Ancient environmental forcings recorded in aeolian stratigraphy: an Earth analog to aeolian strata on Mars.

B. T. Cardenas[1], G. Kocurek[1], D. Mohrig[1], T. Swanson[2], C. M. Hughes[1], S. C. Brothers[1*], and T. A. Goudge[1], [1]Jackson School of Geosciences, UT Austin, [2]Department of Earth Science, Rice University, [*]now at National Academies Space Studies Board. *Contact: benjamin.cardenas@utexas.edu*

Introduction: The size, size variability, wavelength, shape, and climb angles of aeolian dunes are influenced by autogenic processes such as dune interactions [1] and allogenic forcings including sediment supply, source-area geometry, water table, and wind regime [2]. Resultant sedimentary deposits record information about all of these variables, which are of interest to paleoenvironmental interpretations of early Mars, making aeolian strata an important source of information about the ancient martian surface [3,4]. The Jurassic Page Sandstone [5], near Page, AZ, USA, is dominated by meter-scale aeolian cross-strata (Figs. 1&2), and is used here to explore methods of interpreting paleoenvironmental signals from aeolian cross-strata that are possible at both rover and remote sensing scales.

Methods: Primary data collection included field mapping of bounding surfaces at well-exposed 3-D outcrops and assembly of 2-meter spatial resolution DEMs via Total Station surveying. Measurements of set thicknesses and stratal geometry were made from these 3-D data. To test how spatial resolution may modify the measured population of set thicknesses we sequentially removed set measurements from the Page dataset using threshold thicknesses in the range of HiRISE resolution. Outcrop surface slope is also considered, as a shallower slope cutting obliquely through a thinner set will expose it over a longer distance, making it more likely to be above resolution limits (Fig. 3). Simplifying assumptions include the accurate interpolation of HiRISE stereo DEMs, such that set detection in visible data is the primary bottleneck of these measurements, and that look angles are nadir.

Results: Two facies are dominant. 1) Thick cross-sets, mean thickness of 2.34 meters and standard deviation of 2.10 meters, that feature thick grainflow/wind-ripple packages without grainfall strata. Sets truncate each other laterally and do not show climbing architecture (Fig. 1). 2) Thin cross-sets, mean thickness of 0.11 meters, feature individual grainflows separated by grainfall strata, a climbing architecture, and are only preserved at the base of the Page along a major regional unconformity that had local relief much greater than the average set thickness [6] (Fig. 2). Eight intra-Page erosional surfaces are associated with deflation down to the water table following successive episodes of dune-field accumulation [5]. These erosional surfaces define the basal surfaces of distinct dune fields that are preserved as thick sets, stacked from 1 to 5 sets high.

Discussion: Grainfall deposits rarely reach the bottoms of large dunes where they might become preserved in strata. The presence of grainfall strata in the thin cross-sets, and lack thereof in the thick cross-sets, indicates an associated change in dune size [7]. Autogenic dune interactions merge smaller dunes into fewer larger dunes over time and migration distance, leading to the interpretation that thin sets represent early-phase dune-field accumulations. The large-scale relief preserved on the base-Page regional unconformity relative to the size of the thin sets suggests that this relief is antecedent to dune-field activity, rather than the product of dune scouring. The lack of early-phase strata in the remainder of the Page suggests cannibalization of these strata by later-phase, larger dunes, an autogenic process observed at other outcrops [8] and in numerical models [9]. Cannibalization is the product of low-to-no dune climb due to a lack of environmentally-forced aggradation. At low-to-no climb angles, set thicknesses dominantly represent the fills of only the deepest dune scours, such that thin truncated sets and thick scour-fill sets are common and their standard deviation approaches the mean [10]. The ratio of standard deviation to mean set thickness measured in the thick-set facies of the Page is consistent with the no-to-low climb scenario (Fig. 1,3). At high climb angles this ratio has been shown to approach a value of 0.45 [10]. The aeolian Entrada Sandstone [8], the archetype of wet, climbing dune-field deposits, is presented as an opposite end-member to the Page and demonstrates the significant range in values found for the standard deviation to mean set thickness ratio (Fig. 3).

The Page strata are a valuable record of the Jurassic environment, and demonstrate the effectiveness of simple measurements in aiding interpretations of any aeolian sandstone. The methods used here can be directly applied to Mars strata using high-resolution rover data [4,11], but the effect of remote sensing resolution on the measurements is worth considering.

The relationship between set thickness distribution and climb angle is extremely informative for interpretations of allogenic forcings, as drivers of climb are likely to be important aspects of paleoenvironment and depositional setting such as antecedent topography, decrease in transport capability of winds, or a near surface rising water table [2,8,10]. By removing Page set thicknesses below plausible HiRISE observation limits, we again calculate the ratio of standard deviation to mean set thickness and observe how the loss of resolution modifies the results (Fig. 3). The slope of the outcrop surface is a significant control. Slopes in excess of 35° would significantly alter interpretations of Page set thicknesses at HiRISE detection limits. At lower slopes, a representative collection of Page set thicknesses could be collected from HiRISE.

Conclusion: The paleo-environmental forcings interpreted from Page strata and its distribution of set thicknesses are significant for reconstructing the ancient setting. HiRISE observations taken from gently sloping outcrops can re-create the set thickness measurements presented here without significant modification. This important result supports the use of set-thickness statistics in the interpretation of paleo-climate signals preserved by aeolian strata exposed on the surface of Mars using remote sensing data [e.g., 3,4].

References: [1] Ewing R.C. and Kocurek G. (2010a) *Sedimentology, 57,* 1199-1219. [2] Ewing R.C. and Kocurek G. (2010b) *Geomorphology, 113,* 175-187. [3] Milliken R.E. et al. (2014) *GRL, 41,* 1149-1154. [4] Banham S.G. et al. (2016) *LPS XLVII, abstract #2346.* [5] Havholm et al. (1993) *Spec. Publs Int. Ass. Sediment., 16,* 87-107. [6] Pipiringos G.N. and O'Sullivan R.B. (1978) *USGS 1035-A,* 35 p. [7] Kocurek G. and Dott Jr. R.H. (1981) *JSR, 51,* 579-595. [8] Kocurek G. and Day M. (2017) *Sedimentology* [9] Swanson T., pers. comm. [10] Jerolmack D.J. and Mohrig D. (2005) *Geology, 33,* 57-60. [11] Grotzinger et al. (2005) *EPSL, 240,* 11-72.

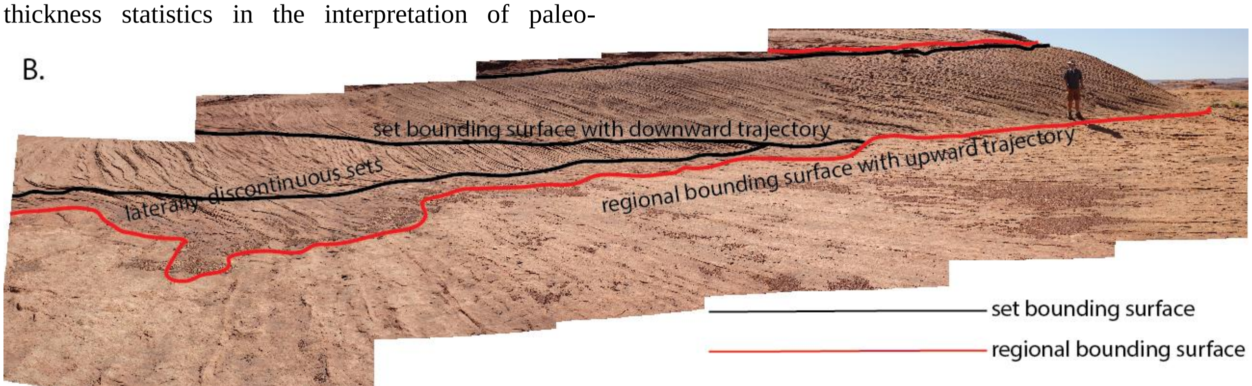

Figure 1 (above) – Example of thick sets showing the variable truncation of prior accumulations associated with the scour-fill aeolian architecture common of the Page.

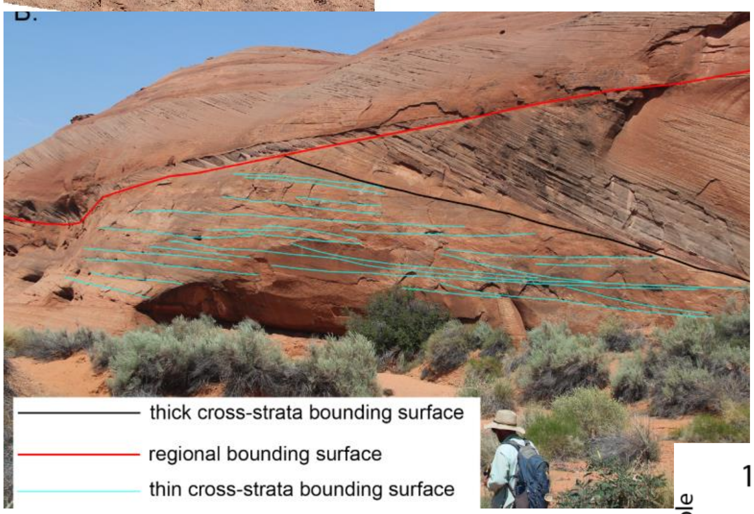

Figure 2 (left) – Example of thin climbing sets filling antecedent topography. Laterally, this accumulation is partially scoured by a thick set.

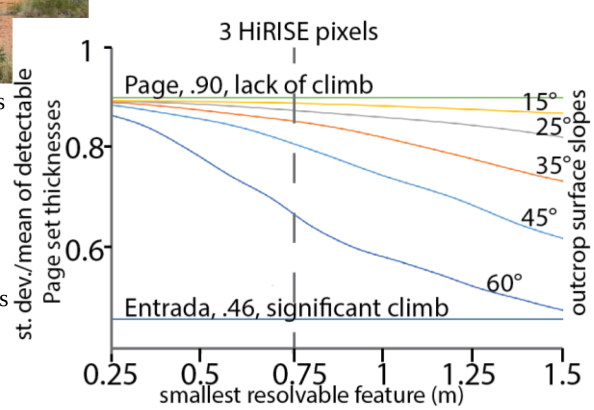

Figure 3 (right)– Smallest resolvable feature on the x-axis represents the detectable limit below which Page sets are filtered out, which will modify the st.dev/mean of remaining set thicknesses (y-axis). A significant range of values is represented by the Page and Entrada [8] Sandstones. Whether or not a set is resolvable is based on its thickness and the slope of the outcrop surface, represented by colored lines. Shallow slopes expose thin sets over longer distances, making them more detectable, meaning a resolution limit creates less error in st. dev/mean than it would for steeper outcrop slopes. The size of three HiRISE pixels, a general detection limit, is marked.