Chojnacki M. et al. (2006) *JGR, 111,* doi.10.1029/2005JE002601. [12] Malin, M. C. et al. (2006) *Science, 314,* 1573-1577.

Chasma	Mineral Type	Total Area (km^2)	Z (m)	ΔZ (km)	MOLA Roughness	Slope (deg)	Albedo	Thermal Inertia (tiu)	Dust Index
Ophir	Hematie	290	-2924	4.6	4.8	8.4	0.19	439	1.55
	Kieserite	318	-616	5	6.5	13	0.19	383	1.64
	PHS	623	-1447	5.9	7.5	15.7	0.23	397	1.48
Candor	Hematie	1792	-2504	4.7	5.2	12.5	0.18	351	1.53
	Kieserite	3269	360	5.0	4.0	11.8	0.20	351	1.65
	PHS	1360	-440	2.9	4.5	8.6	0.19	368	1.62
Melas	Hematie	389	-3103	3.4	5.5	10.2	0.17	347	1.54
	Kieserite	1702	-2138	2.4	3.3	6.7	0.18	340	1.57
	PHS	2053	-2383	4.2	4.5	9.8	0.15	415	1.62

Table 1. This table catalogs the averages of characteristics for the larger occurrences of mineral deposits within the major chasmata. Substantial diversity exists between the chasmata and mineral types. All numbers are mean values. Z refers to MOLA derived elevation values. Higher MOLA pulse-width roughness [6] values imply rougher surfaces. TES dust cover index values range from 0.85-1.84 (max dust to min dust) [8]. PHS = "Polyhydrated Sulfate"