SEDIMENTARY PROCESSES AT MUARA CRATER PROVIDE EVIDENCE OF LAKES OR SEAS IN PAST AT MAWRTH VALLIS, MARS. D. R. Lowe¹, J. L. Bishop²³, D. Loizeau⁴, J. J. Wray⁵, R. A. Beyer²³, ¹Department of Geological Sciences, Stanford University (Stanford, CA, drlowe@stanford.edu), ²SETI Institute (Mountain View, CA), ³NASA-Ames Research Center, (Moffett Field, CA), ⁴Institut d’Astrophysique Spatiale (CNRS/Univ. Paris-Sud, France), and ⁵School of Earth and Atmospheric Sciences, Georgia Institute of Technology (Atlanta, GA).

Summary: This study investigates the character of clay-rich strata exposed in the rim of Muara crater (Fig. 1) in the Mawrth Vallis region of Mars. These layered materials provide evidence for the presence of large, persistent standing bodies of water on early Mars as well as a complex association of flanking shoreline, alluvial, and aeolian systems [1]. Some of the clays, especially the Fe/Mg smectites appear to have formed through subaerial weathering whereas the montmorillonite, kaolinite, hydrated silica, and poorly crystalline aluminosilicates formed mainly through alteration of fine sediment in subaqueous environments.

Introduction: The presence of abundant phyllosilicate minerals in Noachian (>3.7 Ga) rocks on Mars has been taken as evidence that liquid water was stable at or near the surface early in martian history [e.g. 2-3]. Studies of OMEGA and CRISM imagery have shown that phyllosilicate-bearing rocks include two contrasting assemblages of phyllosilicate minerals: a basal sequence over 100 m thick of Fe/Mg smectite-bearing rocks and an overlying unit variously estimated at 50 to over 100 meters thick containing Al-bearing phyllosilicates and hydrated silica [e.g. 4-6]. We extended this work to evaluate the nature of sedimentary features at Mawrth Vallis [1]. We focused on exposures in the walls of Muara crater (Figs 1-3) due to their clarity, although they are similar to outcrops elsewhere in Mawrth Vallis.

Fig. 1. Muara crater featuring bedrock outcrops around the crater walls and a field of windblown dunes covering the crater floor (from HiRISE image PSP_004052_2045).

Fig. 2. Northwest wall of Muara crater enlarged from Fig. 1 highlighting layered outcrops in the bedrock.

Fig. 3. Closer view of northwest wall of Muara crater showing main subdivisions of the Mawrth Vallis Group.

Fig. 4. Stratigraphy of the Mawrth Vallis Group, NW wall of Muara crater. (A) Stratigraphic divisions of (A) Loizeau et al. (2010) and (B) Bishop et al. (2013). (C) Stratigraphic subdivisions recognized in the present study. Correlations between the spectral divisions of (A) and (B) and the lithologic divisions of the present study are approximate.
Fig. 5. Unit 1 on the north wall of Muara crater. (A) Middle to upper part of Unit 1 showing thicker, crude layering that includes large cross sets (a) and undulating layering (b). This sequence may consist largely of windblown sand. (B) Massive fractured rock at the top of Unit 1 (a). Some areas of well-defined layering are laterally equivalent to fractured rock (b) and some layering can be seen through fractures (c).

Fig. 6. Views of the upper part of Unit 2 and most of Unit 3 in the northern wall of Muara crater. Unit 2 illustrates the interlayering of dark- and light-toned units, often with swaly undulations. Above the zones of dunes and lenticular dark layers, Unit 3 consists of tabular light-toned layers separated by very thin, continuous layers of dark material (b), many of which appear thicker than they actually are because of younger, dark, windblown sand accumulating on small benches marking bedding surfaces. A set of closely-spaced joints produces saw-tooth like fractures of the light-toned layers that are filled by dark windblown(? ) sediment.

Fig. 7. View of a joint set (a) in the upper wall of Muara crater immediately above the crater slope view in Fig. 6. This region includes Units 4 (light toned) and overlying Unit 5, which is largely covered by dark debris. The joints extend down into Unit 3, where they form saw-tooth fractures and displaced blocks (b). Lower on the crater wall, it is difficult to distinguish these joints and inclined stratification in most areas.

**Stratigraphy:** The over 200-m thick, clay-rich Mawrth Vallis Group strata were subdivided into 5 informal units numbered 1 (base) to 5 (top) and are illustrated in Figs. 4-7 [1]. Unit 1 consists of interbedded sedimentary and volcanic or volcanioclastic units showing weak Fe/Mg-smectite alteration deposited in a range of subaerial depositional settings. Above this, Unit 2 and lower Unit 3 consist of dark-toned sediment inferred to represent debris deposited mainly as aeolian sand dunes draped by thin layers of light-toned material representing fine suspended aeolian silt and clay. These lower sediments show extensive alteration to Fe/Mg-smectite, probably reflecting subaerial weathering. This is consistent with liquid water and rain in a warm (Earth-like) environment for tens of thousands to hundreds of thousands of years [7]. Upper Unit 3 and Units 4 and 5 are composed of well-layered, fine-grained sediment dominated by Al-phyllosilicates, kaolinite, and hydrated silica. Deposition occurred in a large lake or arm of a martian sea.


**Acknowledgments:** We are grateful for support from NASA’s MDAP program, the NASA Astrobiology Institute, Stanford University, and the European Research Council.