PS Interpreting Backwater Effects on Fluvial Style and Architecture in a High-Gradient Compound Incised-Valley Deposits: Example from Cretaceous Ferron Notom Delta, Southeastern Utah*

Mohammad S. Ullah[1] and Janok P. Bhattacharya[2]

Search and Discovery Article #51161 (2015)**
Posted October 13, 2015

*Adapted from poster presentation given at AAPG 2015 Annual Convention and Exhibition, Denver, Colorado, May 31 – June 3, 2015

[1]Earth and Atmospheric Science, University of Houston, Houston, Texas, USA (msullah@uh.edu)
[2]School of Geography and Earth Sciences, McMaster University, Hamilton, Ontario, Canada

Abstract

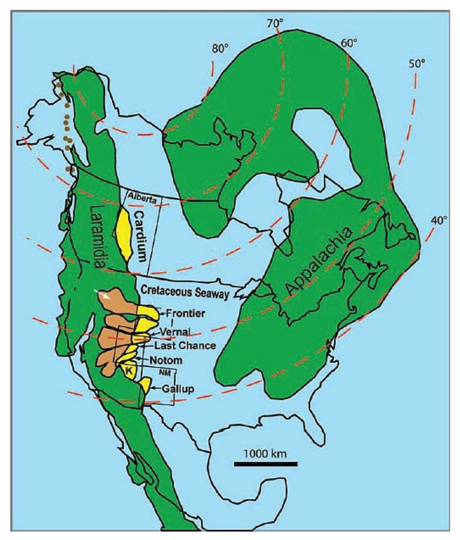
Non-marine sequence stratigraphic models for incised valleys predict systematic changes in fluvial style from lowstand through transgressive to highstand system tracts, assuming a constant rate of marine transgression. Downstream base-level influence on fluvial style however, can be highly variable, and may produce less predictable pattern. The main purpose of this paper is to evaluate the change in plan-view style of rivers from their upstream to downstream versus extent of the effects of backwater length recorded within a Cretaceous compound incised-valley fill in the Ferron Notom Delta, Henry Mountain region, southeast Utah. It was hypothesized that the backwater length, which is proportional to river flow depth and inversely correlated to river slope theoretically controls the effects of base-level change to propagate upstream. Previous studies on modern Mississippi river valley demonstrated that channel, channel-belts in a coastal-plain valley experience predictable morphological and sedimentological changes as they enter their backwater length, and characterized by rivers that are aggradational, avulsive and distributive in nature. This paper, for the first time, attempts to test these hypotheses in an ancient compound valley fill by detailed facies architectural analysis of channel and bar deposits from vertical measured sections and estimation of backwater limits from paleo-flow depth measurements in combination with measured changes in base level, tidal range and fluvial slope along an extensively exposed fluvial long profile. Three major erosional surfaces partitioned the compound valley fill into three sequences that have noticeable morphological and sedimentological differences from the upstream to downstream area. All three incised-valley fills in the downstream area shows a vertical translation from fluvial to tidal facies at the top of the valley. This suggests the rivers entered into their backwater length at the later phase of valley filling causing a systematic vertical decrease in overall grain size as well as an upward increase in preserved dune height and bar thickness. The valley fill deposits at the upstream area, which is roughly 15 km southwest, however, lie beyond the reach of the backwater effect and hence do not show any tidal influence, but consist of much coarser facies within channel bodies of relatively low width-thickness ratio.

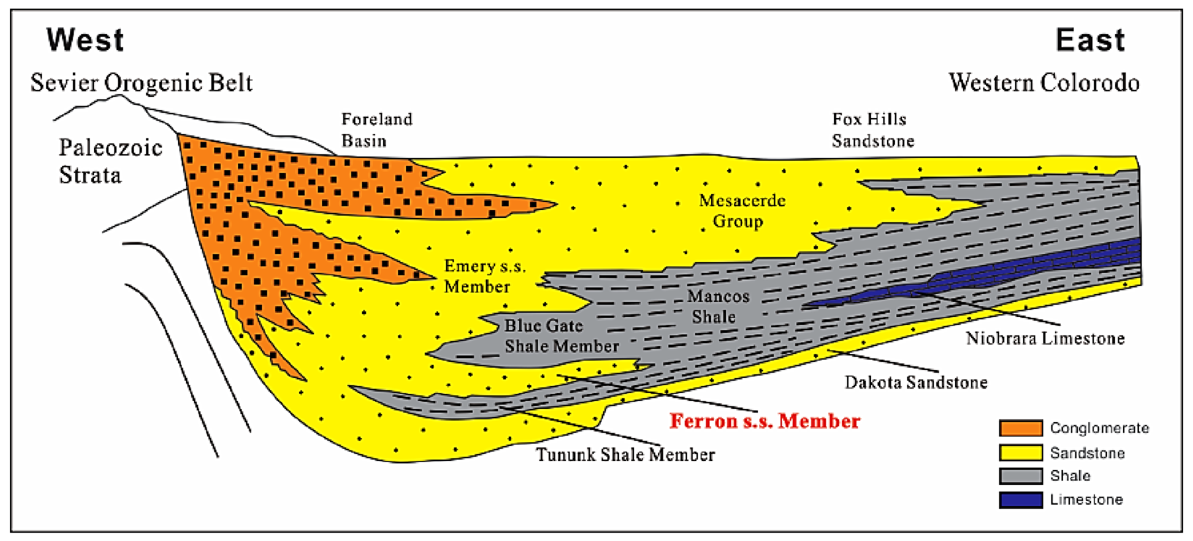
ABSTRACT

Incised valleys formed by fluvial incision during the periods of falling sea level, and are intrinsic components of non-marine sequence stratigraphic models, as they mark the regional sequence boundary. Non-marine sequence stratigraphic models for incised valleys predict systematic changes in fluvial style from lowstand through transgressive to highstand system tracts, assuming a constant rate of marine transgression. Downstream base-level influence on fluvial style however, can be highly variable, and may produce less predictable pattern. The main purpose of this paper is to evaluate the change in plan-view style of rivers from their upstream to downstream versus extent of the effects of backwater length recorded within a Cretaceous compound incised-valley fill in the Ferron Notom Delta, Henry Mountain region, southeast Utah. It was hypothesized that the backwater length, which is proportional to river flow depth and inversely correlated to river slope theoretically controls the effects of base-level change to propagate upstream. Previous studies on modern Mississippi river valley demonstrated that channel, channel-belts in a coastal-plain valley experience predictable morphological and sedimentological changes as they enter their backwater length, and characterized by rivers that are aggradational, avulsive and distributive in nature.

This paper, for the first time, attempts to test these hypotheses in an ancient compound valley fill by detailed facies architectural analysis of channel and bar deposits from vertical measured sections and estimation of backwater limits from paleo-flow depth measurements in combination with measured changes in base level, tidal range and fluvial slope along an extensively exposed fluvial long profile. Three major erosional surfaces partitioned the compound valley fill into three sequences that have noticeable morphological and sedimentological differences from the upstream to downstream area. All three incised-valley fills in the downstream area shows a vertical translation from fluvial to tidal facies at the top of the valley. This suggests the rivers entered into their backwater length at the later phase of valley filling causing a systematic vertical decrease in overall grain size as well as an upward increase in preserved dune height and bar thickness. The valley fill deposits at the upstream area, which is roughly 15 km southwest, however, lie beyond the reach of the backwater effect and hence do not show any tidal influence, and consist of much coarser facies within channel bodies of relatively low width-thickness ratio.

REGIONAL SETTING AND STRATIGRAPHY





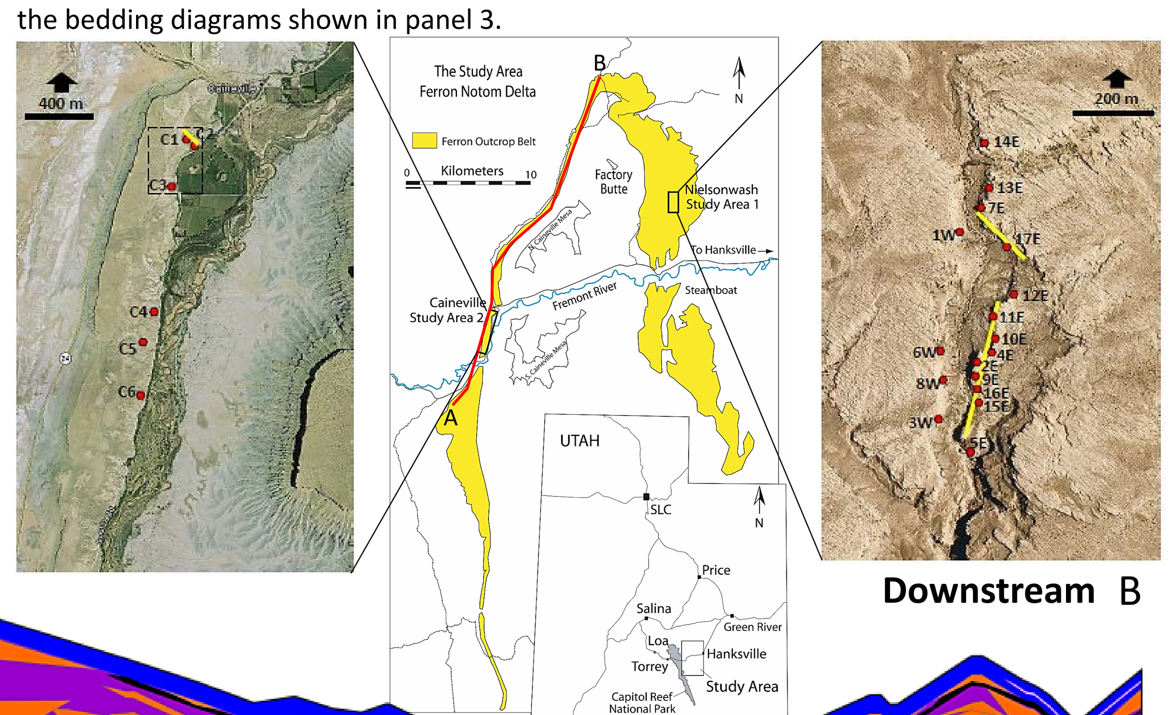
Paleogeographic reconstruction of mid-Cretaceous fluvio-deltaic wedges flowing into the Western Interior Seaway (Bhattacharya and James, 2009). The Ferron Delta complex includes the Notom, Last chance, and Vernal deltas of Middle Turonian to Late Santonian age that has both non-marine and marine dominated systems.

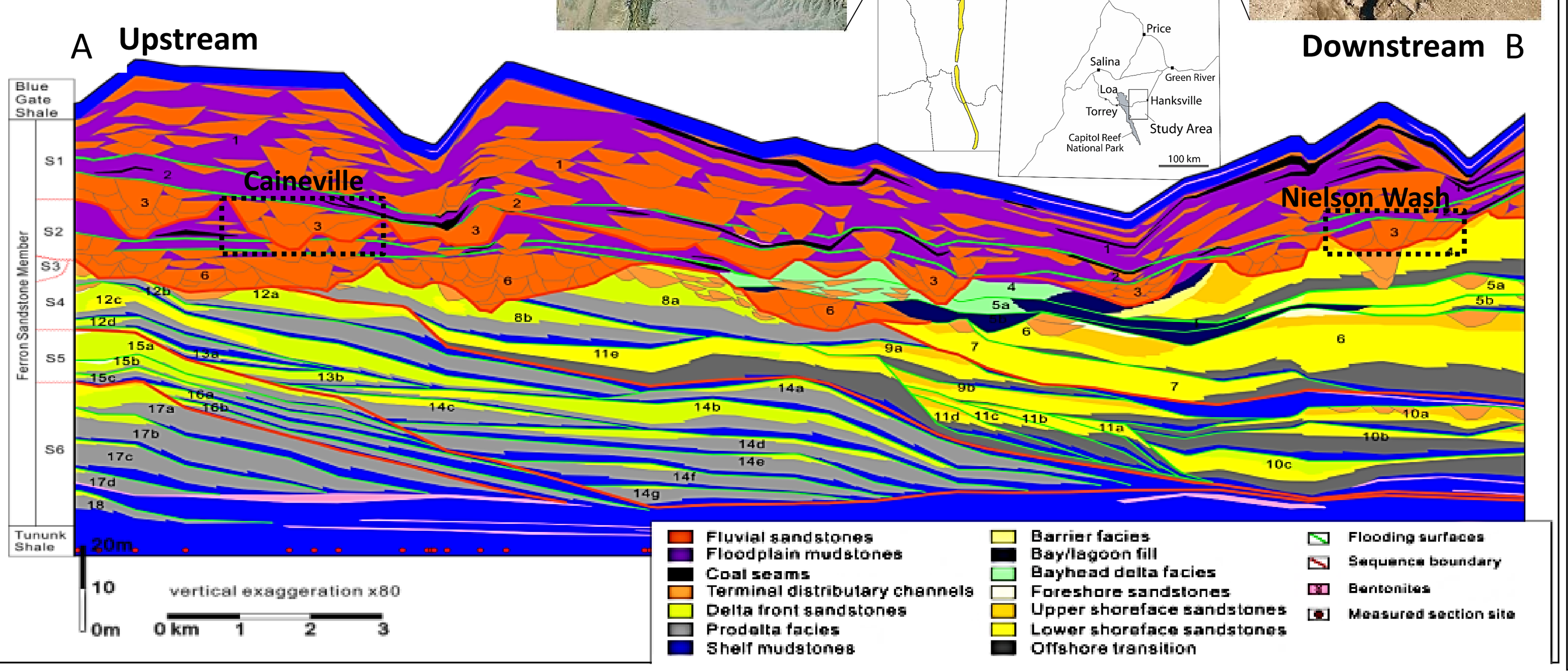
STUDY AREA AND METHODS

Field observations and vertical measured sections at intervals along physically accessible cliffs were used to document lithologies, sedimentary structures, and stratal architecture of the rock units from proximal Caineville to distal Nielson Wash segments of the valley fill.

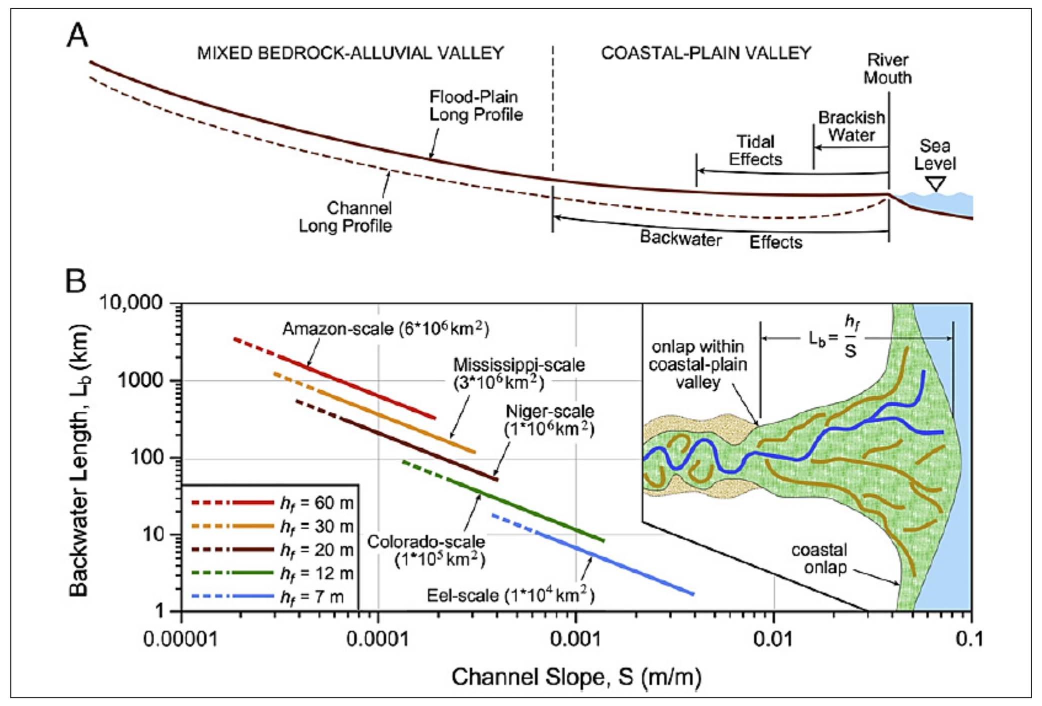
The architecture of the compound valley fills and surfaces of incisions were physically traced by walking out and from photomosaics and cross-sections constructed from 24 measured sections along the depositional strike and dip directions in Nielson Wash and Caineville area.

Shown in yellow is the outcrop of the Ferron Notom delta between Hanksville and Caineville, Southeast Utah. The red line indicates the location of the displayed depositional dip profile by Zhu et al. (2010) (shown below). The yellow lines in the study area represent the locations of the bedding diagrams shown in panel 3.

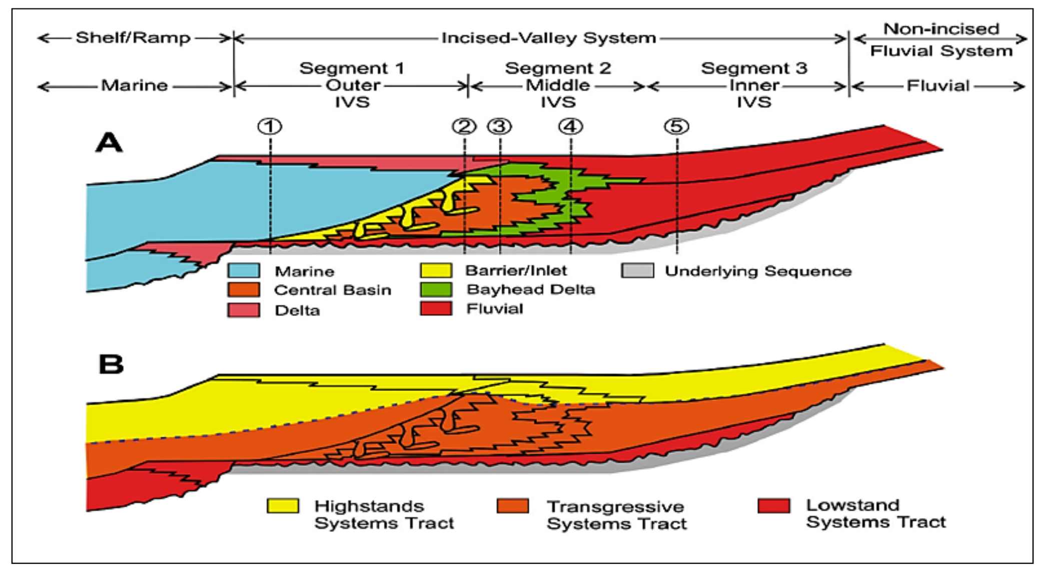




THE CONCEPT OF BACKWATER EFFECT



Backwater length theoretically controls the ability for sea-level change to propagate upstream (Blum et al., 2000 and 2013)



Overall facies composition mainly depends on the position along valley profile (Zaitlin et al., 1994).

There are numerous attempts in the literature to distinguish the signatures of upstream climate versus downstream base-level change in fluvial rock sequences. One of the tractable ways to identify the effect of downstream base-level on upstream fluvial valley deposits is "Backwater effect".

Paola and Mohrig (1996) first proposed the concept of backwater effect over a length scale that controls the streamwise distance over which an open-channel flow responds to imposed spatial changes in the elevation of a body of standing water downstream. They named this length scale as the "backwater length (L_{bw})" which is proportional to the flow depth (H) and inversely correlated to river slope (S).

Blum et al. (2013) further hypothesized that most of the Texas coastal-plain alluvial valleys are well within the range of backwater effects and thus characterized by rivers that are aggradational, avulsive and distributive in nature. Hudson and Kesel (2000) and Nittrouer et al. (2012) for example showed the extraction of suspended sand fraction by net deposition that might cause channels to become narrower and deeper after reaching the backwater length. These morphological and sedimentological changes, therefore, can induce a downstream transition of fluvial style from braided to meandering as suggested by the traditional non-marine sequence stratigraphic models yet without a change in base-level.

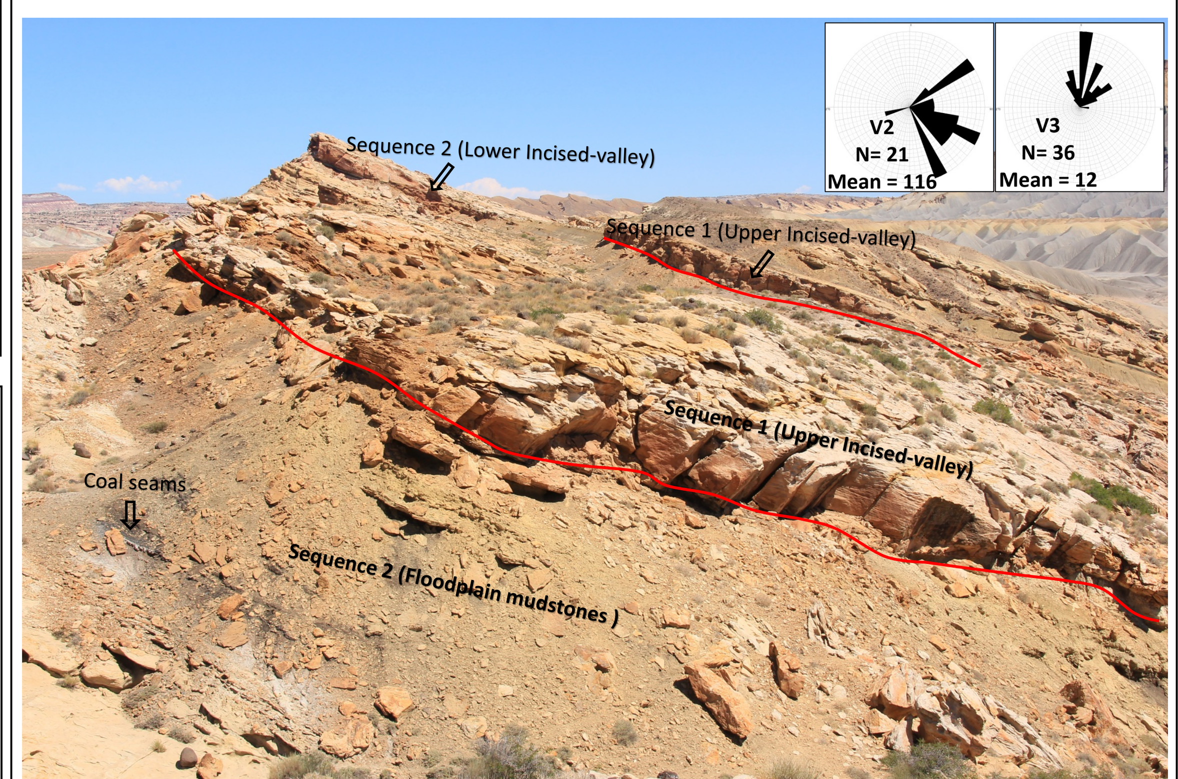
This study attempts to test the hypothesis of Blum and Tornqvist (2000) and Blum et al. (2013) in an ancient fluvial deposit by detailed analysis of morphological and sedimentological changes along a continuously exposed fluvial long profile within a Cretaceous compound incised-valley fill at the top of the Ferron Notom Delta, north of Henry Mountain region, southeast Utah.

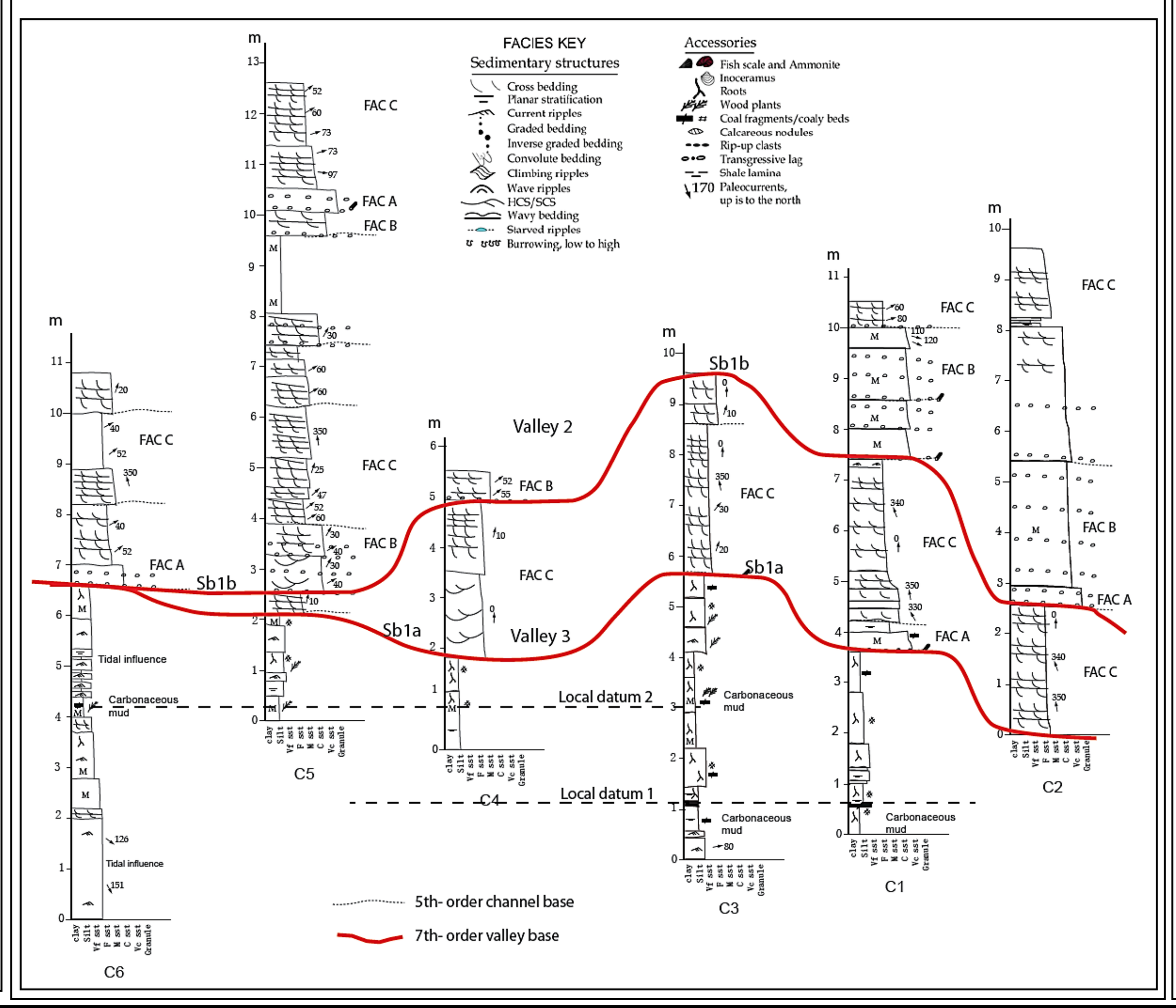
The main purpose of this study is to understand the backwater effects on fluvial Style and architecture in an ancient incised-valley fill, and to what extent the effect of can be traced upstream from a paleoshoreline, which is yet to be tested in an ancient fluvial sequence.

FERRON COMPOUND INCISED-VALLEY SYSTEM

Caineville (Upstream)

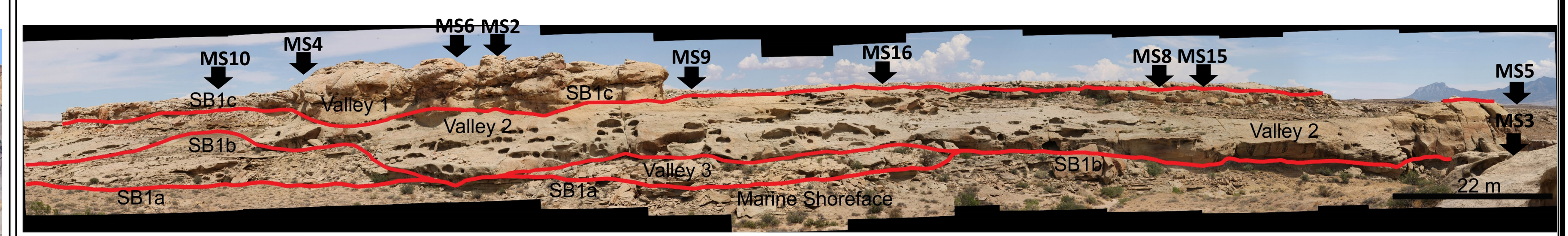
Photomosaic (top) and correlations of the measured sections (bottom) showing the valley systems and fluvial facies recognized and documented in the upstream area.

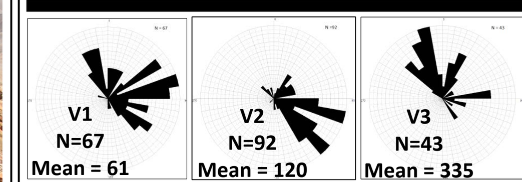




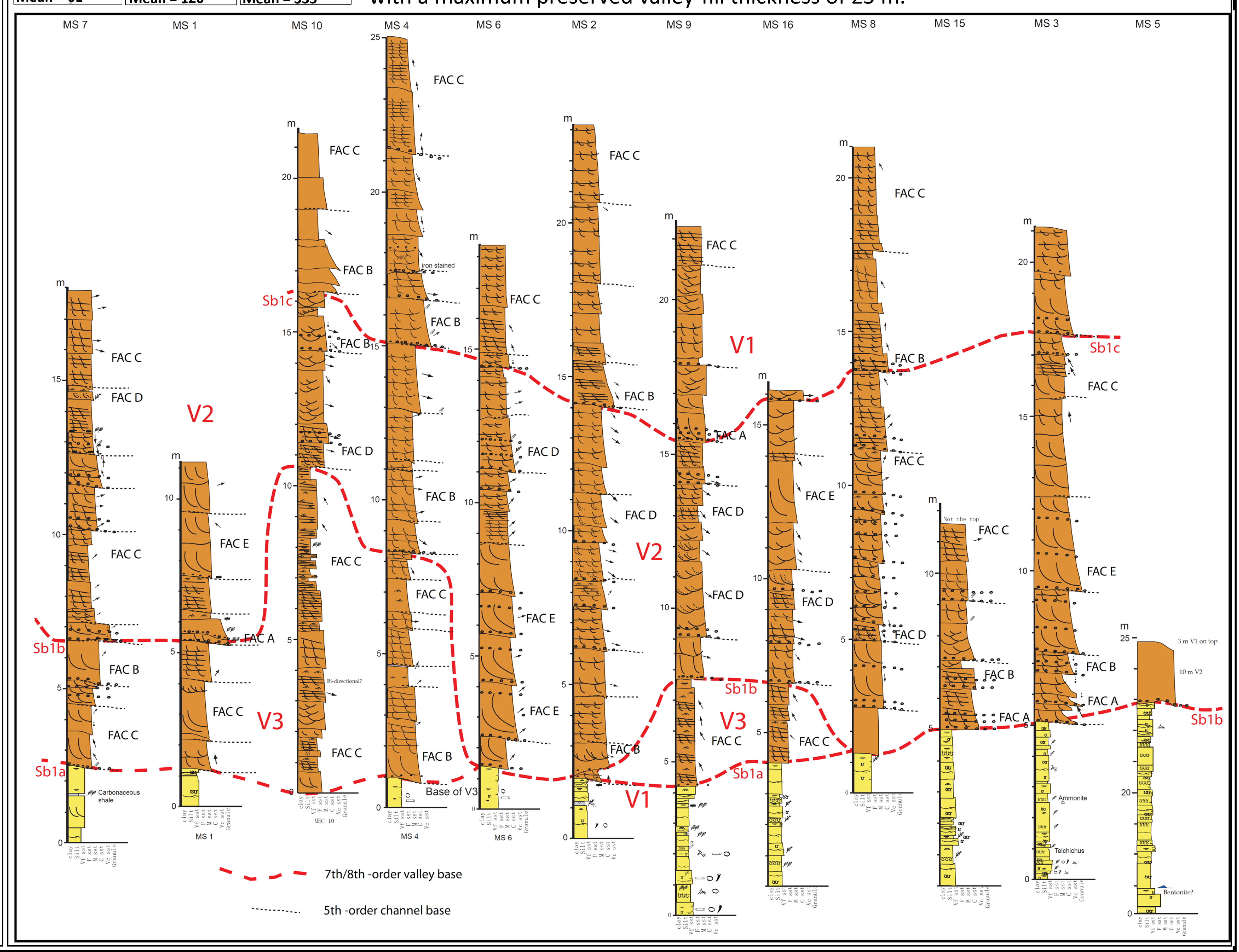
Nielson Wash (Down stream)

Photomosaic (top) and correlations of the measured sections (bottom) showing the valley systems and fluvial facies recognized and documented in the downstream area.





At least two episodes of cuts and fills in the upstream part of the studied compound-incised valley system (sequence 1) in Caineville . The maximum preserved compound valley-fill thickness in Caineville is 14 m. Three episodes of cuts and fills in Nielson Wash with a maximum preserved valley-fill thickness of 25 m.



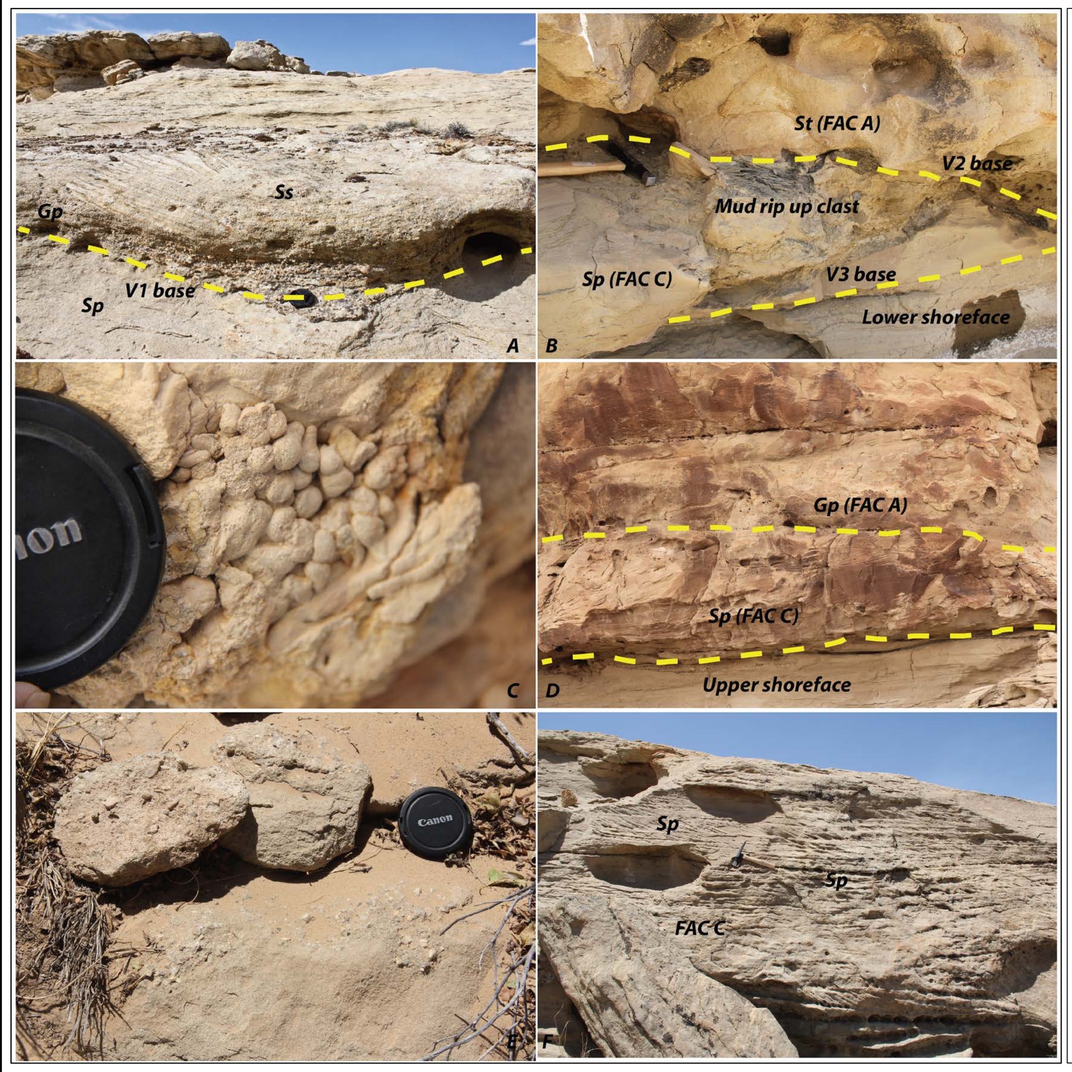
Interpreting Backwater Effects on Fluvial Style and Architecture in a High-Gradient Compound Incised-Valley Deposits: Example from Cretaceous Ferron Notom Delta, Southeastern Utah

Mohammad S. Ullah[1], Janok P. Bhattacharya[2]
[1]Department of Earth and Atmospheric Science, University of Houston, Texas, U.S.A (msullah@uh.edu)
[2]School of Geography and Earth Sciences (SGES), McMaster University, Hamilton, ON, Canada

FACIES ANALYSIS

Facies Association	Facies Description	Bounding surface	Interpretation	Valleys
A: Valley/ Channel Basal Lag Deposits	Trough/Planar-Cross-Bedded (Gt/Gp) or massive sand matrix-filled basal channel pebbles; Scour-Fill Sand lithofacies Ss; frequent mud rip-up clasts, intra-basinal overbank clasts.	5th- order channel or 6th – order valley erosional surface at the base.	Coarsest fraction of the bed-load sediments retained during relative sea level fall and early lowstand	V1, V2 in Nielson Wash; V2, V3 in Caineville
B: Coarse Fluvial Sandstone	Highly amalgamated medium to coarse grained dune/bar -scale Trough Cross-Bedded Sands (St) and Planar-Tabular Cross-Bedded Sands (Sp).	1st and 2nd – order internal bounding surface; 4th/5th order surface at the base.	Channel-fill or bedform deposits representing most of the bed-load sediment.	V1 (basal part), V2 in Nielson Wash; V2, V3 in Caineville
C: Fine Fluvial Sandstone	Very fine to medium-grained dune and bar-scale Trough Cross-Bedded Sands (St) and Planar-Tabular Cross-Bedded Sand (Sp), Upper Plane Horizontally Bedded Sand (Sh) Current Ripple Cross-Laminated Sand (Sr) and climbing ripples.	1st and 2nd – order internal bounding surface; 4th/5th order surface at the base.	Channel-fill or bedform deposits in mostly lateral accretional depositional units; Levee and bank deposits.	V1, V2 (upper part), V3 in Nielson Wash; V2 (upper part), V3 in Caineville.
D:Tidally Influenced Fluvial Sandstone	Very fine- to fine grained sandstones often interbedded with thin clays and siltstones. Current ripple cross-laminations, climbing ripples, planar and flaser beddings, and dune-scale cross stratifications; presence of brackish water fossils.	1st and 2nd – order internal bounding surface.	Late lowstand to transgressive deposits as indicated by comparatively finer grained, less amalgamated sand bodies.	Middle and top part in V1 and V2, basal part in V3 in Nielson Wash; not observed in Caineville.
E: Steeply Dipping, Laterally Accreting Large-Single Foresets	Large-scale single foresets, dipping at or greater than the angle of repose. The individual foresets are between 1.5 and 4 m in height and can extend more than 20 m laterally. They are comprised of 0.5 - 1 cm thick, alternating very fine- to medium sandstone.	5th -order channel erosional surface at the base, 4th – order surface at the top; no internal bounding surface.	Distinct unidirectional accretion towards the channel cut bank as the river migrated laterally over the deep thalweg near the river bend filling a scour.	V1, V2, and V3 in Nielson Wash; not observed in Caineville.

Various fluvial lithofacies in downstream Nielson Wash area

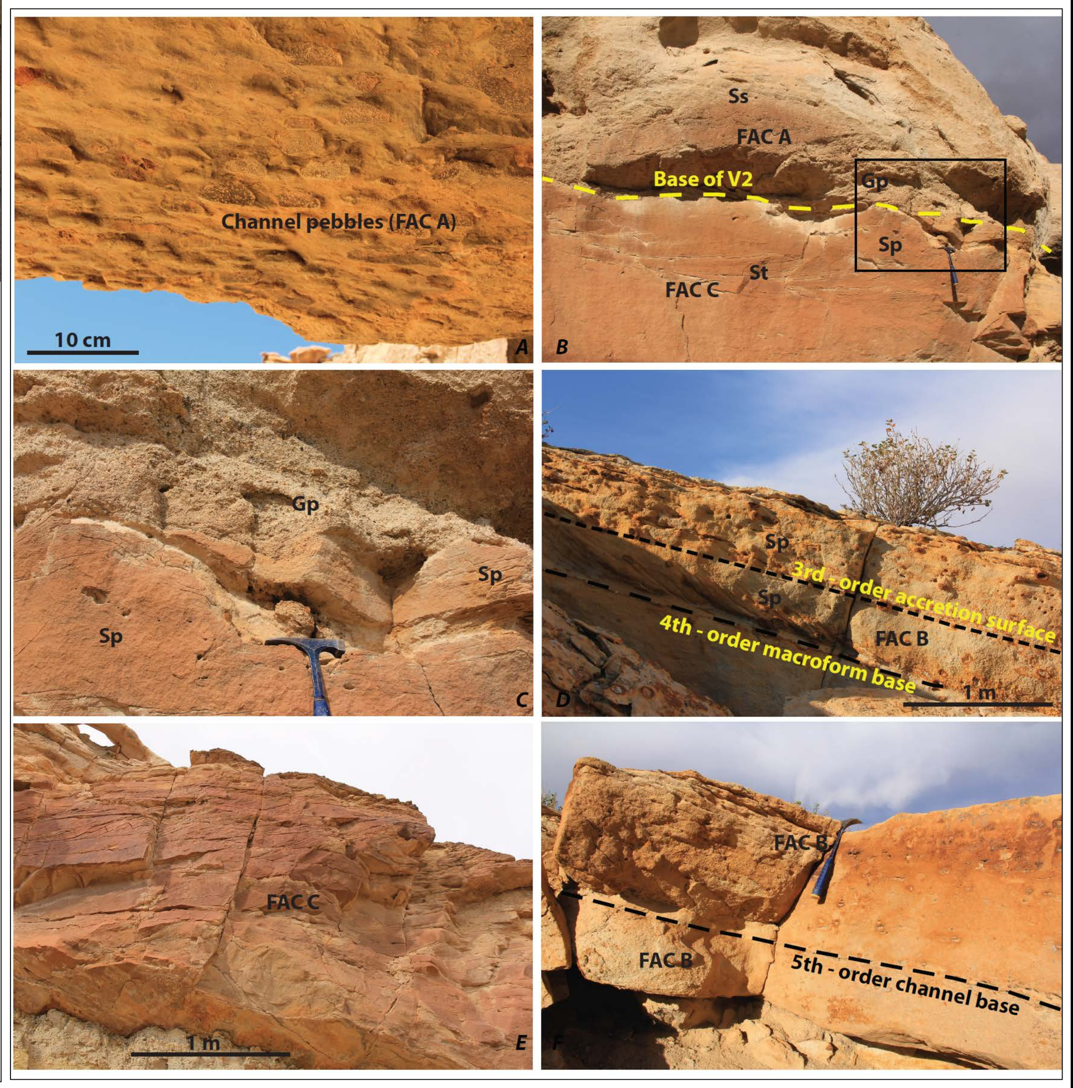


A) Planar-cross-bedded basal channel pebbles (Gp) overlain by poorly sorted coarse-to very coarse-grained sand (Ss) at the base of V1, B) Wide occurrence of extrabasinal pebbles and large mud rip-up clasts at the base of V2, C) *Teredolites longissimus* at the base of V3 indicating flood-dominated tidal facies, D) Multistory valley fill in V1 and V3. The fluvial sandstones in V3 have a sharp, erosional contact (marked by lower yellow line) with the shoreface facies below, E) Wide occurrence of poorly sorted extrabasinal pebbles at the base of V2, F) Cosets of decimeter-thick planar-tabular cross-sets on a 2-D outcrop.

A) Large, simple planar-cross bed set (Sp) at the bottom, overlain by high-angle small-scale cross-sets, B) Very fine to fine-grained sandstones with Liesegang banding, C) Upper plane-bed Lithofacies (Sh) with flat, parallel lamination, with parting lineation occurring on bedding planes, D) 3-D current ripples with rounded tops at the V1 surface. Arrow represents the flow direction, E) Low-angle cross-bedding (Sp) downlapping onto Sh bedding surface, indicating deposition close to the upper plane-bed condition. Double mud drapes in the foresets of dune-scale cross strata at the very top of V2 (area in box), F) Double mud drapes in the foresets of dune-scale cross strata within tidal-channel deposits (area within the box in image E).

A) Tide-influenced large, simple planar-cross bed sets (Sp) in bar deposits in V2., B) Double mud drapes in the foresets of dune-scale cross strata in V1, C) Steeply dipping, large-single foreset facies (Sf) in laterally accreting unit bar in V1, D) Single set of downstream accreting large-scale trough cross-beddings (Sf) filling a scour., E) More than 20 m long single foresets bounded by 5th –order channel-basal erosional surface at the base and truncated by a 4th – order macroform-basal erosional surface at the top.

Various fluvial lithofacies in upstream Caineville Area

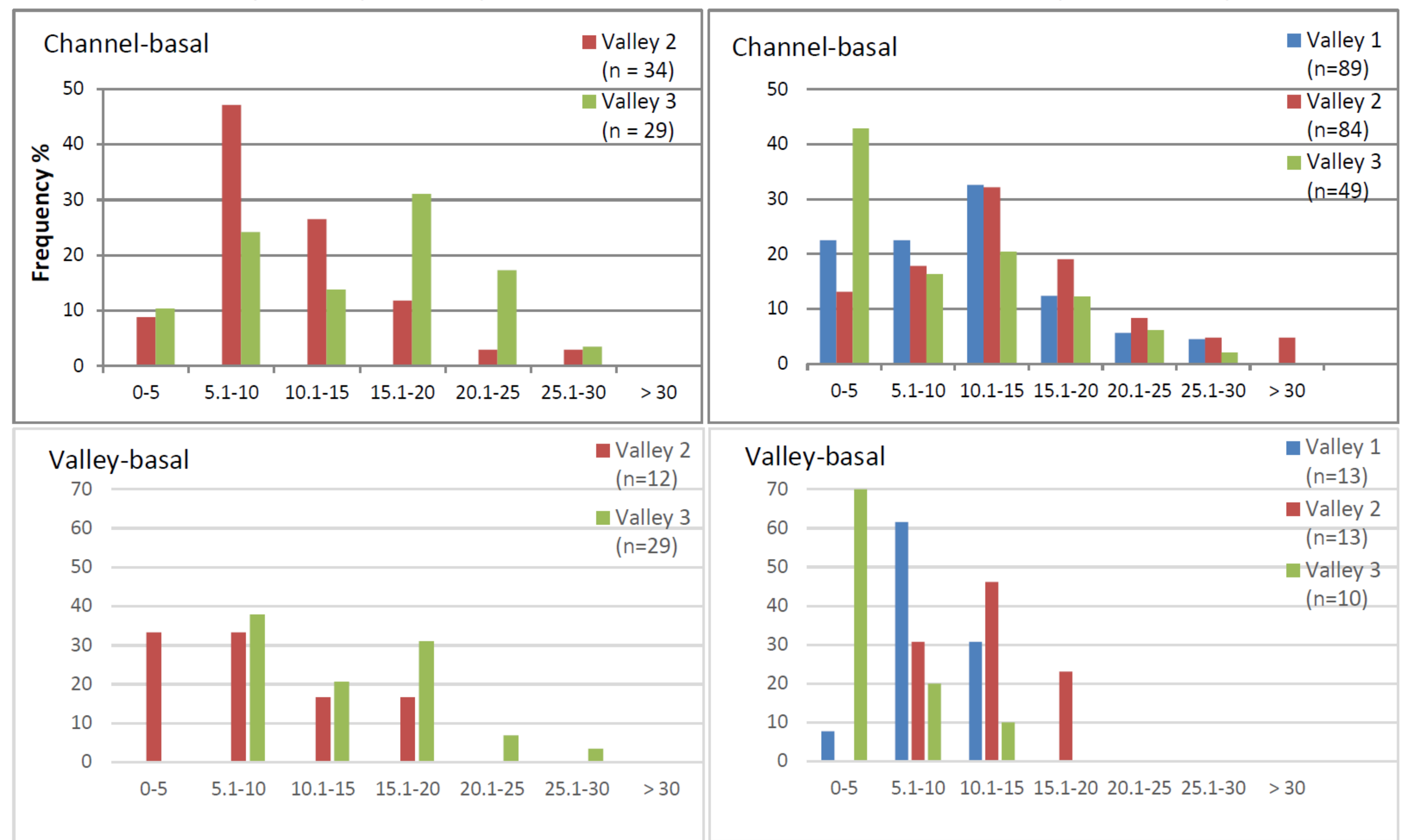


Various lithofacies in valley-filling fluvial deposits in upstream Caineville: A) Sand matrix-filled intra-basinal pebbles/clasts in channel basal lag deposits at the base of V3, B)Erosional contact between poorly sorted planar-cross-bedded lithofacies Gp at the base of V2 (top) and underlying fine to medium-grained lithofacies Sp and St in V3, C) Close up of the erosional contact between V2 and V3 (box in Fig. B). Paleoflow in V3 is to the left of the image as indicated by the small-scale cross sets (Sp), D) Coarse-to very coarse-grained bar-scale planar-cross-bedded sand overlain by 5-10 cm thick dune-scale cross-bedding in V2, E) Laterally accreting cosets of fine to medium-grained dune-scale planar-cross-bedded sand in V3. The set thickness gradually decreases from the bottom to the top of the channel story, F) Multistory valley fill in V2. The fluvial sandstones in the bottom channel story comprises of decimeter-thick tabular cross-sets, whereas the upper channel story has small-scale cross-set in sheet fluvial sandstone.

CALCULATION OF BACKWATER LENGTH

A. CALCULATION OF CHANNEL DEPTH

Histograms of cross-strata thicknesses of fluvial sandstones at the base of channels and valleys



Comparison of cross-strata thicknesses of fluvial sandstones at the base of channels and valleys

	Upstream (Caineville)			Downstream (Nielson Wash)		
Cross-strata location	Total Samples	Avg. Cross-strata thickness	Standard deviation	Total Samples	Avg. Cross-strata thickness	Standard deviation
Channel-basal						
Valley 1	_	_	_	89	12.3	6.8
Valley 2	34	11.9	5.7	84	15.1	8.3
Valley 3	29	15.6	6.3	49	10.2	7.4
Valley-basal						
Valley 1	_	_	_	13	9.9	2.9
Valley 2	12	10.0	5.1	13	13.4	3.6
Valley 3	29	13.9	5.9	10	6.2	3.3

Comparison of estimated water depths of valley-filling and valley-formative channels

	Upstream (Caineville)		Downstream (Nielson Wash)	
	Average dune height (cm)	Estimated water depth (m)	Average dune height (cm)	Estimated water depth (m)
Valley-filling channels				
Valley 1	_	_	35.7 ± 21.5	285.4 ± 186.1
Valley 2	34.5 ± 18.6	275.7 ± 163.8	43.7 ± 26.2	349.9 ± 227
Valley 3	45.3 ± 21.4	362.4 ± 193.8	29.5 ± 22.6	236.3 ± 190.3
Valley-formative channels				
Valley 1	_	_	28.8 ± 11.0	230.2 ± 104.9
Valley 2	29.0 ± 16.5	232.0 ± 143.8	38.8 ± 14.0	310.5 ± 136.6
Valley 3	40.2 ± 19.6	321.6 ± 176.0	18.0 ± 10.5	143.8 ± 91.6

B. CALCULATION OF CHANNEL SLOPE

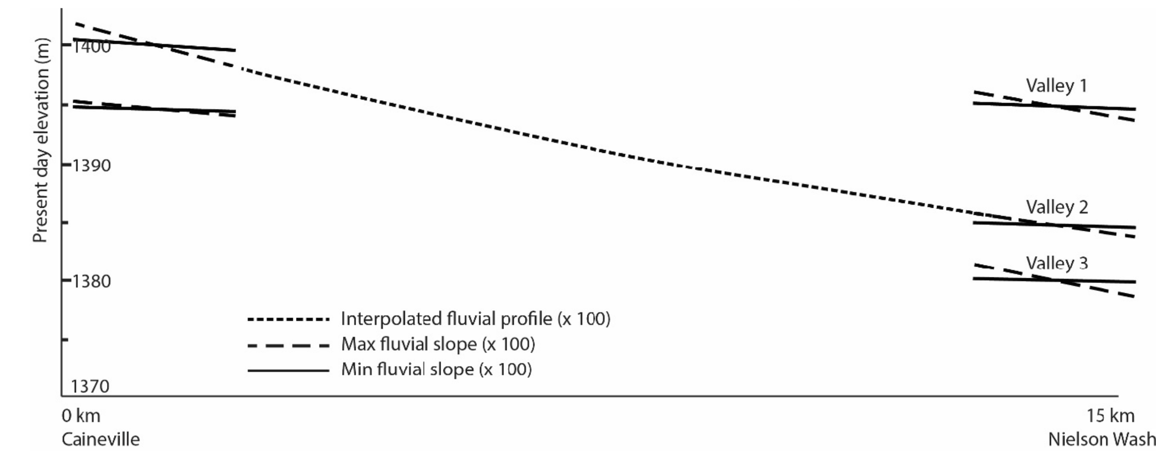
$$\text{Slope, } S = \frac{R D_{50} X \tau_{bf50}}{H_{bf}}$$

Submerged density (R) = 1.65 g/cm^3
Bankfull depth (H_{bf}) estimated from cross-set thickness.
Bankfull Shields number for dimensionless shear stress (τ*bf50) is assumed to be ***1.86.***
D_{50} is median grain size.

Comparison of calculated slopes of valley-filling and valley-formative channels

	Upstream (Caineville)			Downstream (Nielson Wash)		
	Min	Max	Mean	Min	Max	Mean
Channel-basal slope (percent)						
Valley 1	–	–	–	0.0004	0.0017	0.0006
Valley 2	0.0007	0.0026	0.0011	0.0003	0.0014	0.0005
Valley 3	0.0003	0.0009	0.0004	0.0002	0.0020	0.0004
Valley-basal slope						
Valley 1	–	–	–	0.0005	0.0015	0.0008
Valley 2	0.0007	0.0031	0.0012	0.0004	0.0011	0.0006
Valley 3	0.0003	0.0010	0.0004	0.0004	0.0016	0.0006

Schematic diagram of slopes of valley-filling channels



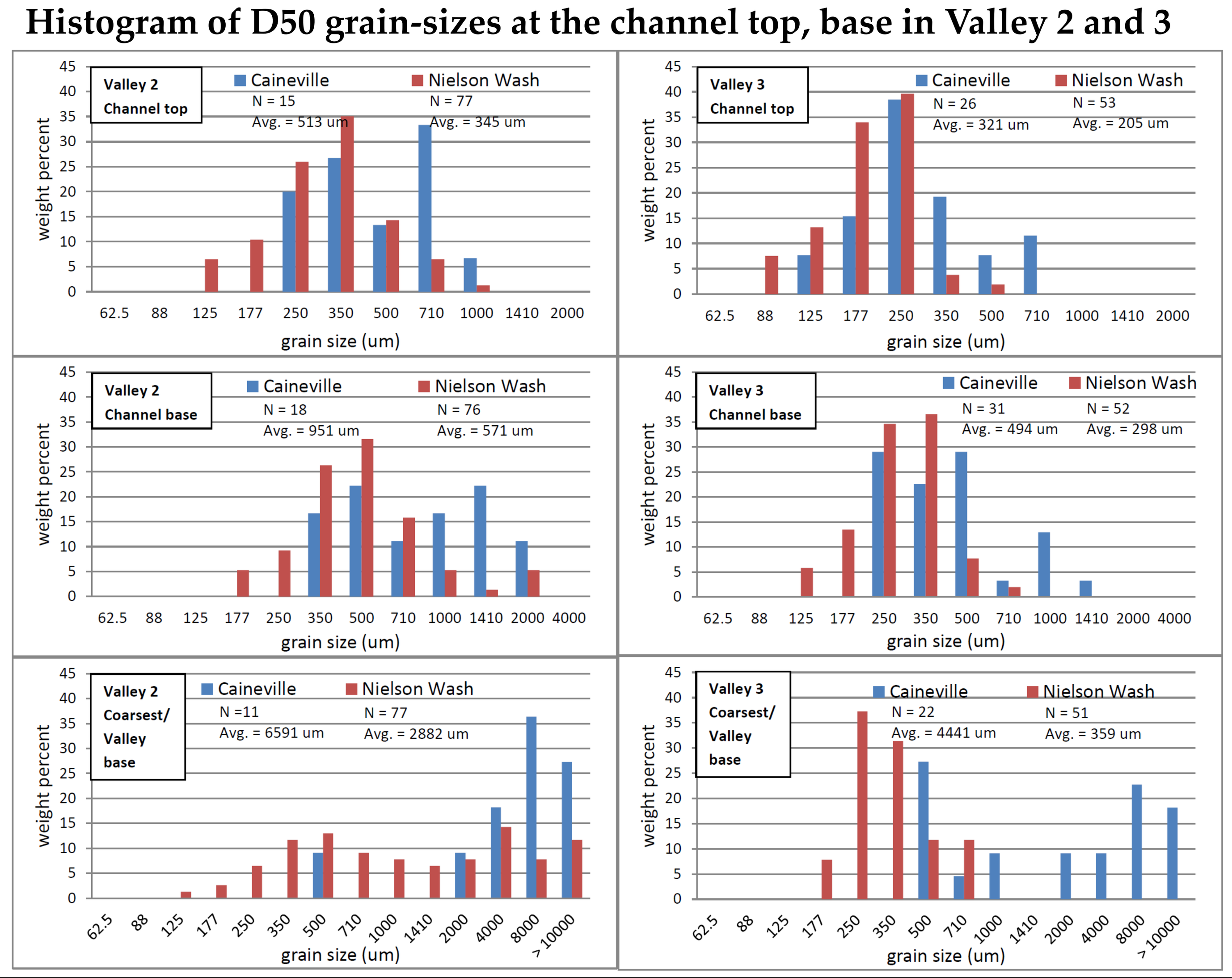
Comparison of estimated backwater lengths of valley-filling channels in Nielson Wash

	Valley 1			Valley 2			Valley 3		
	Channel depth (m)	Slope	Backwater length (km)	Channel depth (m)	Slope	Backwater length (km)	Channel depth (m)	Slope	Backwater length (km)
Average	2.9	0.0006	**4.7**	3.5	0.0005	**7.0**	2.4	0.0004	**6.1**
Max	4.7	0.0004	**13.0**	5.8	0.0003	**19.0**	4.3	0.0002	**20.0**
Min	1.0	0.0017	**0.6**	1.2	0.0014	**0.9**	0.5	0.0020	**0.2**

Given Ferron river slopes are likely on the order of 0.01° - 0.17° (0.0002 - 0.0031), the maximum backwater length for the rivers within these valleys would range from 13 km up to 20 km.

Bhattacharya (largely unpublished) estimated slopes of the Ferron rivers from as steep as 0.14° to as flat as 0.043° with an estimated valley slopes of about 0.06° (0.001).

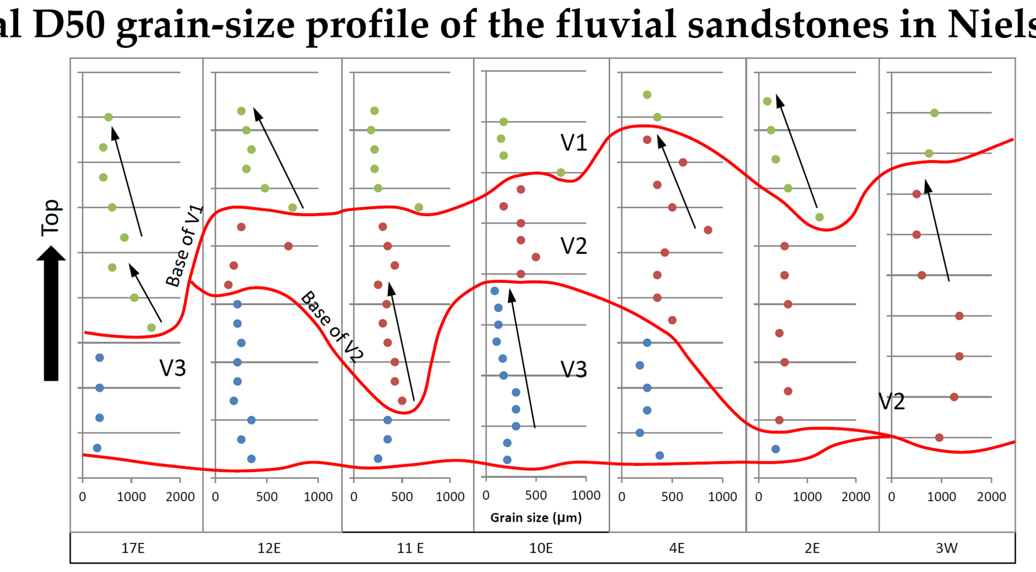
Histogram of D50 grain-sizes at the channel top, base in Valley 2 and 3



Comparison of average median (D50) grain sizes of valley-basal and channel basal cross-sets

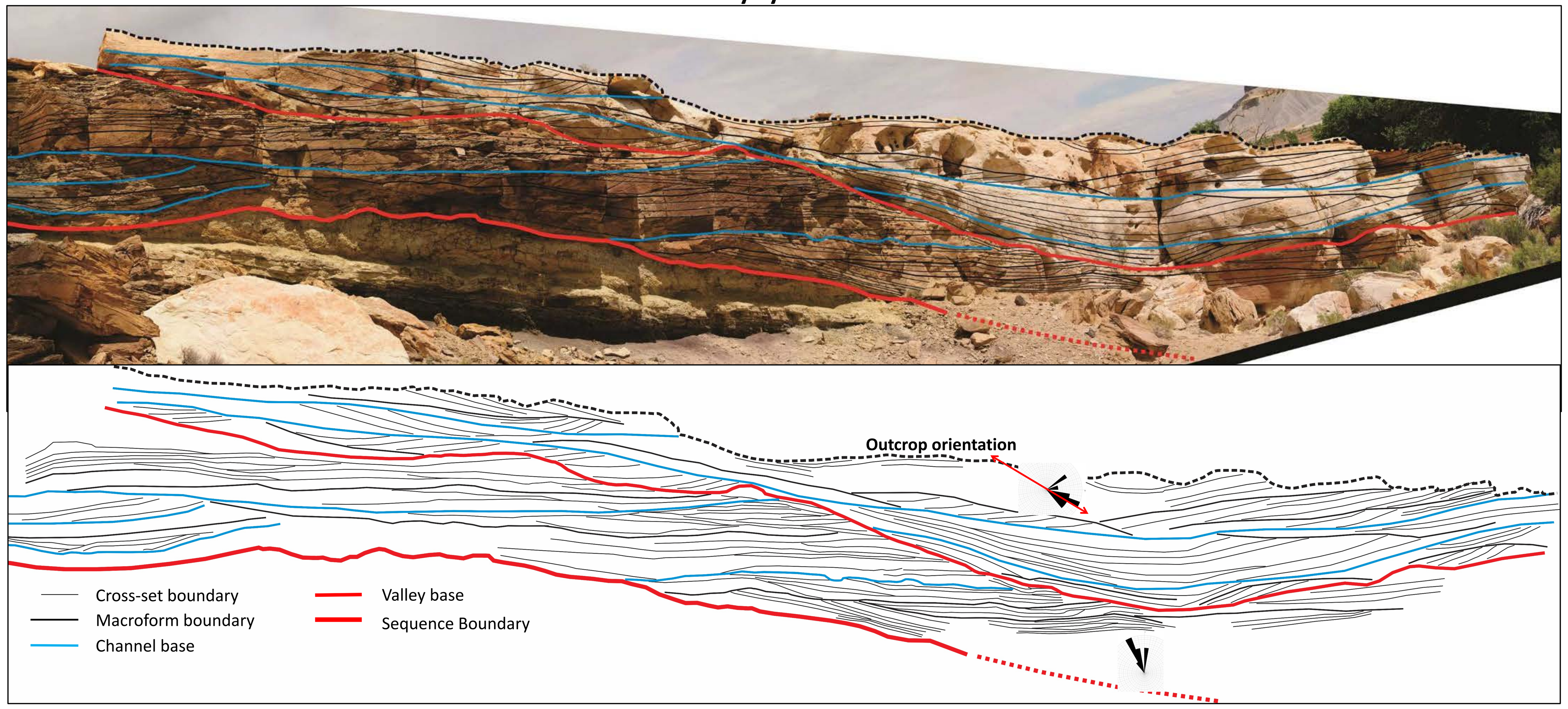
	Upstream (Caineville)		Downstream (Nielson Wash)	
Sample Type	Total Samples	Avg. D50 size (um)	Total Samples	Avg. D50 size (um)
Channel-basal				
Valley 1	–	–	68	559
Valley 2	18	951	76	571
Valley 3	31	494	52	298
Valley-basal				
Valley 1	–	–	12	595
Valley 2	7	883	15	616
Valley 3	17	463	12	273

Vertical D50 grain-size profile of the fluvial sandstones in Nielson Wash

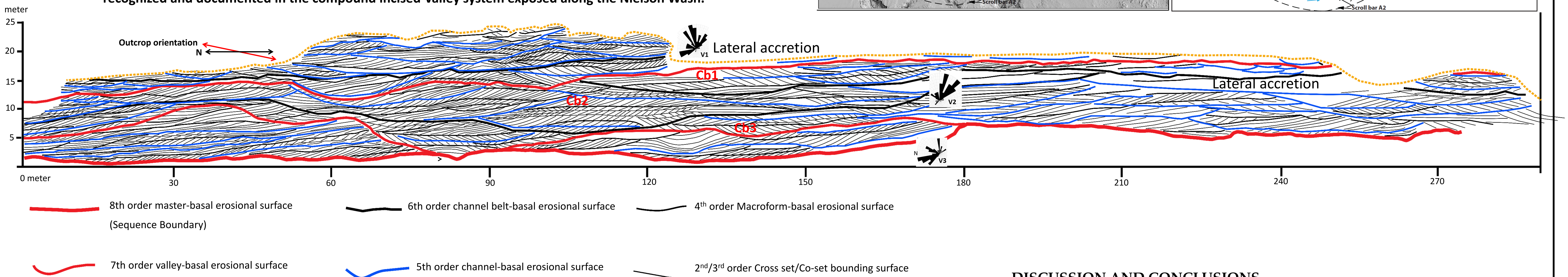


FLUVIAL GEOMETRY AND BEDDING ARCHITECTURE

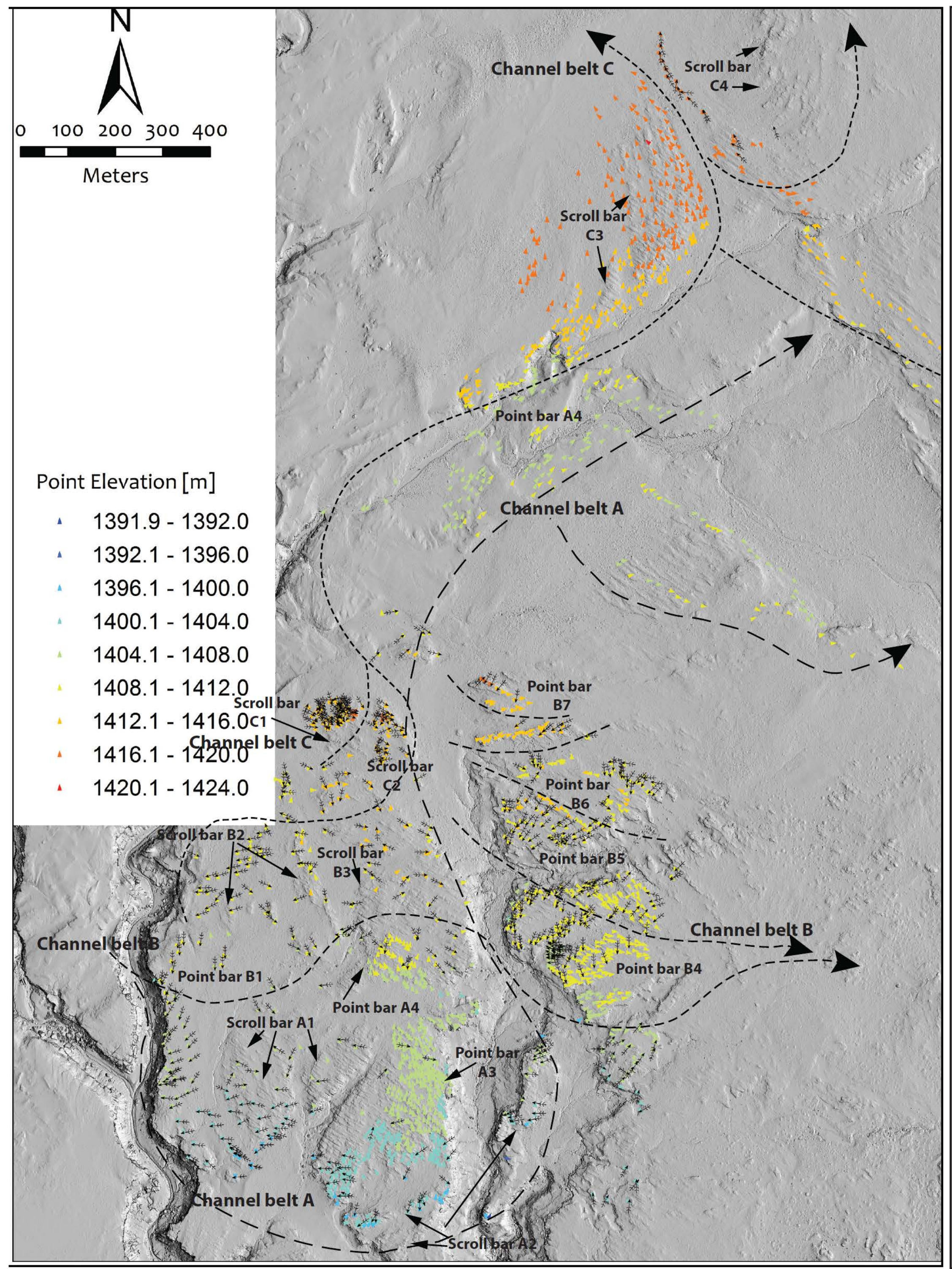
Photomosaic and bedding diagram showing internal architecture of the channel-belts and major erosional surfaces in the compound incised-valley system in Caineville

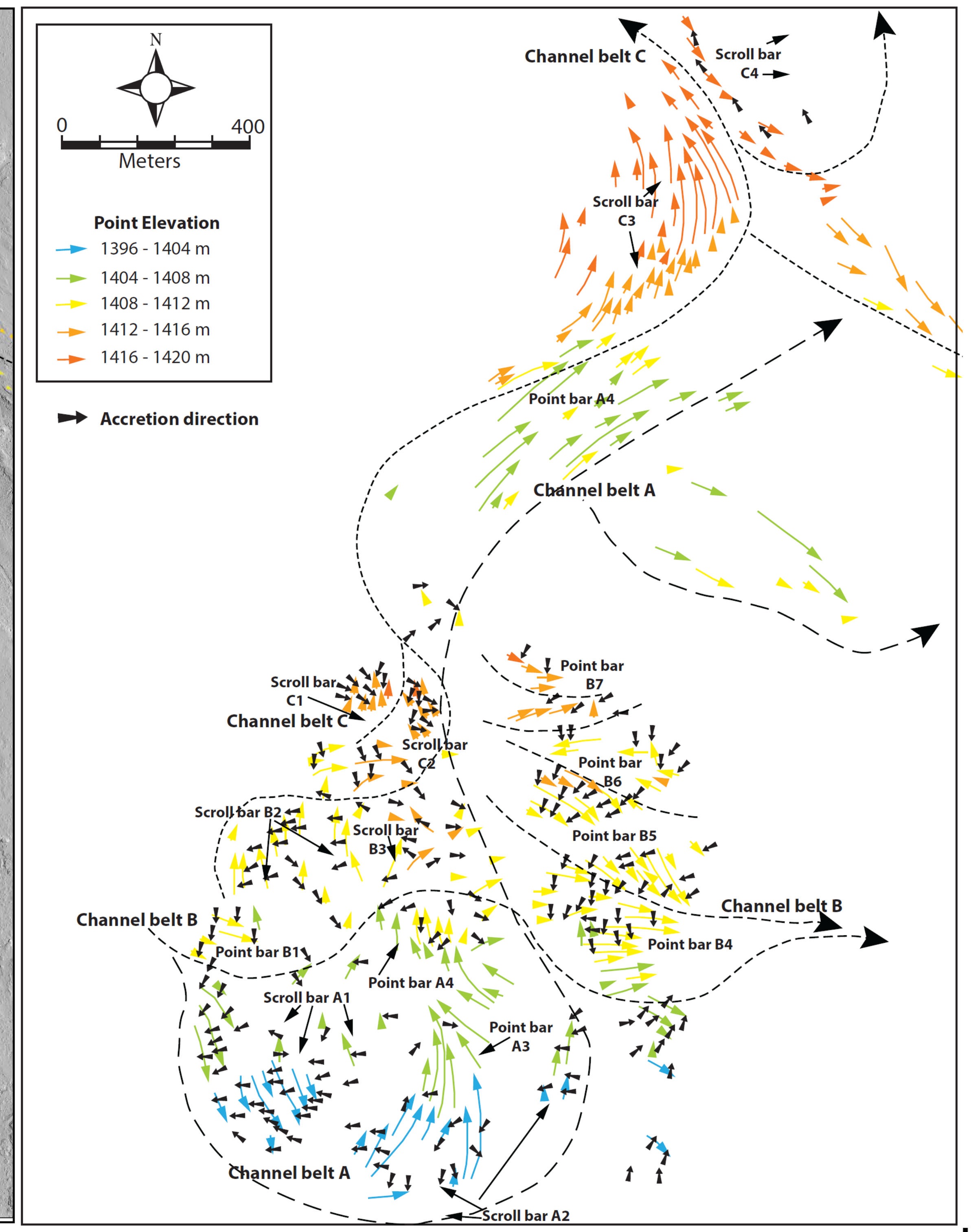


Photomosaic and bedding diagram showing internal architecture of the channel-belts and major erosional surfaces recognized and documented in the compound incised-valley system exposed along the Nielson Wash.

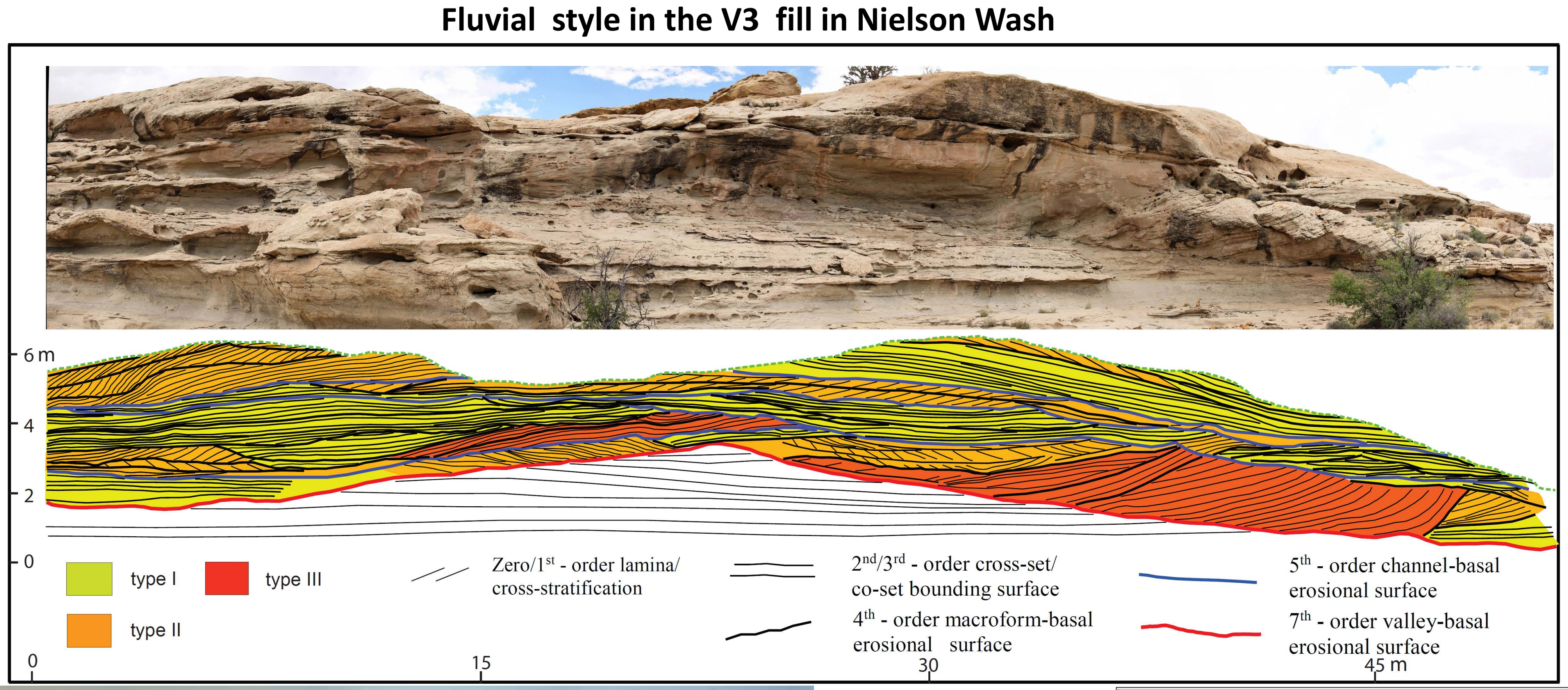


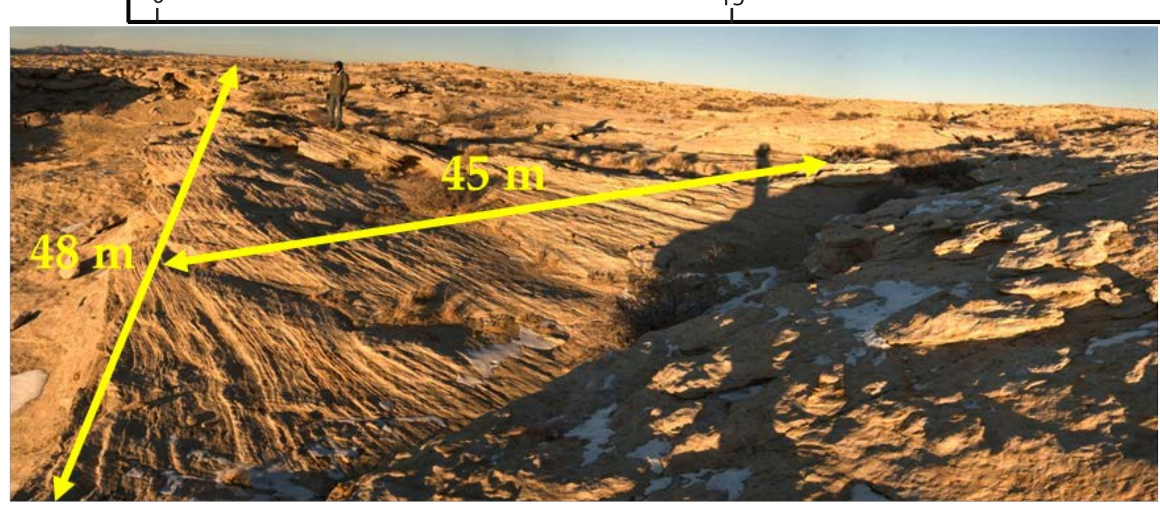
PALEOGEOGRAPHIC RECONSTRUCTIONS OF THE CHANNEL BELTS ON TOP OF V1





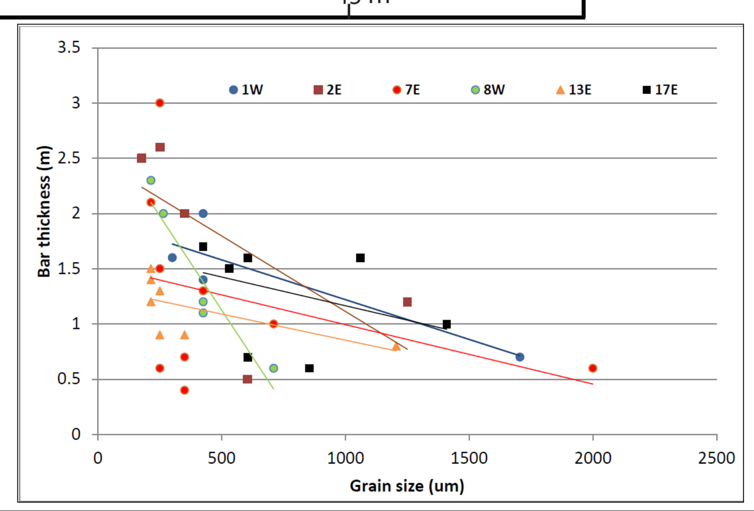
Fluvial style in the V3 fill in Nielson Wash





(right) A decrease in grain-size corresponds to an upward increase in bar thickness in V1 in Nielson Wash area.

(Left) The top of the Valley 1 is dominated by large laterally accreting point bars.



DISCUSSION AND CONCLUSIONS

Three major erosional surfaces (Sb1a, Sb1b and Sb1c) partition the compound valley fill into three sequences (V3, V2 and V1) which were documented based on detailed outcrop studies, field correlation, field photomosaics, paleocurrent data, and 24 measured sections at angles approximating depositional strike and dip in both the upstream and downstream areas. The distinct basinward shifts in facies across the base of the V3 (Sb1a), from upstream Caineville to downstream Nielson Wash area, are interpreted as unconformities or sequence boundaries.

The maximum valley-fill thicknesses in Nielson Wash and in Caineville area are 25 m and 14 m respectively indicating that the amount of incision gradually decreases towards the upstream area. There are also noticeable differences in facies, grain-size, and paleocurrent directions among the valleys in both study areas.

The maximum backwater length calculated for V3, V2 and V1 rivers were between 2.5 km to 4.3 km, 3.9 km to 6.5 km and 3.2 km to 5.2 km respectively. The Caineville area, which is roughly 15 km upstream of the Nielson Wash, most probably, lies beyond the reach of the backwater effect.

All three incised-valleys recognized in the Nielson Wash East show a vertical translation from fluvial to tidal facies that correspond to a systematic vertical decrease in overall grain size as well as change in fluvial channel geometry and architecture. Steady upward increase in accommodation during the development of the late lowstand to transgressive systems tract is most probably linked with backwater length resulting in not only an upward increase in preserved dune height and bar thickness in the Nielson Wash area, but also an increase in average channel depths from Caineville to Nielson Wash area. This supports the findings by Hudson and Kesel (2000) and Nittrouer et al. (2012) that channels become narrower and deeper after reaching the backwater length.

Formative rivers of the fluvial bodies in downstream Nielson Wash were mostly meandering as indicated by the dominance of unidirectional accretion within channel stories exposed perpendicular to flow. The plan-view paleogeographic reconstructions of the channel belts on top of V1 in Nielson Wash also indicate that side-attached, laterally migrating point bars are the dominant macroform. Whereas, in the Caineville area, bedding architecture within V2 and V3 shows distinct unidirectional downstream accretion and mounded shape with bilateral downlap, and is interpreted to indicate braid bars.