Stratigraphic Evolution of the Jurassic Navajo Sandstone Erg, San Rafael Swell, Central Utah

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Abstract

The Jurassic Navajo Sandstone of central Utah records an intermediate region of eolian deposition between an erg margin to the east and the erg center towards the southwest. Stratigraphic analyses of the total Navajo formational thickness reveal that there are several vertical trends in grain size, bed set thickness, soft sediment deformation intervals, and facies that vary spatially across the San Rafael Swell, indicating a dynamic history of evolving depositional conditions across the erg system.

Lithofacies are broadly categorized into three facies groups based on interpretations of the depositional environment. 1) Dune deposits are characterized by different styles and thicknesses of crossbed sets and geometries of set bounding surfaces. 2) Interdune deposits (ID) contain interbedded mudstones and sandstones, with common cm-scale crossbed sets, ripple laminations, vuggy and crinkle laminations, massive sandstones, and mudstone conglomerate lags with autochthonous rip-up clasts. 3) Synsedimentary, soft-sediment deformation structures include contorted and massive beds. Local, large-scale (3-10 m) contorted beds are commonly with associated breccias, and microfaults.

The eolian Navajo Sandstone represents the largest erg recorded in geologic history. Despite the record of a vast dry desert, interdune deposits and synsedimentary structures indicate periods of high-water table conditions present as far as 130 km from the erg margin. Across the San Rafael Swell, Navajo thickness averages about 130 m on the east, to roughly 140 m in the west. Three stratigraphic "zones" show vertical changes in Navajo deposition. 1) The lowest 10 m consist of cm- to dm-scale trough crossbedded sandstones. 2) The middle 70 m interval consists of planar crossbedded eolian sandstones and lenticular interdune beds that correlate to first order bounding surfaces. 3) The upper 60 m is dominated by large scale (3-20 m) trough-cross beds. Stratigraphic data indicates that early Navajo depositional history was typified by small dune forms interspersed with interdune oases and later abruptly transitioned to a drier environment with large draas that lacked interdune oases and were subject to either periodic draas slope failures or seismicity.

Conclusions

- The Navajo evolved from an erg with oasis interdunes, which supported fauna and microbial mats, into a drier sand-sea with massive draas and no interdunes.
  - The upper Navajo's larger grain size, large trough crossbeds, and larger foreset thicknesses indicate formation in a very dry eolian system.
- Fluid alteration and some deformation features are lithologically bounded by 1st or 2nd order surfaces and occasionally by 3rd order.

Hierarchy of Eolian Bounding Surfaces

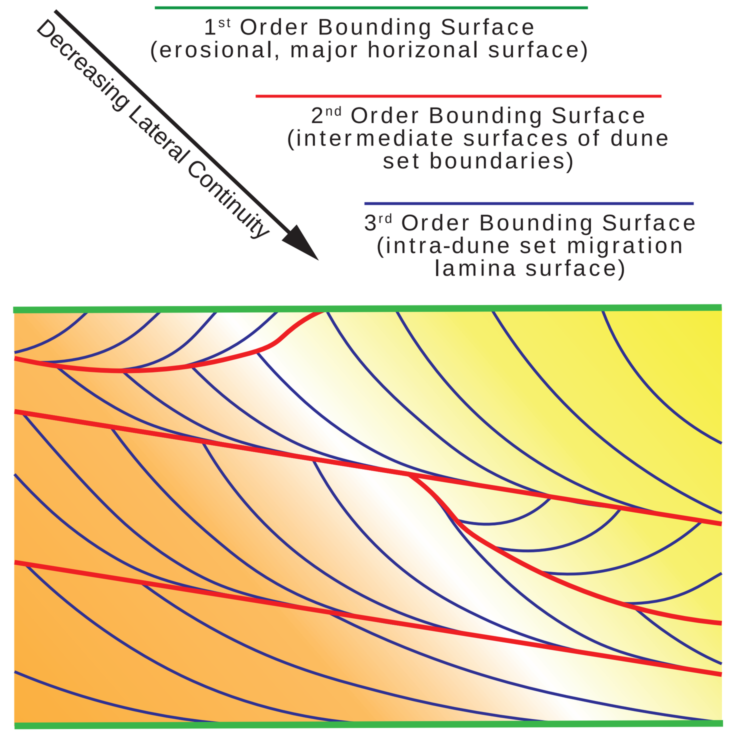


Figure 1. Cross cutting relationships and lateral extent of bounding surfaces (Brookfield, 1977).

Evidence of Water

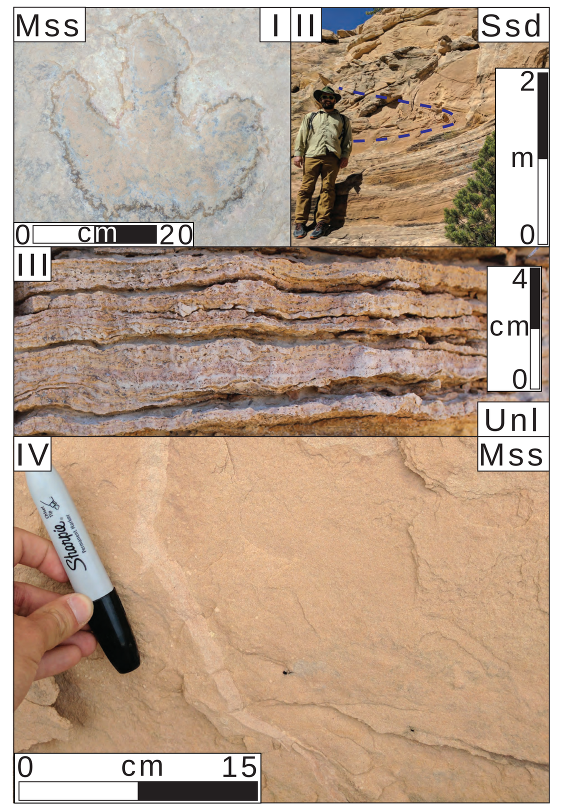


Figure 2. (left) *Evidence of near-surface water:* (I) theropod footprint on paleo-moist interdune 1st order surface; wet interdune oases even supported large fauna in the Navajo erg. (II) microbial-mat carbonate developed in interdune pond, (IV) tap-root growing beneath interdune. *Deeper subsurface water:* soft-sediment deformation of dune strata from subsurface fluidization (III). I, III, IV from Figure 5 section B; IV from D.

Study Area

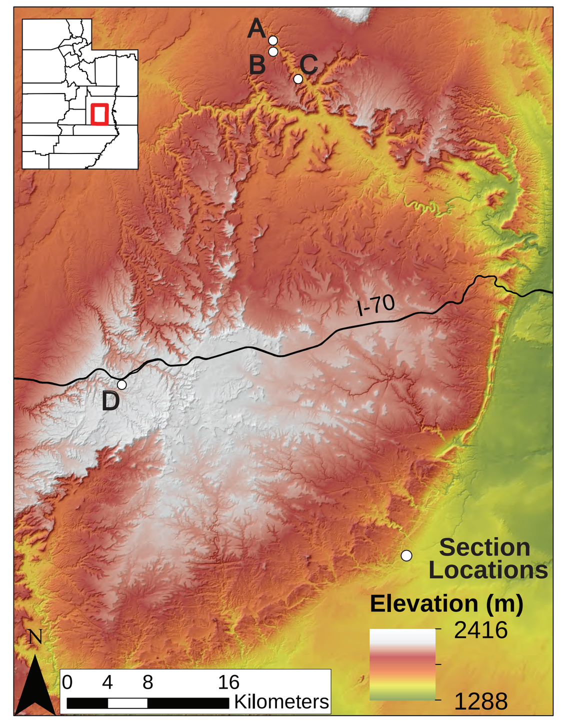


Figure 3. Elevation map of San Rafael Swell with lettered locactions corresponding to sections in Figure 5.

General Navajo Trends

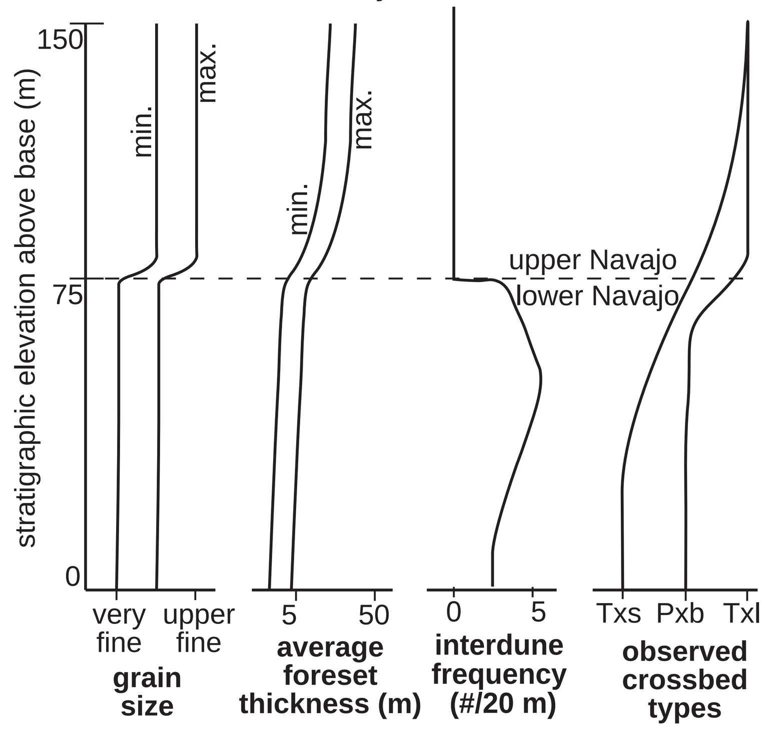


Figure 4. General vertical trends observed in measured Navajo stratigraphic sections, see Figure 5. Crossbed types: small trough (Txs), planar (Pxb), and large trough (Txl).

Lithofacies Legend

- planar cross-bedded sandstone
- small trough crossbedded sandstone
- large trough cross-bedded sandstone
- soft-sediment deformed sandstone
- brecciated sandstone
- sheet sandstone
- ripple-laminated sandstone
- undulose laminated sandstone
- massive sandstone
- interbedded sheet sandstone and conglomerate
- intraformational conglomerate
- sheet mudstone
- cross-bedded to cross-laminated sandstone
- pseudo-bedded sandstone

Stratigraphic Zones

- Upper Navajo (75-100 m thick)
- Lower Navajo (60-80 m thick)
- Navajo Zone Boundary
- Distinct Stratigraphic Horizon Boundaries

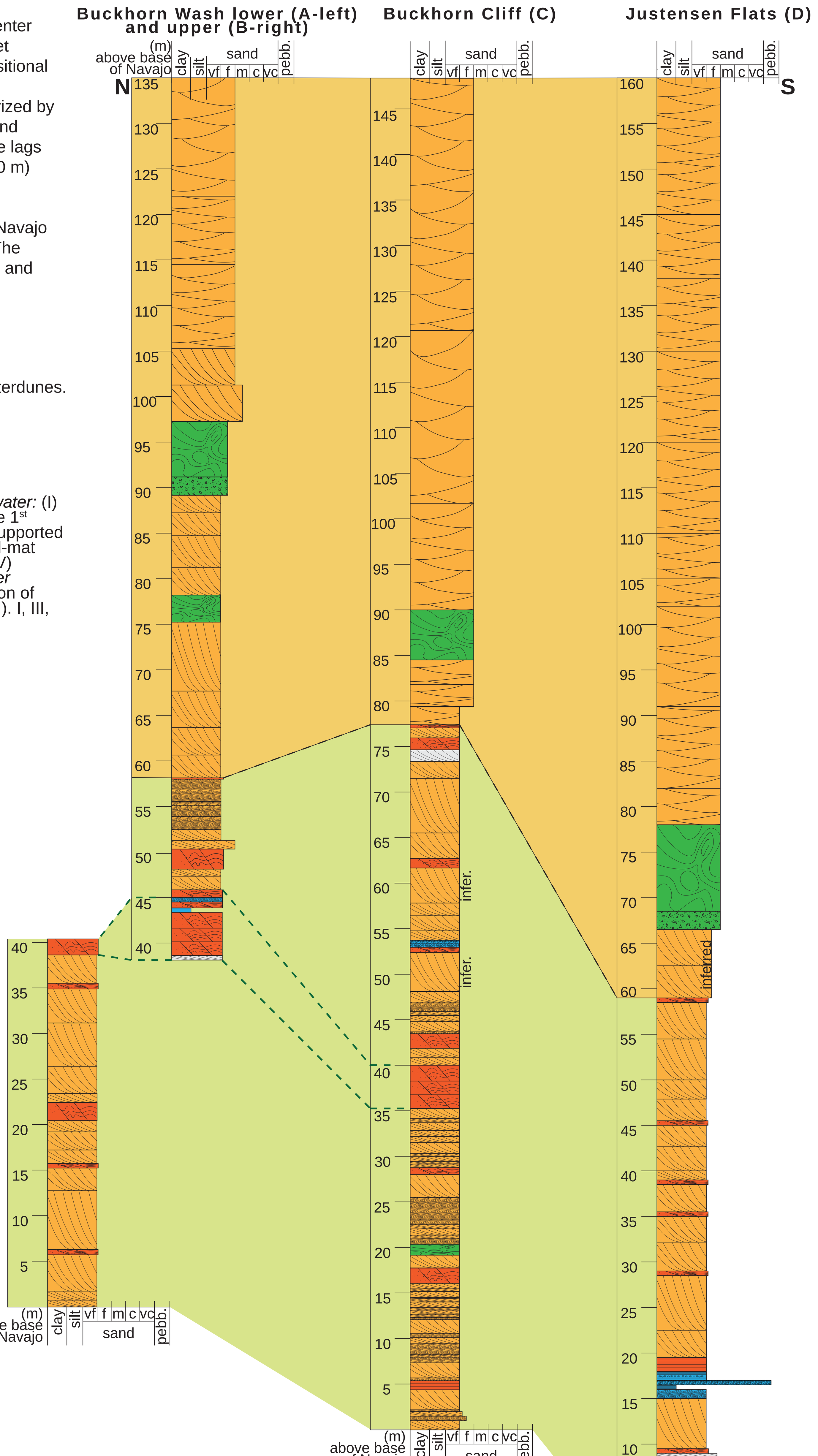
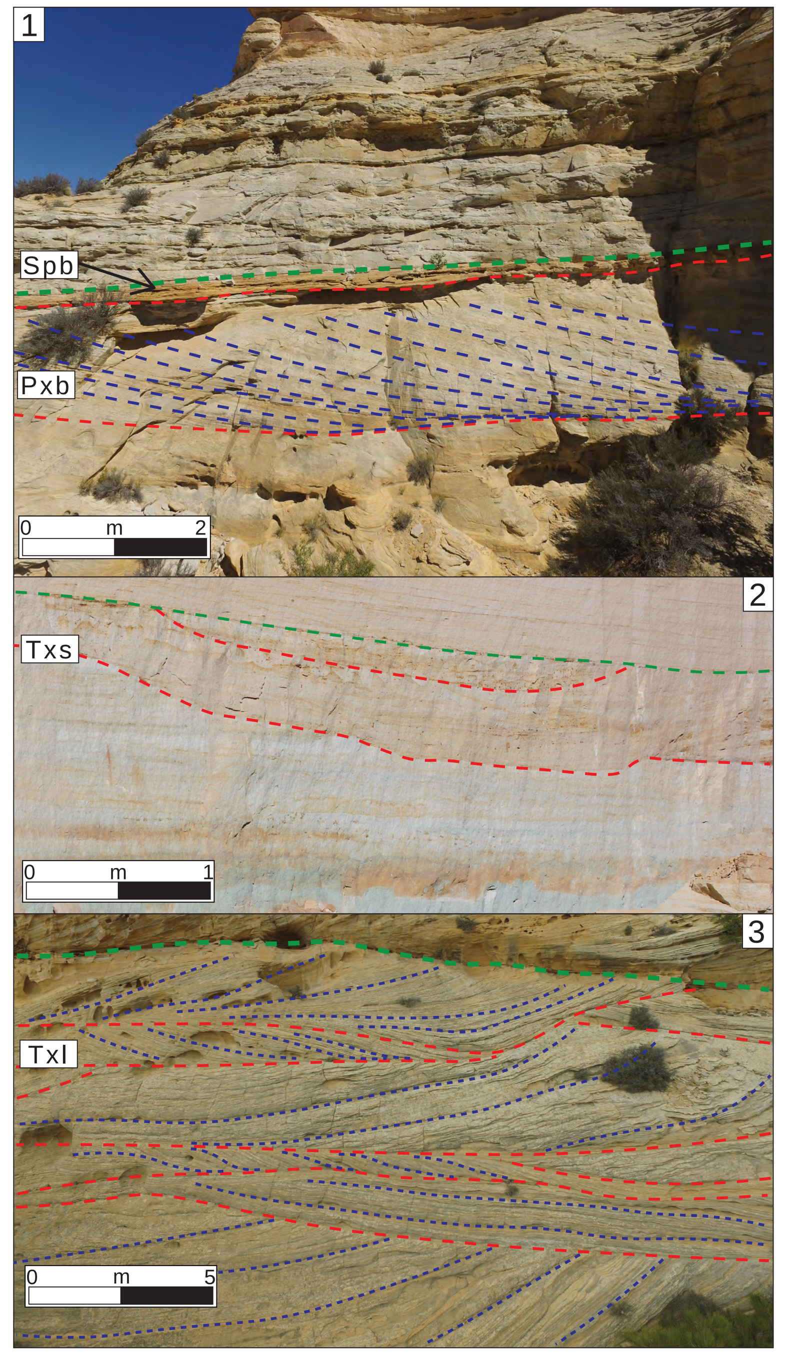


Figure 5. Measured stratigraphic sections with lithofacies described in Table 1. Sections have been broken into upper and lower zones based on the last measured occurrence of interdune facies. Note that sections A, B, and C are located within ~5 km of each other while section D is located ~50 km to the southwest, towards the erg-center.

Dune Associations



Navajo Sandstone Facies of the San Rafael Swell

Association	Lithofacies Name	Code	Grain Size	Sedimentary Structures	Thickness (m)	Lateral Extent (m)	Depositional Environment	Diagenetic Color
Dune	planar crossbedded sandstone	Pxb	vf-f	planar to wedge cross-stratification	1–5	10–100	straight-crested dunes	tan - unaltered; white to grey altered (reduced); red - altered (oxidized)
Dune	large trough crossbedded sandstone	Txl	f	large-scale trough cross-strat.	5–30	10–100	large barchanoid, sinuous to linguoid-crested dunes	tan - unaltered; white to grey altered (reduced); red - altered (oxidized)
Dune	small trough crossbedded sandstone	Txs	vf-f	small-scale trough cross-strat.	0.1–1	1–10	small barchanoid, sinuous to linguoid-crested dunes	tan - unaltered
Interdune	sheet plane-bedded sandstone	Spb	vf-f	planar laminae	<0.1	10–100	dry interdune flats	tan - unaltered
Interdune	ripple laminated sandstone	Rip	vf-f	ripple laminations	0.1–0.5	10–50	ripples in shallow interdune pond	pink to red - altered (oxidized)
Interdune	undulose laminated sandstone	Unl	vf-f	undulose laminations	<0.1	10–50	crinkly texture from microbial mat in shallow interdune pond	pink to red - altered (oxidized)
Interdune	massive sandstone	Mss	vf-f	structureless	0.1–1	10–100	saturated sediments beneath interdune pond	tan - unaltered; white to grey altered (reduced); red - altered (oxidized)
Deformed	soft-sediment deformed sandstone	Ssd	vf-f	ductiley deformed crossbeds	1–10	10–100	weakly-cemeted strata ductilely deformed via liquefaction and fluidization	white - altered (reduced); red - altered (oxidized); diagenesis pre-deformation
Deformed	brittley deformed sandstone	Bss	vf-f	breccias, fluid escapes, microfaulting	1–5	10–100	partially-lithified strata brittely deformed via liquefaction and fluidization	grey - altered (reduced)
Eolian-Fluvial	interbedded sheet sandstone and conglom.	Isc	vf-peb.	planar pebble and sandstone beds	0.5–5	10–100	channel-proximal floodplain	tan - unaltered, green clasts - ripup
Eolian-Fluvial	intraformational conglomerate	Itc	clay-peb.	load struct., & inv. to norm. grading	0.1–1	1–100	confined debris flow and unconfined sheet flow in erg interdunes	unaltered: brown - mud, tan - sand; green/other colors - ripup
Eolian-Fluvial	sheet mudstone	Smd	clay- f	sheet planar muds with sharp base	0.1–1	10–100	channel-distal floodplain	green mud and vf white sand
Eolian-Fluvial	crossbedded to crosslaminated sandstone	Xxs	f-m	cross-lam., norm. grad., sharp base	1–5	10–100	interdune river channel	tan - unaltered; grey - altered (reduced)
Fluid altered	pseudo-bedded sandstone	Psb	vf-f	structureless w/ some primary bed.	2–30	10–100 (to 500)	modified dune crossbed foresets	grey or white - altered (reduced)

Table 1. Classification scheme based on outcrop-derived measured sections within the San Rafael Swell, Emery County, Utah. 5 major asssociations are distinguised by groups of related lithofacies. Range in thickness and lateral extent of each lithofacies was based on Table 1 from Dalrymple and Morris (2007).

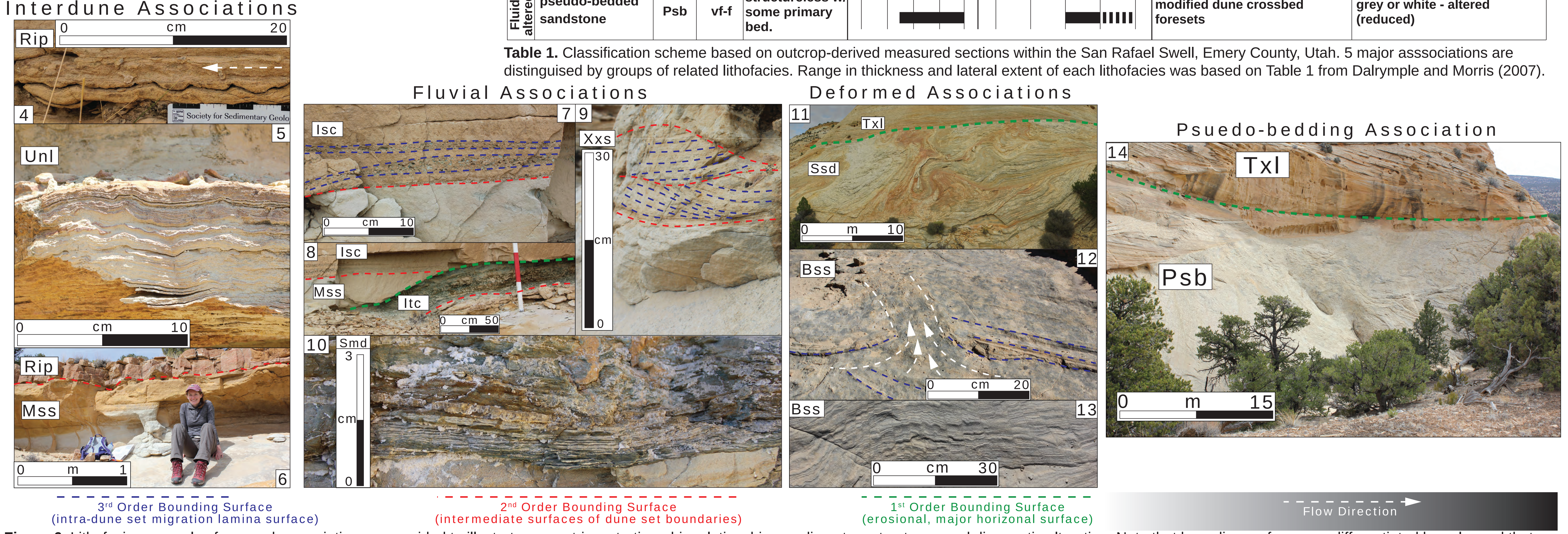


Figure 6. Lithofacies examples from each association are provided to illustrate geometries, stratigraphic relationships, sedimentary structures, and diagenetic alteration. Note that bounding surfaces are differentiated by color and that fluid flow directions are provided where applicable (4, 12). Bounding surfaces correspond to Figure 1. Pictures were taken around Justensen Flats and adjacent Devil's Canyon both in Emery County, Utah.

References:

Dalrymple, A., and Morris, T., 2007, Facies analysis and reservoir characterization of outcrop analogs to the Navajo Sandstone in the central Utah thrust belt exploration play: Utah Geological Association Publication 36, p. 311–322.

Brookfield, M.E., 1977, The origin of bounding surfaces in ancient aeolian sandstones: Sedimentology, v. 24, p. 303–332, doi: 10.1111/j.1365-3091.1977.tb00126.x.

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