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

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1. Introduction

-Aeolian stratigraphic architecture records signals from dune autogenics[1-2] and allogenic boundary conditions under which the dune field develops[3-5].

-Boundary conditions and autogenics represent paleo-environmental conditions at the time of accumulation, including water table position, wind regime, and antecedent topography, making aeolian stratigraphy an important record of a planetary surface.

-The Page Sandstone represents a relatively minor Jurassic coastal sand sea in present day Arizona and Utah[6-7] (Fig. 1). It is dominated by sets of aeolian cross-strata (Figs. 2-4), and is nowhere thicker than 100 m (Fig. 1).
-The major J-2 unconformity bounds it at the base from the aeolian Navajo Ss.
-Interfingering and capping the Page is the coastal Carmel Fm.

- By quantifying Page architecture, we interpret paleo-environmental conditions using methods repeatable for other aeolian sandstones, including those exposed at the surface of Mars. Effects of observation resolution are tested.

2. Methods

Several datasets were gathered during a field campaign to 3 Page outcrops exposed in three dimensions near Page, AZ, USA, representing over a kilometer of exposure ~60 m thick.
(1) Total Station surveys used to create .6-2m resolution elevation models of each outcrop.
(2) Field maps showing all cross-strata bounding surfaces, facies changes, and other prominent surfaces in 3-D.
(3) Measurements of grainflow thicknesses, as a proxy for dune size.
(4) Measurements of cross-strata dip directions, a proxy for paleotransport direction
Following field work, 3-D field data was digitized into more easily interpreted 2-D cross-sections.

3. Results

Facies: Thick cross-stratified sets (Fig. 2), Thin cross-stratified sets (Fig. 3 & 4), Wavy-laminated sandstones and sandstone wedges at regional bounding surfaces (Fig. 5)

Prominent Surfaces: Cross-strata bounding surfaces (Fig. 2-4), Regional bounding surfaces (Fig. 1 & 5), J-2 unconformity (Fig. 1)

Architecture Quantification

-Dominant set geometry is scour-fill, lack of climb (Figs. 6)
-Plots suggest scour-fill dominated system with reworked regional bounding surfaces, little to no dune climb (Fig. 7)
-Where present, thin cross-stratified sets show a climbing, very aggradational architecture, in contrast with thick sets. Such accumulations are laterally truncated by thick sets and only occur directly above antecedent J-2 surface (Fig. 4).

4. Discussion

-Regional packages represent individual Page dune fields separated by extended hiatal regional bounding surfaces associated with water table high stands and sabkha development forced by relative high stands in the adjacent Carmel Sea[6-7] (Fig. 1).
-Over time and distance, dunes in a field mature from small and closely spaced to larger and farther spaced[3-4].
-Thin cross-stratified sets represent early phases of aeolian sedimentation in the Page dune field. They are only preserved in J-2 depressions where protected from later scour from above, but preservation is laterally incomplete (Fig. 4).
-Thick cross-stratified sets represent later phases of aeolian sedimentation. During mature phases, dune scour cannibalized: young phase accumulations not protected by antecedent J-2 topography (Fig. 4), prior mature phase accumulations (Fig. 6), and basal regional bounding surfaces, creating co-eval erosional topography (Fig. 5) lacking the preservation potential of antecedent J-2 topography.
-Without water table high stands driving preservation (but not accumulation), the Page would be represented by amalgamated erosional surfaces.
-Modeling supports the cannibalization/local preservation of early phase strata, formation of regional bounding surface topography by variable dune scour overpowering climb angle associated with a more mature dune field [8-10].
(*Aeolian stratigraphy model animation! Is the tablet charged?*)

5. Analog considerations

-Measurements can be recreated at rover scale.
-Measurements of set thickness are modified by remote sensing resolution and outcrop slope (Fig. 8). The population of set thickness measurements is used to interpret Page dynamics, and its modification from resolution and outcrop slope is explored.

6. Conclusions

-Autogenic dune scour, climb angle, antecedent topography, and a deep water table affected the accumulation of the Page Sandstone. Episodes of water table high stand drove the preservation of the Page. These signals are important for paleoenvironmental interpretations because they describe dune field interactions with water and wind, substrate erodibility, and the timing of topography generation.
-The metrics used here to quantify Page stratigraphy should be useful in describing and interpreting any aeolian sandstone. Geometric experiment can help guide outcrop interpretation using remote sensing data.

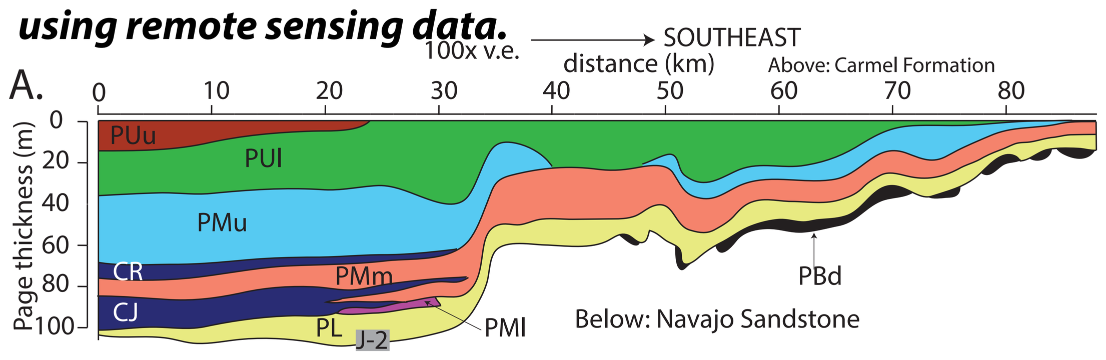


Fig. 1 - Cross-section of the Page Sandstone [6] showing informal units, intertonguing Carmel deposits, the J-2 erosional surface, and the bounding geologic units. Erosional surfaces dividing units tied to Carmel tongues and represent episodes of deflation down to high stand water table forced by Carmel Sea high stand.

6. References
[1] Brothers et al., 2017, Sedimentology. [2] Day and Kocurek, 2017, Sedimentary Geology. [3] Ewing and Kocurek, 2010, Sedimentology. [4] Ewing and Kocurek, 2012, Geomorphology. [5] Swanson et al., 2016, Sedimentology. [6] Havholm et al., 1993, Aeolian Sediments: Ancient and Modern [7] Blakey et al., 1996, JSR. [8] Swanson et al., Numerical modeling manuscript in prep. [9] Paola and Borgman, 1991, Sedimentology. [10] Bridge and Best, 1997, Sedimentology. [11] Jerolmack and Mohrig, 2005, Geology. [12] Kocurek and Day, 2017, Sedimentology.

Figure 2 (above) - A: The thick cross-stratified sets facies dominant at the Page Sandstone. Mean thickness: 2.34 m, locally exceeds 10 m. B-C: Associated grainflows are organized into packages several tens of cm thick, suggesting larger dunes than represented by the thin cross-strata facies (Fig. 3).

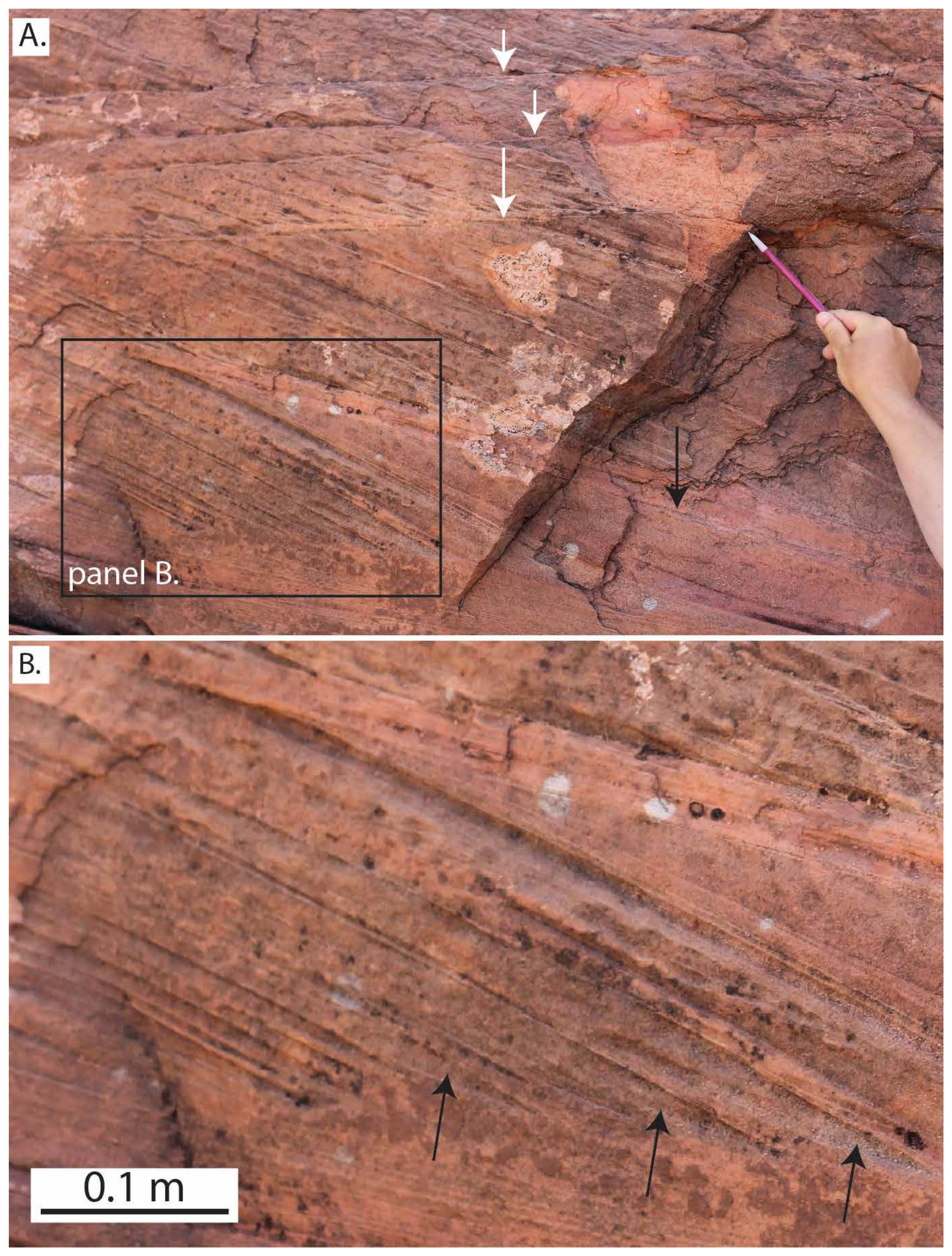


Figure 3 - A: Thin cross-stratified set facies. Minor component of overall Page Sandstone. White arrows point to set bounding surfaces. Black arrow points to reactivation surface. Mean set thickness of .11 meters. B: Zoom in on box in A. Black arrows point to individual grainflow deposits bound by grainfall strata.

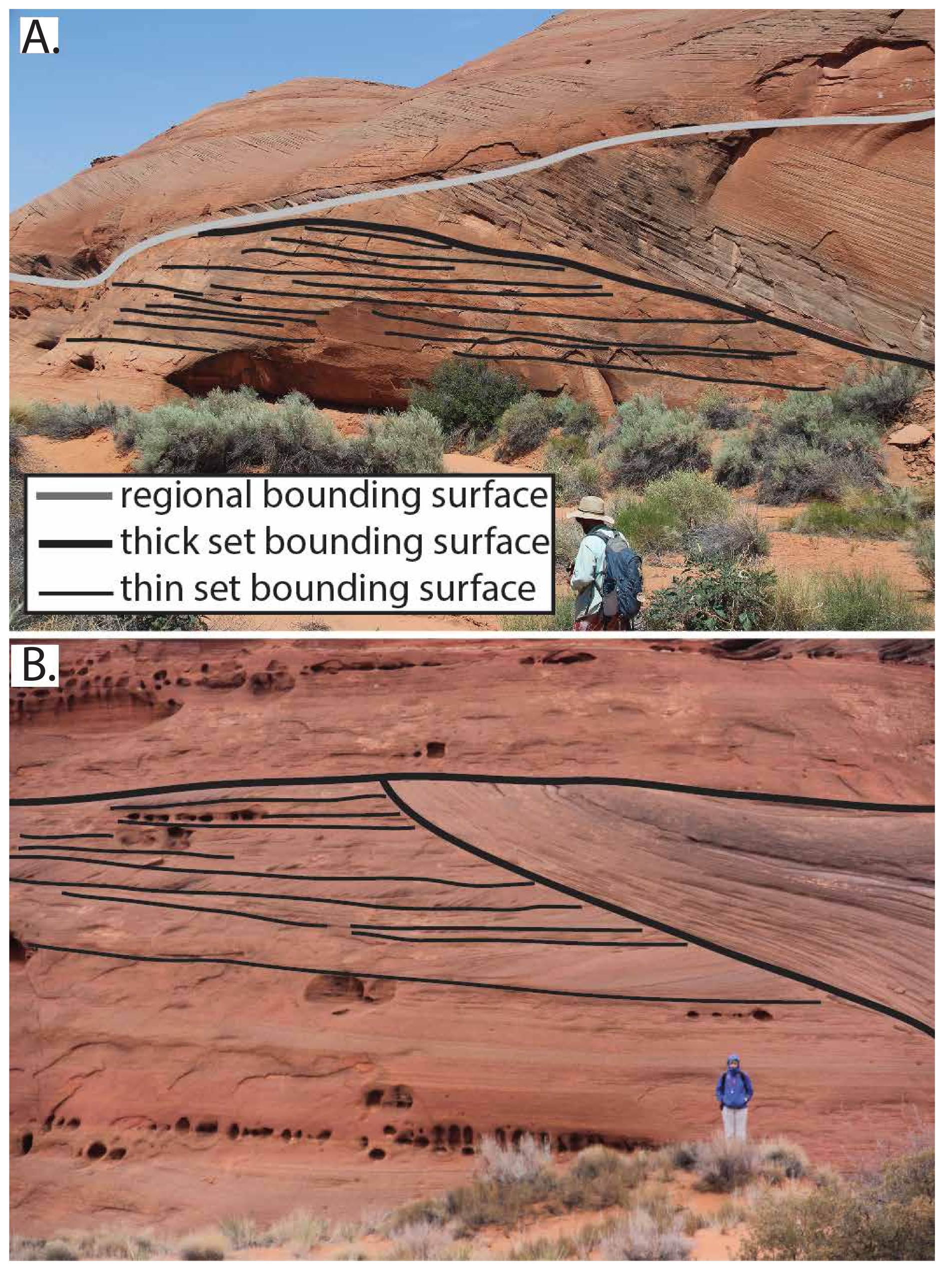
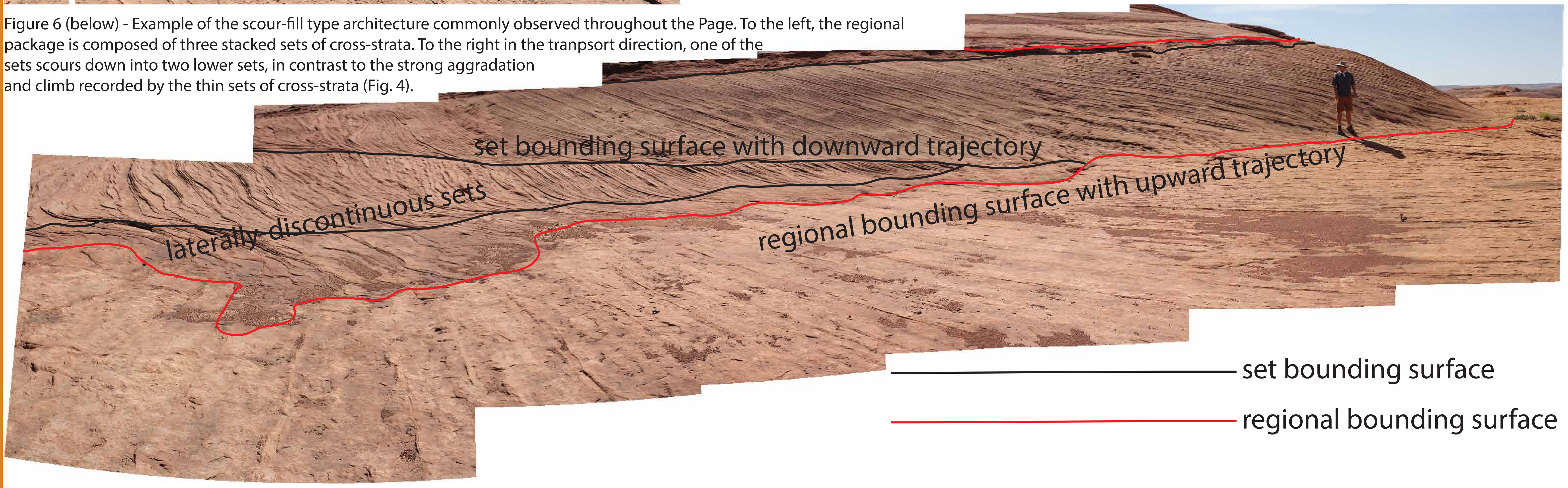


Figure 4 - Two locations preserving thick accumulations of thin cross-stratified sets laterally truncated by thick sets. Mean thickness of .11 m. Accumulation in panel B is within a protective J-2 depression of ~10 meters. Panel A is at a different location also above the J-2, but J-2 relief is not directly measurable at that location.

Figure 5 (below) - Variably thick sabkha deposits (white arrows) and sandstone wedges (black arrows) truncated from above define a reworked regional bounding surface associated with a water table highstand.

Figure 6 (below) - Example of the scour-fill type architecture commonly observed throughout the Page. To the left, the regional package is composed of three stacked sets of cross-strata. To the right in the tranpsort direction, one of the sets scours down into two lower sets, in contrast to the strong aggradation and climb recorded by the thin sets of cross-strata (Fig. 4).



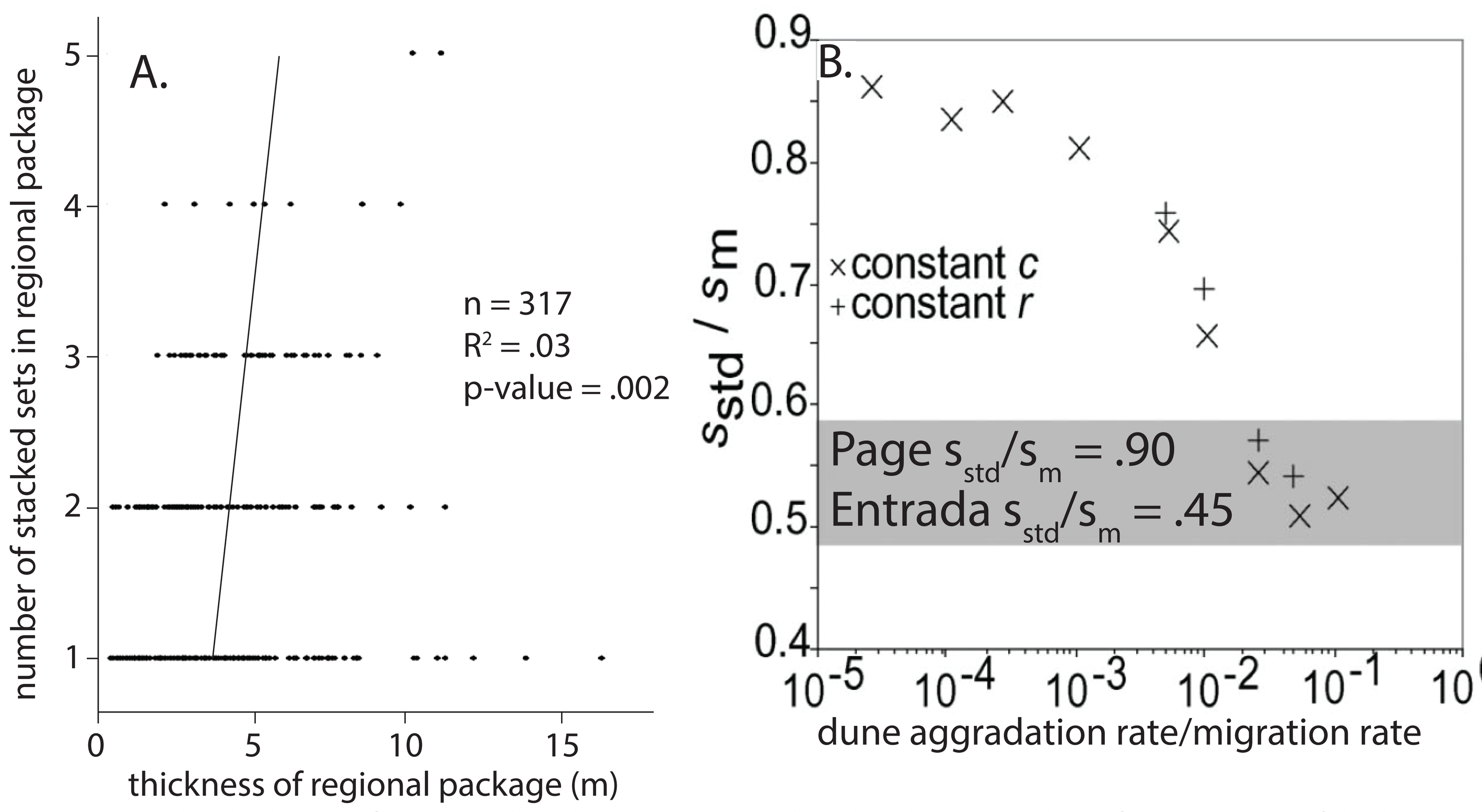


Figure 7 - A: The thickness of a regional package is not correlated with the number of stacked sets of thick cross-beds within the package, inconsistent with a climbing architecture. B: The ratio of standard dev. to mean set thickness of thick cross-beds at the Page are consistent with no dune climb. Plot from [11], Entrada from [12].

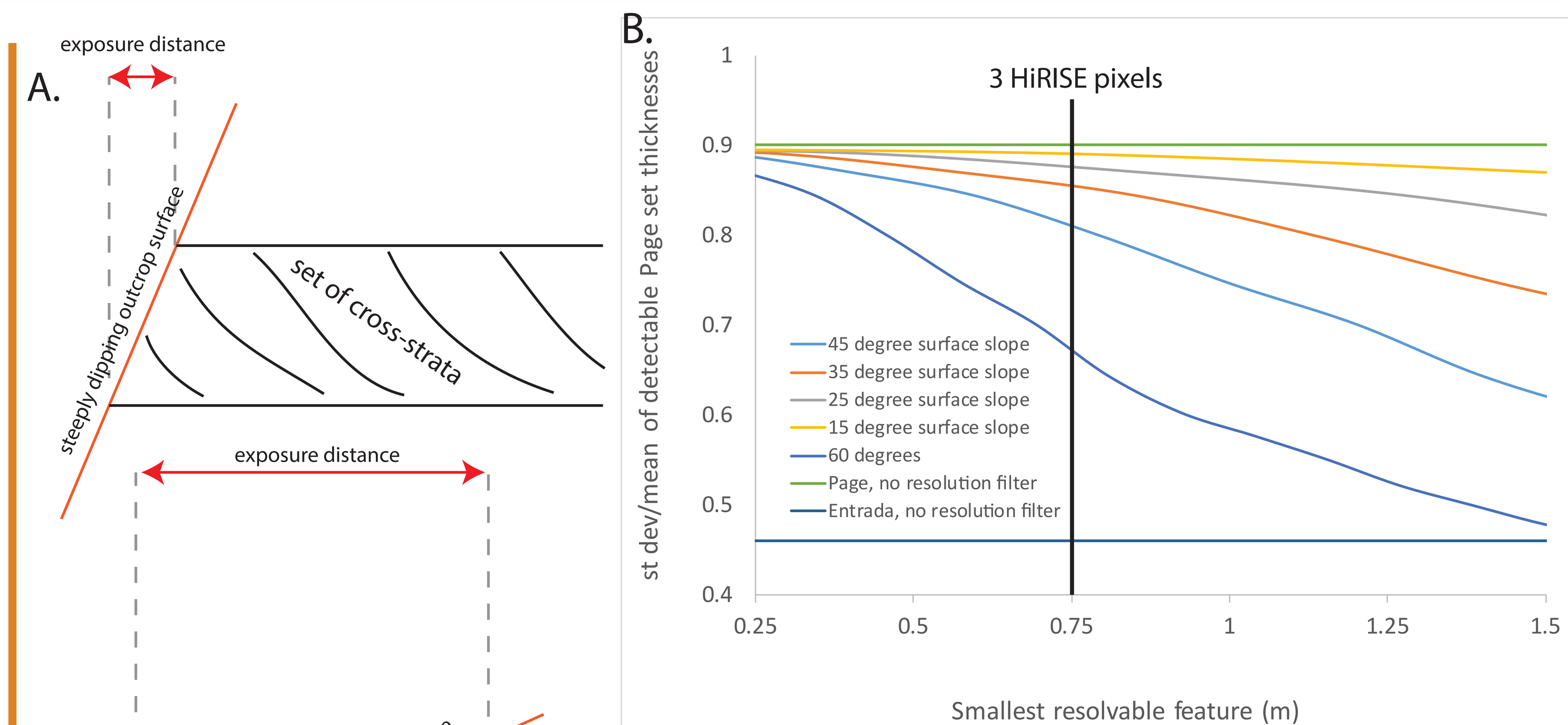


Figure 8 - A: The exposure distance and detectability of a set of cross-strata depends on surface slope and set thickness.
B: St. dev/mean set thickness of Page measurements (Fig. 6A) but modified by resolution and surface slope and assuming nadir viewing angle. Interpretations greatly modified by steep slopes.