THE ANCIENT PHYLLOSILICATES AT MAWRTH VALLIS AND WHAT THEY CAN TELL US ABOUT POSSIBLE HABITABLE ENVIRONMENTS ON EARLY MARS.
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Introduction: Characterization of the Mawrth Vallis region with OMEGA and HRSC images showed the presence of phyllosilicates on Noachian-aged, bright outcrops [1, 2]. Phyllosilicates observed in the Mawrth Vallis region of Mars by MRO/CRISM indicate a wide range of past aqueous activity [3, 4]. Here we discuss the phyllosilicate stratigraphy observed at Mawrth Vallis and possible formation scenarios. We then describe possible links to prebiotic chemistry and biosignatures.

Phyllosilicates at Mawrth Vallis: A similar phyllosilicate stratigraphy is observed throughout Mawrth Vallis (and elsewhere). Fe/Mg-smectite (nontronite) is observed in outcrops of the ancient cratered terrain. This unit is overlain by rocks rich in hydrated silica, montmorillonite, and kaolinite. A Fe^{2+} phase is present at the transition from Fe/Mg-smectite to Al/Si-rich material. The stratigraphy of Fe/Mg-smectite overlain by a ferrous phase, hydrated silica and then Al-phyllosilicates implies a complex aqueous history. This stratigraphy is shown in Fig. 1 with example spectra in Fig. 2. As the clay profiles are nearly the same across a 10^6 km wide expanse [5], orbital images probably only see small windows through cap material into one large phyllosilicate formation. Common aqueous processes likely occurred throughout the Mawrth Vallis region to produce this expansive clay profile.

Formation processes. Multiple massive aqueous events were required in order to produce such extensive and varied phyllosilicate outcrops. An initial long-term and large-scale aqueous event likely took place to form the Fe/Mg-smectite. What happened next is less certain and more interesting. The presence of hydrated silica and kaolinite suggests intense alteration and possibly acidic leaching. This is consistent with a warm and wet climate.

A diagram of a possible scenario is shown in Fig. 3. The upper unit (Fe^{2+} material, hydrated silica, montmorillonite and kaolinite) could have formed together in one complex chemical system – perhaps hydrothermal. Also possible is that these aqueous components could have formed in separate aqueous events. Nontronite is likely to have formed under reducing, low-O_2 conditions where the Fe^{2+} oxidized *in situ* to

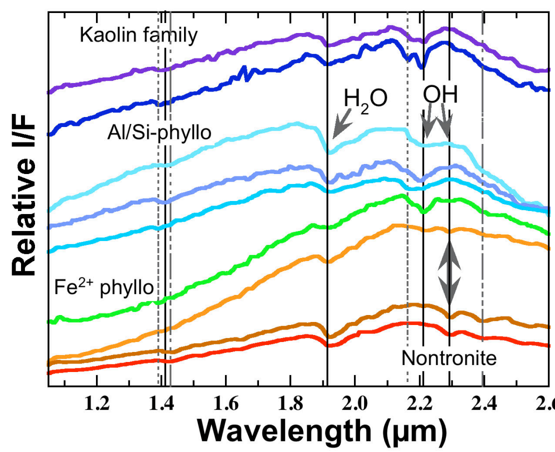

Fig. 2 CRISM ratioed I/F spectra from Mawrth Vallis including outcrops dominated by nontronite (bottom), a Fe^{2+} phase (clays?), hydrated silica, montmorillonite, and kaolinite (top) approximately color-coded to Fig. 1B.

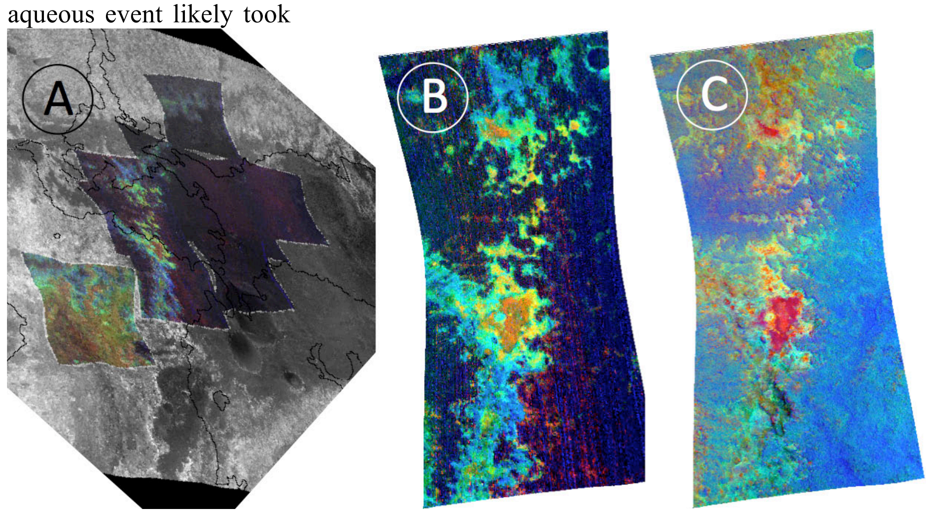

Fig. 1 CRISM image mosaic overlain on CTX (A) showing nontronite in red/orange, Al-phyllosilicate and hydrated silica in blue and a ferrous phase in green/yellow, along with a single CRISM image (FRT43EC) with the same color scheme (B) and also with R bd530 nm (Fe^{3+} minerals), G SH600 nm (coatings), and B bdi1000 nm in (C).

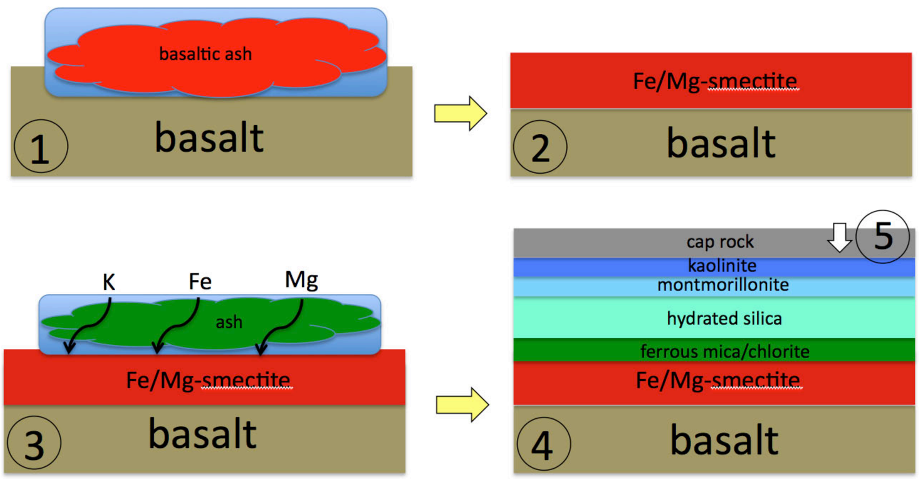

Fig. 3 Diagram of possible formation processes to form phyllosilicate outcrops at Mawrth Vallis. 1) basaltic ash is altered in an aqueous environment to form Fe/Mg- smectite (2) that is then covered by one or more subsequent aqueous events with ash (3), where elements such as Fe, Mg and K are leached out of the ash to form Al-phyllosilicates and hydrated silica on top and form Fe/Mg-bearing mica or chlorite below (4) where the leached elements are trapped at the upper boundary of the Fe/Mg-smectite unit. Finally, a cap rock is deposited on the surface (5).

Fe^{3+} in the Fe/Mg-smectite unit [6]. The presence of a ferrous phase (Fe^{2+}) on top of the nontronite (Fe^{3+}) is further evidence for anoxic conditions, active chemistry and changing redox conditions. This Fe^{2+} phase could be an Fe^{2+} clay such as mica or chlorite, or it could be another mineral such as a carbonate, sulfate or olivine. As this phase is mixed with the nontronite below and montmorillonite above, it is likely another clay mineral. On Earth microbes are nearly always responsible for Fe^{2+} phases in aqueous systems.

Fig. 4 Diagram of possible aqueous epoch on early Mars and the phyllosilicates produced then (blue layer) that were subsequently buried by other materials (from [7]). Liquid H_2O may have been stable on early Mars, but is likely present only as water ice or in mineral structures today.

Phyllosilicates and pre-biotic chemistry: Early phyllosilicate-bearing rocks may have been an ideal place on Mars for pre-biotic chemistry and possibly for the development of life. Phyllosilicates are found on Mars in the ancient Noachian rocks (Fig. 4) in a presumed warm and wet climate. Phyllosilicates can catalyze chemical reactions due to their surface acidity and by bringing together molecules on their surfaces [8]. Experiments with Fe-exchanged montmorillonites found these clays can simulate well the Viking biology experiments [9,10]. Metal ions in a clay matrix may also have played a crucial role in the origin and early evolution of life by reacting with amino acids and nucleotides [11]. Fe-bearing phyllosilicates such as nontronite, Fe-rich montmorillonite, and glauconite/illite form preferentially in anoxic waters [12] such as the conditions on early Earth and Mars.

Biosignatures: Preservation of biosignatures is favored in rapid burial conditions in fine-grained clay-rich systems and long-term preservation is most successful in phyllosilicate- and silica-bearing host rocks that are resistant to weathering and provide an impermeable barrier for the biosignatures [13]. Experiments with soil bacteria and viruses have shown that they can survive in a variety of soil and clay environments including temperature and moisture extremes replicating Martian conditions [e.g. 14]. This suggests that if microbes did once inhabit the early aqueous environment at Mawrth Vallis, they could have been sustained for some time after the water was gone and biosignatures could be retained in the phyllosilicate and hydrated silica deposits.

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