POTENTIAL ANCIENT SOILS PRESERVED AT MAWRTH VALLIS FROM COMPARISONS WITH EASTERN OREGON PALEOSOLS: IMPLICATIONS FOR EARLY MARTIAN CLIMATE. B. Horgan[1], J. L. Bishop[2], P. R. Christensen[1], and J. F. Bell[1], [1]School of Earth and Space Exploration, Arizona State University, Tempe, AZ (briony.horgan@asu.edu), [2]Carl Sagan Center, SETI Institute, Mountain View, CA.

Introduction: 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.*, 1-9], and these units are best exposed in the region surrounding Mawrth Vallis. Based on mineralogy [1-5] and morphology [6], a minimum of six stratigraphic units have been identified (Figs. 1a, 2): (1) A heavily cratered lowermost unit 300-400 meters thick, brown in HRSC and HiRISE color, with weaker spectral signatures of Fe/Mg smectites relative to higher units; (2) A layered, light or blue unit ~30 meters thick with unknown composition; (3) A layered yellow/red/pink unit ~150 meters thick with stronger Fe/Mg smectite and nontronite spectral signatures and weak hematite absorptions; (4) A layered and light-toned transitional unit with Fe^{2+} spectral signatures attributed to ferrous clays; (5) A layered, blue unit ~50 meters thick with spectral signatures variously attributed to montmorillonite, kaolinite, hydrated silica, hematite, allophane, and gibbsite, with stronger kaolinite/hematite signatures stratigraphically higher; and (6) A pyroxene-bearing and erosion resistant dark mantle. Localized deposits of jarosite and bassanite have also been identified [7,8]. Units (2) and (4) are not found in all locations. The lack of a confining basin in the region and the mantling nature of the units has been interpreted as evidence that the layered sediments are volcaniclastic in origin [6], but the timing of clay formation is poorly constrained. Possible formation scenarios include post-depositional leaching to form a deep weathering profile and syn-depositional surface alteration (pedogenesis) to form a sequence of preserved soil profiles (paleosols) [3,4,6]. Here we use new, detailed spectral analyses [4] and terrestrial analogs to show that the clay-bearing units are more consistent with syn-depositional alteration. We then use a pedogenic framework to constrain surface environments and climate at the time of alteration.

Evidence for paleosols: The first constraint on the origin of the Mawrth Vallis layered units is their thickness: typically 150-200 meters. Terrestrial deep weathering profiles (saprolite mantles) are typically several tens of meters thick, and this thickness is limited by weathering rates, landscape stability, and decrease in permeability with weathering [10]. Development in sediments, rapid tectonic uplift, and high biological activity can all increase weathering profile depths; however, terrestrial weathering profiles rarely exceed 100 meters in total thickness [10]. Thus, the Mawrth Vallis deposits may be too thick to be entirely due to a post-depositional leaching event, so in this scenario, the smectites must have been present before leaching occurred. However, there is no thickness constraint for sequences of paleosols, which can form stacks of altered layers several hundreds of meters thick [11].

Furthermore, the Mawrth Vallis deposits exhibit lateral and vertical diversity beyond the overall Fe/Mg-smectite-Al/Si-phase trend, as demonstrated by the heterogeneous distribution of units (2) and (4), and the presence of isolated color units [6]. This diversity is inconsistent with a deep weathering profile, but is consistent with paleosols, which exhibit diversity in composition and color on the meter scale (Fig 1c-e) [11].

Finally, relic layering and possible fluvial landforms are present throughout the units [3], and some layers may be sources of dark sand (Fig. 1b), suggesting that the coarse fraction of the parent material is preserved in some layers. These relic characteristics are inconsistent with a pervasively weathered profile, but are consistent with paleosols, which often preserve bedding and sand-sized parent material in less weathered layers [11]. All of the above characteristics are in contrast to the putative saprolite mantle at Nili Fossae [12], which has a thickness of several tens of meters, and no parent materials apparent above the saprolite.

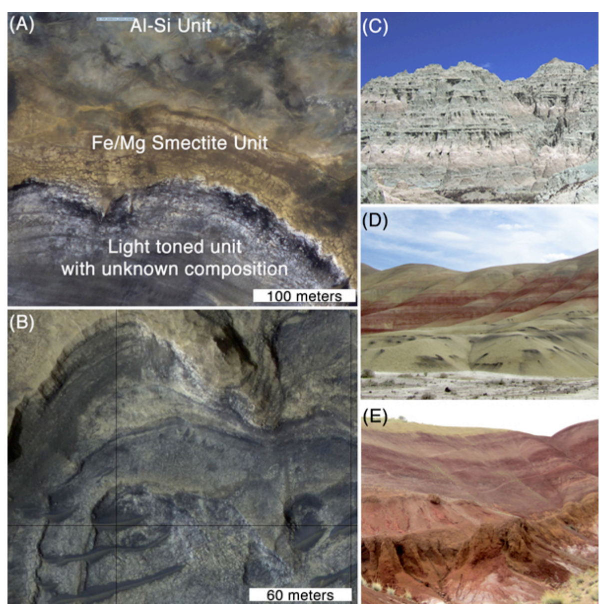

Figure 1: (a) Mawrth stratigraphy, HiRISE PSP_008034_2050. (b) Potential sand sources in exposed layers, PSP_001929_2050. (c-e) John Day paleosols formed at low (c), moderate (d), and high (e) weathering rates.

Terrestrial analog: Over 500 individual meter-scale paleosols have been identified in a 440 meter section of clay-rich (30-90%) layers in the John Day Fossil Beds National Monument in eastern Oregon [11], and the mineralogy, layering, and volcanic source for these deposits bears a striking similarity to the Mawrth Vallis layers (Fig 1c-e). The John Day paleosols developed in andesitic volcaniclastics deposited on the flanks of the Cascades Range over a period of 15 My, and many of the paleosurfaces between the paleosols show evidence for fluvial, alluvial, and lacustrine processes. The deposits span the Eocene-Oligocene boundary, a period of global cooling. The mineralogy of the paleosols reflects this climatic shift through a transition from high kaolinite and oxide abundances at the base, to high smectite abundances, to low abundances of smectites and poorly-crystalline phases at the top of the stratigraphy (Fig. 2) [11].

Pedogenic mineral trends: As demonstrated in the John Day paleosols, basaltic and andesitic ash soils are dominated by four minerals: smectite, halloysite, allophane, and kaolinite [13-17]. The mineralogy depends on many factors, but is usually determined by precipitation rates, as halloysite and allophane are favored under rapid weathering [13,16]. Smectite dominated soils tend to form under the lowest precipitation rates (<1 m/year), either due to a dry or highly seasonal climate, while halloysite, allophane, and kaolinite dominated soils formed under progressively higher precipitation rates [13-15]. Other important factors include acidity, which inhibits allophane precipitation [17], and poor drainage, which produces smectites [13].

Susceptibility of volcanic soils to burial alteration is highly variable, as demonstrated throughout the John Day paleosols [11]. Paleosols with abundant clays do not experience notable changes during moderate burial (*e.g.*, ~1 km at John Day), although burial reddening (goethite-hematite transformations) can occur. Poorly crystalline phases like relic glass and allophane are often transformed to zeolites and silica. Poorly drained soils with limited access to atmospheric oxidants produce ferrous iron, and during burial, the ferrous iron is incorporated into ferrous micas like celadonite [11].

An evolving climate at Mawrth Vallis: In the context of pedogenesis on Earth, the overall trend from smectites to Al-Si phases at Mawrth Vallis would indicate an increasingly humid climate through time. The Fe/Mg-smectites in unit (3) exhibit weak iron oxide absorptions and few signs of burial alteration, consistent with well-developed soils in an arid or sub-humid climate. The Al-Si phases in unit (5) appear to increase somewhat in crystallinity and iron oxide content with position in the stratigraphy, consistent with a general maturation trend of allophane/halloysite - kaolinite/hematite in a sub-humid to humid climate. The patchy distribution and correlation with topographic lows of the ferrous unit supports the interpretation that this unit represents soils that were poorly drained and altered to ferrous mica upon burial. Furthermore, the decrease in ferrous absorptions with stratigraphic position in unit (5) also supports increasing crystallinity of this unit through time and therefore also increasing humidity through time.

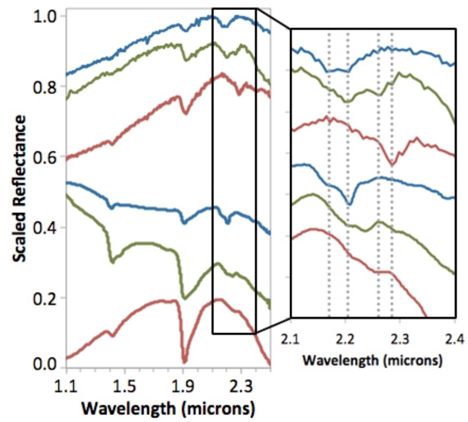

Figure 2: Representative CRISM spectra (FRT863E) from Mawrth Vallis [4] compared to lab spectra of John Day paleosols. Top three: CRISM kaolinite, Al/Si doublet, and nontronite dominated spectra. Bottom three: John Day spectra with varying contributions of kaolins/illite/smectites/silica as interepreted from both near and thermal IR spectra.

Implications: If average deposition and alteration rates were similar to those recorded in the John Day paleosols, the units at Mawrth Vallis may record many millions of years of climatic evolution and habitable environments during the Noachian. More generally, if the Mawrth Vallis layers are indeed paleosols, this has the rather dramatic implication that rain or snow fell on the region and that temperatures were at least seasonally above freezing for an extended period of time. This is consistent with studies suggesting fluvial activity at this time, both globally [*e.g.*, 18] and in the Mawrth Vallis region [1,3].

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