CLIMATE CHANGE AND A SEQUENCE OF HABITABLE ANCIENT SURFACE ENVIRONMENTS PRESERVED IN PEDOGENICALLY ALTERED SEDIMENTS AT MAWRTH VALLIS, MARS. B. Horgan[1], J. A. Kahmann-Robinson[2], J. L. Bishop[3], P. R. Christensen[1]. [1]School of Earth and Space Exploration, Arizona State University (briony.horgan@asu.edu), [2]Department of Geology & Geophysics, University of Utah, [3]Carl Sagan Center, SETI Institute.

Introduction: Noachian outcrops in the Arabia Terra region expose a thick stack of light-toned layered deposits that have near-infrared spectral characteristics consistent with a variety of clay minerals [*e.g.*, 1-10], and these units are best exposed in the region surrounding Mawrth Vallis. While many different origins have been proposed for these clays, including lacustrine, diagenetic, hydrothermal, and pedogenic, few have been able to explain the full diversity of clay minerals, and good terrestrial analogs for the site have been lacking. In this study, we provide a new look at the mineralogy of Mawrth Vallis and propose a geologic framework for interpreting the clay mineralogy at Mawrth Vallis based on terrestrial paleosol sequences.

Paleosol sequences: The majority of terrestrial non-marine clays are formed via pedogenic weathering in soil profiles. When soils are buried, they are preserved as paleosols, and can be used to reconstruct ancient surface environments and paleoclimates [11], such as oxygenation of the Earth's atmosphere in the Precambrian [12]. When sediments are repeatedly deposited over long periods, such as in alluvial, deltaic, or volcaniclastic sediments, paleosol sequences can form that track paleoenvironmental changes at high temporal resolutions (10^3-10^6 years). Paleosols can be regionally extensive (deposits many hundreds of km in extent), especially when they are developed on volcaniclastics, as demonstrated by well-known paleosol sequences in the Painted Desert (AZ) [13,14], the Painted Hills (OR) [15], and the North Dakota Badlands. Sub-aerially deposited volcaniclastics have been proposed as the origin for the extensive sediments at Mawrth, and if Noachian Mars had any weather at all, we should expect to see signs of pedogenic alteration in these sediments. Indeed, the clay minerals previously identified at Mawrth are all common pedogenic minerals, and the changes in clay mineralogy with stratigraphic position are similar to paleosol stacks developed under changing climatic conditions.

Methods: For our preliminary analysis, we have used CRISM observation FRT3BFB, located on the south flank of Mawrth Vallis, where significant mineral diversity has been shown [10]. The cube was corrected for atmospheric, phase, and some instrumental effects using the CRISM Analysis Toolkit (CAT) for ENVI. To suppress signals other than those of the minerals of interest, reference spectra were calculated for each column using the average of all spectra that did

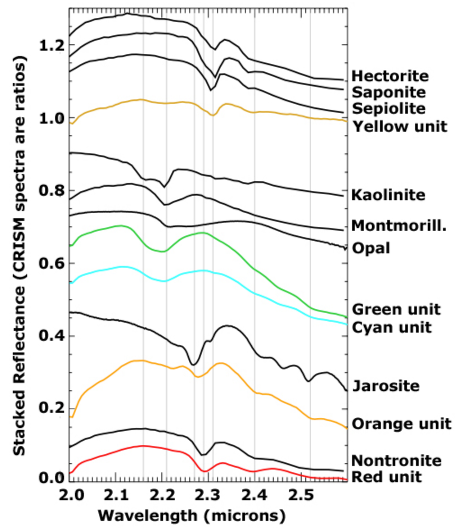

Figure 1: Average spectra for units mapped in Fig. 2, compared to lab mineral spectra from the USGS Spectral Library [23]. Lines at 2.16, 2.21, 2.27, 2.29, 2.31, 2.4, and 2.52 μm.

not exhibit absorptions due to clays (BD2200/ BD2300), ice (BD1500), bound water (BD1900R), or ferrous phases (HCPINDEX/OLINDEX2). Each column was divided by the corresponding reference spectrum to create a ratio spectra cube. Custom band depth parameters were then applied to the ratio cube to detect absorptions at wavelengths of 2.16, 2.21, 2.27, 2.29, and 2.31 μm. Depths > 1% are considered a detection.

Diverse clay mineralogies at Mawrth: Based on absorptions in ratio spectra, we have identified five mineralogic units, with average spectra shown in Figure 1, and mapped in Figure 2. These detections are consistent with previous work in the region [1-10]. *Nontronite-bearing unit (red):* absorption at 2.29 μm, additional near 2.4 and 2.5 μm, consistent with an Fe-smectite (*e.g.*, nontronite). *Jarosite-bearing unit (orange):* absorption at 2.27 μm, additional at 2.42 and 2.52 μm, consistent with a jarosite-like phase [7]. *Aluminosilicate-bearing unit (cyan):* broad absorption at 2.21 μm, consistent with an Al-smectite (*e.g.*, montmorillonite), but enhanced absorption at shorter wavelengths may indicate the presence of kaolinite/smectite interlayer clays [16] or a poorly crystalline phase (allophane) [9,10]. Spectra in this unit with significant absorption at 2.16 μm are grouped into the *Kaolinite-bearing unit (green)*. *Saponite-bearing unit (yellow):* absorption at 2.31 μm, additional near 2.42 μm, consistent with Mg-clays like saponite.

Paleoenvironment Interpretations: *Smectites and a semi-arid climate:* Hydrolysis (leaching of cations by dissolved CO_2) drives clay formation in soils. When fluids are inefficient at flushing cations from the profile, as in arid climates or poorly drained soils, the cations are incorporated into smectites. The widely distributed nontronite unit at Mawrth most likely does not reflect local poorly drained conditions, so it instead most likely indicates a relatively arid climate. On Earth, precipitation rates <1m mean annual precipitation (MAP) generally produce smectites, above which kaolinite becomes more prominent [11,14,15].

Jarosite formation: Jarosite is a common mineral in acid-sulfate soils, which are produced when soils initially formed in reducing, sulfide-producing conditions are then oxidized, such through water level changes in coastal regions [17]. At Mawrth, the jarosite-bearing unit occurs at the change in slope at the edge of the nontronite-bearing unit, and appears to overlap with that unit. This suggests an alteration front within the nontronite-unit, perhaps related to oxidizing waters down welling from higher topography.

Changing smectite composition: Smectite composition is usually directly related to the composition of the parent material. If the aluminosilicate-unit does contain montmorillonite, this may imply a decrease in the mafic content of the parent sediments, perhaps due to magmatic evolution of a volcanic source. However, if this unit is allophane-bearing instead (see below), the parent material may have remained the same.

Kaolinite and high weathering rates: Kaolinite requires high weathering rates that remove cations from the system to form, and so is usually associated with humid climates (MAP >~1m) and/or steep topography [18]. Thus, the presence of kaolinite (or kaolinite/smectite interlayers, a distinctly pedogenic phase) at Mawrth implies a period of high weathering rates. However, this does not necessarily imply high precipitation rates. If small volumes of water are delivered over short periods of time, such as with alpine spring snowmelt or monsoons in tropical deserts, then allophane is the dominant pedogenic mineral, and will transform to kaolinite over time (10^5-10^6y) [19]. Thus, determining the presence of smectite vs. allophane at Mawrth will be key for interpreting the climate history, but in either case, the presence of kaolinite indicates a sustained period of high weathering rates.

Aqueous deposition of Mg-clays: Because Fe-smectites are generally more stable, Mg-smectites rarely form pedogenically, except as weathering products of pre-existing Mg-clays like serpentine or talc [20,21]. Mg-smectites more commonly form in alkaline (pH>9) fluids in lakes, hydrothermal systems, or swamps, either as precipitates or via transformation of Al-clays [22]. The relatively localized deposits of Mg-smectites in Mawrth Vallis associated with the top of the Al-clay-bearing unit could indicate alteration of these phases in standing alkaline water.

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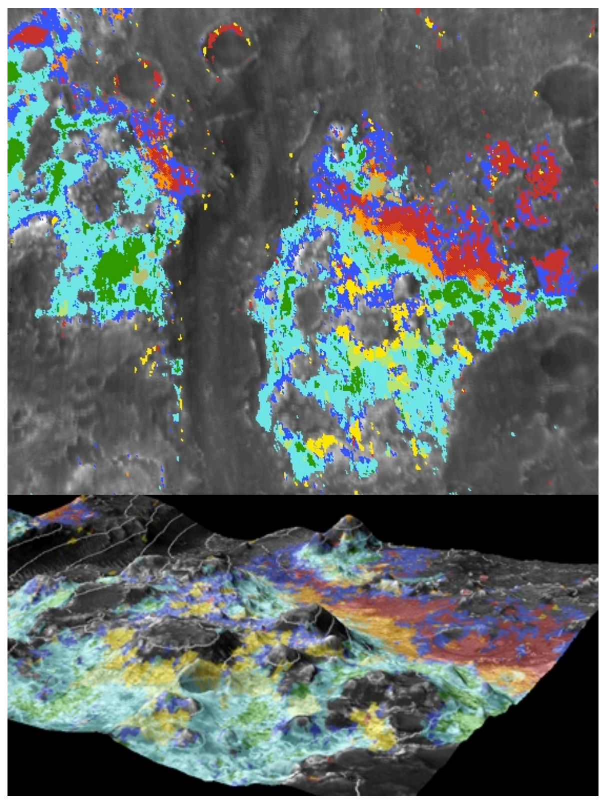

Figure 2: Mineralogic units at Mawrth Vallis, derived from CRISM observation FRT3BFB. *(top)* In plain view, saponite (yellow), kaolinite (green), Al-clays (cyan), jarosite (orange), nontronite (red), and unassigned hydrated phases (purple). Locations where units overlap are indicated by checkered patterns. *(bottom)* Map center draped over HiRISE DTM with 200x vertical exagerration, view is ~6 km in width.