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

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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.
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.

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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 (Lbw)” 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. Hudon and Kessel (2000) and Nittouer 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 Tompkins (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.
**Facies Analysis**

<table>
<thead>
<tr>
<th>Facies Association</th>
<th>Facies Description</th>
<th>Bounding Surface</th>
<th>Interpretation</th>
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<tbody>
<tr>
<td>Tidally Influenced</td>
<td>Very fine to medium-grained dune and bar-scale trough cross-bedded sands (St)</td>
<td>15紫色，V2, V3 in Caineville</td>
<td>Laterally accreting cosets of fine to medium-grained dune-scale planar-cross-bedded sands</td>
</tr>
<tr>
<td>Fine Fluvial Sandstone</td>
<td>Steeply dipping, single foresets</td>
<td>Upper channel, V1</td>
<td>Large-scale single foresets, dipping at greater than the angle of repose. The foresets are highly amalgamated and extend more than 20 m laterally. They are comprised of 0.5 -1 cm thick, alternating very fine- to fine-grained sandstone.</td>
</tr>
<tr>
<td>Coarse Grained Sandstone</td>
<td>Highly amalgamated medium to coarse-grained dune/bar-scale trough cross-bedded sands (Sh)</td>
<td>15紫色，V1, V2 in Nielson Wash, V3 in Caineville</td>
<td>Marked by lower yellow line with the shoreface facies below.</td>
</tr>
<tr>
<td>Beach Sandstones</td>
<td>Current ripple cross-laminated sand (Sr) and climbing ripples.</td>
<td>-</td>
<td>Wide occurrence of poorly sorted coarse- to very coarse-grained beach sandstones.</td>
</tr>
<tr>
<td>Valley/Channel Basal Sandstone</td>
<td>Planar-cross-bedded basal channel pebbles (Gp) overlain by poorly sorted coarse- to very coarse-grained bar-scale planar-cross-bedded sand overlain by 5-10 cm thick dune-scale cross-bedding</td>
<td>-</td>
<td>Postulated beach deposits representing the upper plane of the mudstone of the foresets.</td>
</tr>
<tr>
<td>Fluvial Base</td>
<td>Tidal-influenced large, simple planar-cross bed sets (Sp) in bar deposits in V2.</td>
<td>-</td>
<td>Large, simple planar cross bed set at the bottom, overlain by high-angle small-scale cross sets, which may be in planar-bedded sand or current ripple cross-laminated sand. Double mud-mat deposits in the foresets of dune-scale cross beds.</td>
</tr>
</tbody>
</table>

**Calculation of Backwater Length**

A. Calculation of Channel Depth

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

B. Calculation of Channel Slope

Histograms of cross-strata thicknesses of fluvial sandstones

Schematic diagram of slopes of valley-filling channels

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

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

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.

PALEOGEOGRAPHIC RECONSTRUCTIONS OF THE CHANNEL BELTS ON TOP OF V1

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.