CLAY STRATIGRAPHIES ON ANCIENT MARS: BUILDING A GLOBAL DATABASE. A. Klidaras[1], R. Navarre[1], B. Horgan[1], W. Farrand[2], T. Goudge[3], [1]Department of Earth, Atmospheric, and Planetary Sciences, Purdue University, IN, [2]Space Science Institute, CO, [3]Department of Geological Sciences, University of Texas – Austin, TX

Introduction: The climate of early Mars remains an enigma. In particular, the timing, duration, and temperature of the humid interval(s) is a topic of contentious debate. Water is a potent agent of chemical weathering; given enough time, mafic bedrock infiltrated and leached by water may become gradually replaced by clay minerals and develop an uppermost horizon deprived of mobile elements and enriched in immobile ones. This forms a weathering profile with a distinctive mineralogical zonation, consisting of an uppermost unit with Al-clays and an underlying unit with Fe/Mg-smectite clays [1]. In terrestrial examples, this sequence is typically a few m to 10s of m thick [1,2]. Using Mars Reconnaissance Orbiter CRISM data, over 200 localities have been identified on Mars where this vertical zonation occurs, interpreted as paleo-weathering profiles [1,3]. They have been argued to support a warm and wet early Martian climate, although they are not incompatible with models of a largely cold climate punctuated by brief warm intervals [1,3,4].

So far, the properties of these clay stratigraphies have only been recorded at a handful of the >200 sites known. In this project, we are building a global database of the mineralogy and stratigraphic properties of clay stratigraphies, in order to better constrain the conditions they record, and the climate across Noachian Mars. The preliminary results of this work are presented here.

Methods: 152 sites are currently included in the global database of paleo-weathering profiles (Fig. 1). For each locality, the matching CRISM observations have been recorded, as has any paired stereo imagery (HiRISE or CTX). 18% have stereo HiRISE DEMs, and a further 26% have stereo HiRISE observations that have yet to be generated into a DEM, a process we have begun. Many of the remaining have stereo CTX observations from which a lower-resolution DEM can also be generated.

In ArcMap 10.8 the DEM, high resolution orbital imagery, and CRISM refined spectral parameter maps are georeferenced. CRISM parameter BD2165 highlights the 2.165 μm Al-OH feature characteristic of kaolinite-group clays, whereas BD2290 highlights the 2.3 μm Mg,Fe-OH feature characteristic of Fe/Mg-smectites [6]. These parameters are combined in a colour composite to reveal outcrops of clay stratigraphy in the scene (Fig. 2a). HiRISE images are then studied to identify changes in colour/albedo and texture indicative of the horizon that separates the two units (Fig. 2b). For each locality, various characteristics are recorded, such as exposure quality, bedrock properties (presence of relict bedding, a clear colour difference, jointing style), and stratigraphic measurements of the outcrop.

Stratigraphic measurements include mean elevation, weathering profile strike and dip, and the true thickness of the sequence. These measurements are made following the method of previous publications [5]. The horizon that divides the Al- and Fe/Mg- units is traced as a line feature, which is split into points that are a distance of √2*DEM spatial resolution apart. It is important to avoid tracing relict bedding or diagenetic features, as these represent layering in the local bedrock rather than the proposed weathering front. The elevation of each point is extracted, as are their coordinates (relative to a gnomonic projection centered on each outcrop). Ideally this is repeated at multiple exposures of the same clay stratigraphy, in order to reduce uncertainty. Horizon profiles are fit to a plane using least-squares multiple linear regression in order to determine the strike and dip. From the horizon, elevation profiles are then taken in a direction perpendicular to strike to the upper/lower bound of the two units, and their horizontal/vertical extents averaged. From this the true thickness of each unit can be calculated using the equation in [5].

Results: The clay stratigraphy measurement workflow is demonstrated at a site in the northern rim of Hellas (Fig. 2). Here, Hesperian-Amazonian aged Navua Valles fluvial channels incise Late Noachian highland bedrock, a mesa of which contains the proposed clay stratigraphy [1,7]. Measured thicknesses are minimums because of the gradational lower contact, and the upper contact which is truncated by a capping unit.

The elevation difference between upper and lower boundary – the vertical extent – is 37.4 m and 48.5 m for the Al-clay and Fe/Mg-clay units respectively, therefore the total vertical extent of the clay stratigraphy outcrop is 85.9 m. The horizon dividing the two units has a mean elevation of -2917.7 m, a strike of 54.4°±22.9, and a dip of 9.3°±3.6. Using elevation profiles perpendicular to strike, the minimum true thicknesses are 64.4 m and 83.0 m for the Al-clay and Fe/Mg-clay units respectively. The minimum true thickness of the total sequence is therefore 147.4 m. These findings differ from [1], which listed the kaolinite unit thickness as 10 m and the Fe/Mg-smectite unit thickness of >40 m.

Discussion: The thickness of a weathering profile depends on climate, topography, parent material, and weathering duration. Relative to terrestrial weathering profiles, our calculated thickness is unusually thick, especially that of the Al-clay unit. Our results are also significantly thicker than listed in [1], although their estimates did not take strike/dip into account.

This result may be reasonable. Paleo-weathering profiles with similarly large thicknesses have been proposed on Mars before, such as at Mawrth Valles which hosts an upper kaolinite unit 10s of m thick and a lower Fe/Mg-smectite unit >300 m thick [8]. It could be that the unit mapped as Al-clay here in fact represents a repeating sequence of several thin (<5 m) kaolinite-rich paleosol profiles that are indistinguishable due to limitations in spatial and spectral resolution. Alternatively, the locality simply may not be a weathering profile. It could instead consist of two sedimentary units of different mineralogy, in which case the horizon we traced might be an unconformity.

However, the thickness results could be an overestimation. If the horizon's dip was lower or reversed (strike is 180 degrees off), it would yield a thinner and perhaps more realistic total thickness for both units. An inaccurate dip result could be caused by the poor exposure of the outcrop; at this site CRISM only detects Al-clay in a small patch (Fig. 2a). With a more laterally extensive clay strata outcrop, one could record horizon profiles on a much greater spread of slope aspects. By better capturing the 3D geometry, this would reduce uncertainty in strike and dip. We will take this into consideration as we analyze more sites. As our work progresses, it will be interesting to see whether thicknesses of this magnitude are common or anomalous in our database.

Conclusion: We are building a global database of proposed paleo-weathering profiles, from which Martian climatic conditions can be extrapolated. Preliminary results at one site reveal a weathering profile that is unusually thick, suggesting an episode of intense chemical weathering. This unexpectedly high thickness emphasizes the need for measuring layer geometry at a variety of slope aspects to reduce strike/dip uncertainty. We plan on expanding our technique to record and measure the mineralogy and stratigraphic properties of dozens of clay stratigraphies in the near future.

References: [1] J. Carter et al. (2015) *Icarus*, *248*, 373-382. [2] A. Gaudin et al. (2011) *Icarus*, *216*, 257-268. [3] B. Ye and J. Michalski (2022) *Commun Earth Environ*, *3*, 266. [4] J. L. Bishop et al. (2018) *Nat Astron*, *2*, 206-213. [5] K. M. Stack et al. (2013) *JGR Planets*, *118*, 1323-1349. [6] C. E. Viviano et al. (2014), *JGR Planets*, *119*, 1403-1431. [7] H. Hargitai et al. (2019) *Icarus*, *330*, 91-102. [8] D. Loizeau et al. (2010) *Icarus*, *205*, 396-418.

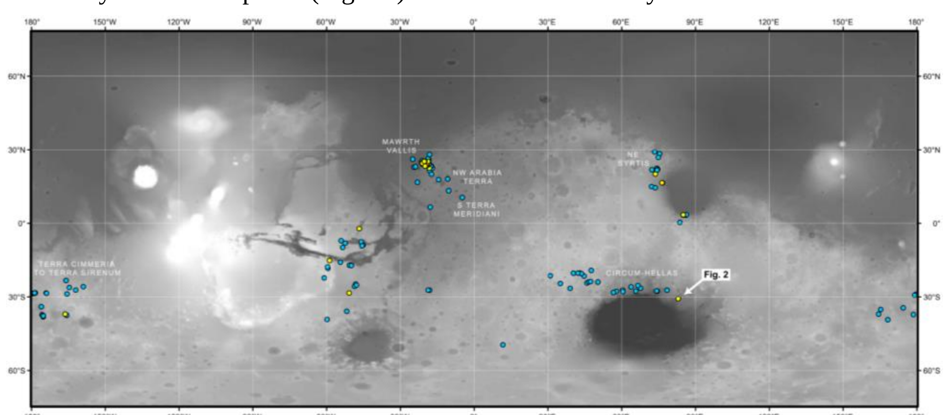

Figure 1
The locations of the 152 sites in our database, displayed over a MOLA elevation basemap. Yellow points indicate sites where a HiRISE stereo DEM is already available.

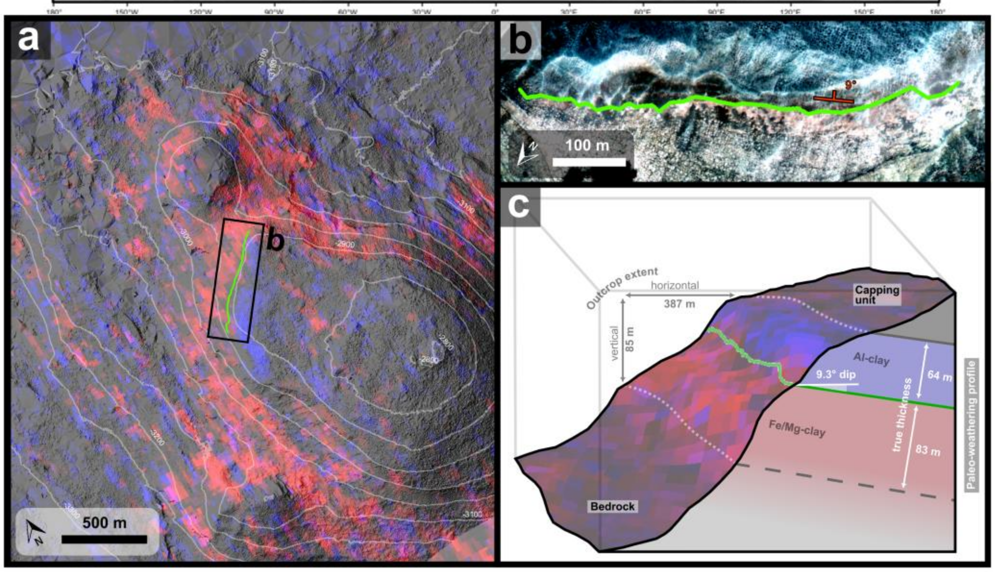

Figure 2
a) Colour composite of CRISM refined spectral summary parameter BD2290 (red) reflecting Fe/Mg-smectite, and BD2165 (blue) reflecting Al-Kaolinite. Overlaid on HiRISE stereo DEM hillshade with 50 m contours. Coordinates = -30.771°, 82.952°.
b) HiRISE colour composite basemap with traced horizon (green) and its strike and dip (red)
c) Illustrative block model (not to scale) of the geometry of this clay stratigraphy