AQUEOUS PROCESSES AND ACTIVE CHEMISTRY INFERRED FROM PHYLLOSILICATE RECORD AT MAWRTH VALLIS, MARS.

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Introduction: Phyllosilicate observations in the Mawrth Vallis region of Mars indicate thick, wide-spread and uniform deposits [1]. Light-toned outcrops imaged by CRISM show abundant phyllosilicates. Fe/Mg-smectite bearing rocks are covered by an Fe^{2+}-rich phase that may be a ferrous mica. This unit is overlain by rocks rich in hydrated silica and Al-phyllosilicates. Montmorillonite and kaolinite appear to be present primarily in mixtures with the hydrated silica. This builds on previous identifications of phyllosilicates in the Mawrth Vallis region [2, 3]. Here we discuss potential formation scenarios for the observed clay species at Mawrth Vallis.

The breadth of the phyllosilicate deposit at Mawrth Vallis implies abundant water in Mars' geologic past. A high density of phyllosilicates is observed along the main channel and nearby craters, however, phyllosilicates are observed in smaller outcrops across hundreds of km (Fig. 1). The extent of hydrated components including phyllosilicates is discussed in detail by [4].

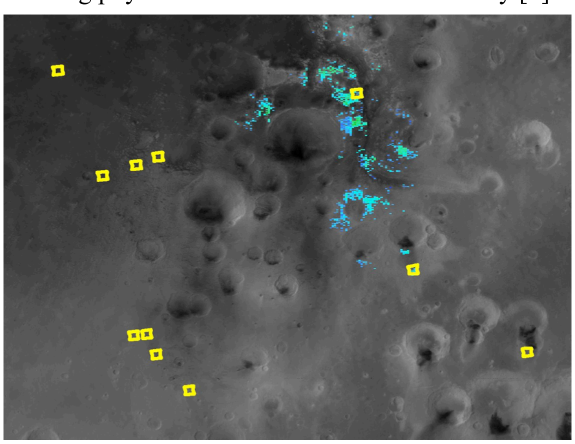

Fig. 1 Phyllosilicate identifications at Mawrth Vallis: Fe/Mg-smectite in OMEGA data (blue), Al-phyllosilicate in OMEGA data (green) and phyllosilicates in CRISM data (yellow squares). Image is 800 km across, modified from [4].

Stratigraphy of Phyllosilicates: The phyllosilicate units at Mawrth Vallis appear to share the same general stratigraphy in CRISM observations throughout the region (Figs. 2 and 3). Small differences are observed in spectral character and the nature of the outcrops; for example, in some cases we see kaolinite bordering the hydrated silica unit, while in other cases we see kaolinite bordering a montmorillonite unit on top of the hydrated silica. However, similar trends are observed in all images. This uniform stratigraphy at Mawrth Vallis is different from other regions on Mars, such as Nilli Fossae, where distinct provinces of clays and associated minerals have been identified [5, 6].

Analyses of spectra collected at Mawrth Vallis in relation to MOLA topography reveal that the Fe/Mg-smectite-rich rocks are typically 200-300 m lower in elevation than neighboring Al-phyllosilicate-rich and hydrated silica-rich layers [1]. The Fe/Mg-smectite exposures appear to be thicker and more resistant to erosion and in most areas they are the lowest unit visible. Differing textures and layering are also observed in HiRISE images for these distinct clay units [7, 8].

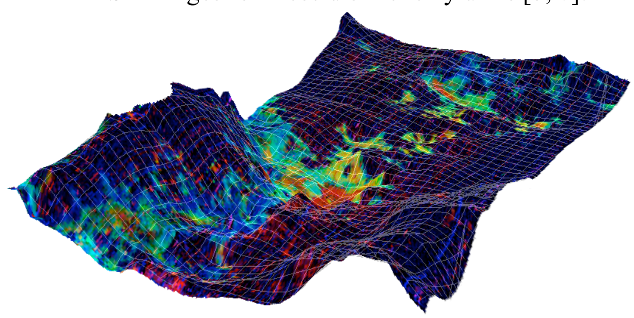

Fig. 2 CRISM image HRL43EC is draped over MOLA terrain and enhanced 20X vertically. Fe/Mg phyllosilicates are shown in orange/red, a ferrous phase in yellow, hydrated silica in green, and Al-phyllosilicates in blue.

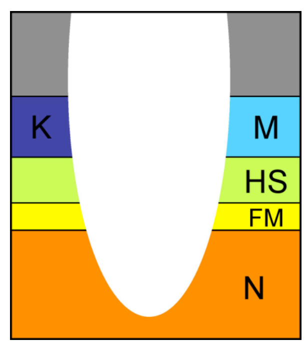

Fig. 3 Stratigraphy of phyllosilicates observed at Mawrth Vallis, where N is Fe/Mg-smectite (e.g. Mg-nontronite) in the lowest unit, FM is ferrous mica or other ferrous species bordering the nontronite, HS is hydrated silica, M is montmorillonite and K is kaolinite.

Possible Formation Scenarios: The nature of the phyllosilicate deposits in the Mawrth Vallis region provide insights into the possible formation processes that took place and enable determination of constraints on the early aqueous activity in the region. Smectites are commonly formed by chemical weathering in marine, lacustrine and hydrothermal environments on Earth and the species of smectite observed can provide information about the geochemical formation environment [9, 10]. Alteration of basaltic rocks typically produces Al- and Fe-bearing dioctahedral smectite, in some cases via formation of serpentine, and metastable Mg-smectite as intermediate phases [11, 12].

The initial Fe/Mg-smectite observed at Mawrth Vallis likely formed via aqueous alteration of basalt, the dominant lithology of the Martian highlands [e.g. 13]. This smectite unit appears to drape the topography and exhibits layered textures suggesting that volcanic ash was the basaltic precursor [1]. Alternative sources include water-lain basaltic sediments and impact ejecta. The stratigraphy of the clay units is complex indicating that multiple depositional events occurred over a prolonged period of time [14].

A number of possible formation processes exist for the additional clay minerals and stratigraphy of these units. Cold and dry climates, such as those found at the Arctic, Antarctic, and high elevations on Earth, as well as on Mars today, have limited liquid water and are dominated by physical weathering [9, 10, 12, 15]. Cool and humid conditions may alter precursor rocks to form free silica and highly degraded rock-derived phyllosilicates, while warm-subarid climates favor formation of iron-bearing smectites, especially in environments with seasonal variations in humidity.

Acid-leaching. Alkaline conditions favor smectites under normal temperatures and pressures on Earth in the presence of Ca and favor mica in the presence of K, whereas acidic conditions support formation of kaolinite and hydrated silica [9, 10]. Assuming the presence of basaltic ash that at least partially altered to Fe/Mg-smectite, subsequent aqueous alteration and acid leaching of Fe and Mg could have produced hydrated silica, montmorillonite, mica, and kaolinite. Dissolution rates are similar for most phyllosilicates in near neutral environments and increase under lower and higher pH conditions [15]. Sedimentary micas (e.g. glauconite, illite) form from smectite under more highly altered conditions [e.g. 9]. Active hydrolysis and ion leaching in soils often results in formation of kaolinite, goethite, opal and gibbsite [e.g. 10]. Acid-leaching studies on smectites in the lab have shown the gradual formation of hydrated silica [16].

Hydrthermal alteration. Lab studies of hydrothermal alteration of volcanic glass have shown formation of increasing amounts of smectite and illite-smectite with reaction time [e.g. 17]. Hydrothermal alteration at Mawrth Vallis via warm standing water could have enabled formation of the multiple clay units observed due to changes in aqueous chemistry. Under long-term exposure to aqueous conditions smectites can convert to ferrous mica (e.g. glauconite) in a reducing environment, if wet/dry cycling occurs, or in the presence of abundant iron or high salinity [9, 15].

Another scenario could be hydrothermal alteration created by a large melt sheet that quickly covered a large region of basaltic ash mixed with H_2O (permafrost of aquifer). The trapped H_2O would have been heated and could have provided a mechanism for smectite formation from the basaltic ash. Perhaps an alteration front expanded downwards from the hot surface, thus forming the most highly altered and leached clay units (hydrated silica and Al-phyllosilicates) above the Fe/Mg-smectites.

A possible scenario for formation of the ferrous material could be an initial widespread aqueous event that produced Fe/Mg-smectite that then hardened, followed by subsequent melt sheet activity. Perhaps this could have created a layer of Fe^{2+} that was leached quickly from the ash as the hydrated silica, montmorillonite and kaolinite were formed, but then was trapped at the border with the Fe/Mg-smectite and then formed Fe^{2+} clays. Without contact with the surface and an oxidizing environment, this Fe^{2+} could have remained in its reduced form.

Summary: Mawrth Vallis appears to have experienced at least one large-scale aqueous event that produced roughly uniform strata 100s of km across. Understanding the processes that formed Mawrth Vallis may enable a better picture of the early epoch of Mars.

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