

A FLUVIAL SANDBODY ON MARS: RECONSTRUCTION OF THE SHALER OUTCROP, GALE CRATER, MARS. L.A. Edgar¹, S. Gupta², D. M. Rubin³, K.W. Lewis⁴, G.A. Kocurek⁵, R.B. Anderson⁶, J.F. Bell III¹, G. Dromart⁷, K.S. Edgett⁸, J.P. Grotzinger⁹, C. Hardgrove¹, L.C. Kah¹⁰, R. Leveille¹¹, M.C. Malin⁸, N. Mangold¹², R.E. Milliken¹³, M. Minitti¹, M. Palucis¹⁴, M. Rice⁹, S.K. Rowland¹⁵, J. Schieber¹⁶, K.M. Stack⁹, D.Y. Sumner¹⁷, A.J. Williams¹⁷, J. Williams¹⁸, R.M.E. Williams¹⁹. ¹Arizona State University, Tempe, AZ, 85287, ledgar1@asu.edu, ²Imperial College London, London, UK, ³UC, Santa Cruz, CA, ⁴Princeton University, Princeton, NJ, ⁵University of Texas at Austin, Austin, TX, ⁶USGS, Flagstaff, AZ, ⁷Universite de Lyon, France, ⁸Malin Space Science Systems, San Diego, CA, ⁹California Institute of Technology, Pasadena, CA, ¹⁰University of Tennessee, Knoxville, TN, ¹¹Canadian Space Agency, Montreal, Canada, ¹²Laboratoire de Planétologie et Géodynamique de Nantes, France, ¹³Brown University, Providence, RI, ¹⁴UC, Berkeley, CA, ¹⁵University of Hawaii at Manoa, Honolulu, HI, ¹⁶Indiana University, Bloomington, IN, ¹⁷UC Davis, Davis, CA, ¹⁸University of New Mexico, Albuquerque, NM, ¹⁹Planetary Science Institute, Tucson, AZ.

Introduction: Despite numerous orbital observations of large-scale sedimentary bodies on Mars inferred to be of fluvial origin, no detailed in-situ observations of facies variations and sedimentary structures have been possible until the discovery of fluvial sedimentary rocks at Gale Crater by the Curiosity rover. During sols 120-121 and 309-324, Curiosity investigated a well-exposed sandstone body (~0.7 m thick, extending for more than 20 m) informally known as the Shaler outcrop. Data from the Mast Cameras (Mastcam), the Mars Hand Lens Imager (MAHLI) and the ChemCam Remote Micro-Imager (RMI) provide insight into the depositional processes and paleoenvironmental setting of the Shaler lithofacies. The objectives of this work are to 1) document the sedimentary facies at the Shaler outcrop, 2) describe the spatial variation in facies and sedimentary architecture 3) reconstruct bedform morphology and motion from stratification, 4) describe paleoflow patterns determined from sedimentary structures, 5) reconstruct the paleoenvironment, and 6) discuss implications for martian climate and habitability.

Large-Scale Stratigraphic Relations and Sedimentary Architecture: The Shaler outcrop is part of the Glenelg member of the Yellowknife Bay formation. Collectively, this package of sediment is interpreted to represent a habitable fluvial-lacustrine environment [1]. The Shaler outcrop is defined by interstratified pebbly sandstones and recessive, likely finer-grained intervals (Figure 1). It is distinguished from the underlying Gillespie sandstone by the presence of well-developed, large-scale trough cross-stratification.

Shaler strata infills three shallow paleo-depressions on the Gillespie sandstone surface. The depressions are ~5-10 m wide and each is infilled by a distinct assemblage of sedimentary facies. Above the infilled paleo-topographic depressions, sedimentary beds can be traced continuously for more than 20 m. We observed several outcrop-length surfaces overlain by cm-thick gravel-rich beds. These surfaces enable correlation of distinct sediment packages across the outcrop.

In general, sedimentary bedsets in Shaler show an upward fining. Coarser-grained cross-stratified beds define the base of fining-up sequences. Grain size and stratification also vary laterally across the outcrop. The northeastern end of the outcrop is characterized by thin resistant beds separated by recessive intervals. The southwestern end of the outcrop is characterized by stacked sets of trough cross-bedding, and a greater abundance of coarser grains.

The top of the Shaler outcrop is defined by a resistant cross-stratified unit with a distinct geochemical signature [2]. This resistant cap, informally known as “Upper Shaler” may be equivalent to a laterally extensive erosionally resistant bed that preserves on its upper surface a higher density of craters. This surface may equate to the Cratered Surface (CS) defined by orbital mapping [1, 3].

Sedimentary Facies: On the basis of grain size, erosional resistance, color, and sedimentary structures, seven distinct facies were identified (Figure 2).

Facies 1: Fine-grained convoluted facies. This facies is found at the contact between Gillespie and Shaler at the northeastern end of the outcrop, and is defined by convoluted bedding and grain sizes finer than Mastcam can resolve. It is interpreted to represent soft sediment deformation.

Facies 2: Fine-grained evenly laminated sandstone facies. This facies is found intermittently through the outcrop and is interpreted to represent aeolian wind-ripple stratification, suggesting aeolian reworking of fluvial sands.

Facies 3: Light toned cross-stratified sandstones. This facies is found within a paleo-depression at the southwestern end of the outcrop, and consists of well sorted, medium and coarse-grained sandstone [4]. It is interpreted to represent straight and sinuous crested bedforms.

Facies 4: Recessive weathering, laminated sandstone facies with vertical fractures. This facies occurs at the top of fining upward sequences at the northeastern end of the outcrop, and is interpreted to represent

desiccation cracks, indicative of intermittent wetting and drying.

Facies 5: Single set, cross-stratified pebbly sandstones. This facies forms the majority of the outcrop and is interpreted to represent the migration of straight and sinuous crested bedforms.

Facies 6: Stacked planar and trough cross-stratified pebbly sandstones. This facies is found at the southwestern end of the outcrop and is interpreted to represent superimposed straight and sinuous crested bedforms.

Facies 7: Smooth cross-stratified facies. Facies 7, informally called “Upper Shaler” is composed of two subfacies: 1) coarse-grained cross-stratified facies and 2) fine-grained well-laminated facies, with occasional nodules. This facies is interpreted to represent a new sediment dispersal system and different sediment provenance. The coarse-grained cross-stratified subfacies represents channel deposits, while the fine-grained well-laminated subfacies may represent a distal fan lobe.

Cross-bedding and Paleocurrents: The majority of the outcrop is composed of decimeter-scale trough cross-stratification, indicating that sediment was transported by the migration of sinuous crested dunes. Small superimposed bedforms and ripples are also present. Bedding geometries indicate sub-critical angles of climb, resulting in preservation of only the lee slope deposits.

Bedding dips suggest that bedforms mostly migrated to the northeast, based on the long-axes of troughs. However, the larger-scale surfaces defined by gravel-rich deposits dip $\sim 10\text{-}15^\circ$ to the southeast [5]. These surfaces define a larger-scale landform such as a bar that was accreting to the southeast.

Paleoenvironmental Interpretation: The Shaler outcrop is interpreted to represent a fluvial environment, with minor aeolian reworking.

We consider four possible geomorphic settings to account for the larger-scale architectural elements (the outcrop-length surfaces that fine upwards and dip to the southeast), 1) a fluvial fan, 2) a point bar, 3) a mid-channel bar, and 4) a southeast-facing scour or concavity within a channel. Each of these geomorphic settings could result in large-scale surfaces prograding or accreting to the southeast, with superimposed bedforms

migrating to the northeast. In the case of a fluvial fan, sediment would have been primarily transported from west-northwest to east-southeast, resulting in the overall fining to the east. In the case of fluvial bars or a scour within a channel, the flow was likely moving approximately from west to east, with possible bar accretion to the southeast. Coarser-grained sediment could have accumulated on the upstream end of the bar, which could explain the abundance of coarse grains at the southwestern end of the outcrop.

Summary: The Shaler outcrop provides a unique opportunity to examine the facies and sedimentary architecture of a fluvial sandbody on Mars. Insight gained from this study will improve our understanding and guide our approach to similar fluvial and lacustrine deposits encountered by Curiosity along the traverse to Mount Sharp.

References: [1] Grotzinger J. P. et al. (2013) *Science*, 10.1126/science.1242777. [2] Anderson R. B. et al. (2013) *AGU Abstract #P21D-06*. [3] Calef F. et al. (2013) *LPS XLIV Abstract #2511*. [4] Williams, A. J., (2014), *LPS XLV* (this meeting). [5] Lewis, K. W., (2013), *AGU Abstract #P14B-01*.

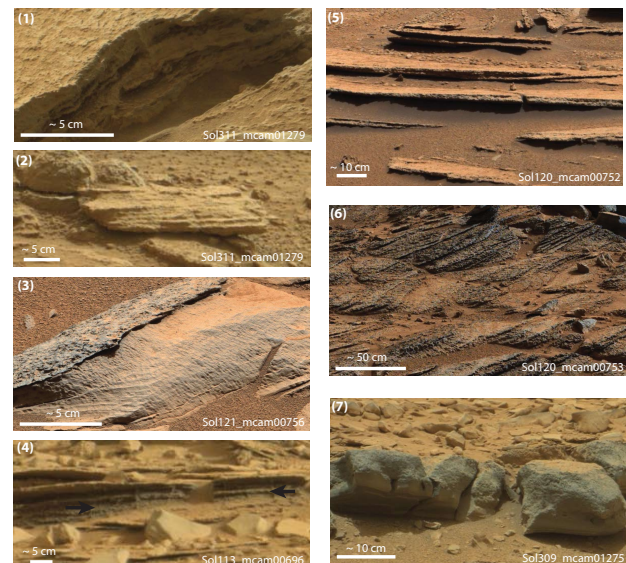


Figure 2: Mastcam images of facies 1-7.

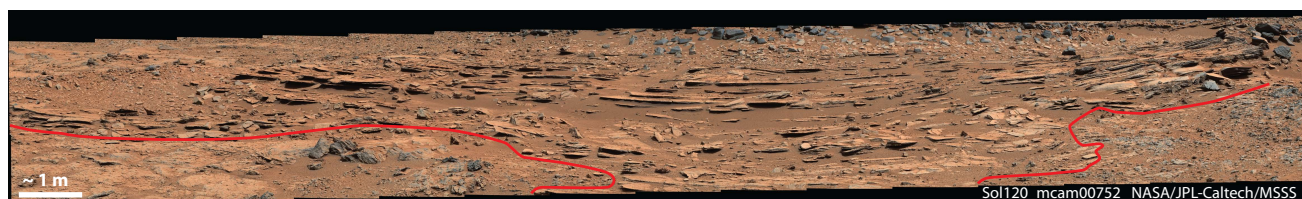


Figure 1: The Shaler outcrop. Red lines mark the contact between Shaler and the underlying Gillespie sandstone. There are several outcrop-length surfaces which represent gravel-rich deposits that fine upwards. These surfaces enable correlation of distinct sediment packages across the outcrop.