3D Mapping, Facies Heterogeneity, Internal Organization and Reservoir Characterization of Incised Valley Systems, FerronNotom Delta, Utah

By
Cameron R. Griffin
Advisor: Dr. Janok P. Bhattacharya
Committee Member: Dr. William Dupre
External Committee Member: Dr. Mark Barton

Proposal submitted to the Faculty of the Department of Earth and Atmospheric Sciences,
University of Houston, in partial fulfillment of the requirements for the degree of:
MASTERS IN SCIENCE

April 13, 2012

3D Mapping, Facies Heterogeneity, Internal Organization and Reservoir Characterization of Incised Valley Systems, FerronNotom Delta, Utah

ABSTRACT

Incised valley systems are important because they contain significant hydrocarbon reserves, provide clues into the geologic history of a region, and are crucial for sequence stratigraphic interpretations. Recent studies have shown that incised valleys are constantly being modified throughout the entire relative sea level cycle. This implies that sequence boundaries are strongly diachronous in nature rather than chronostratigraphically significant as previously believed. Wonderful 3D exposures of the Ferron Sandstone Member of the Cretaceous Mancos Shale exist along Nielson Wash in Southern Utah, providing a an excellent opportunity to study complex incised valley systems of both trunk and tributive valleys. This study aims to: 1. Extend previous work in the area by continued vertical and horizontal mapping of the facies of channel architecture found within the incised valleys, 2. examine the idea that sequence boundaries are diachronous in nature, 3. test the idea that in any vertical section, older terraces formed during early falling stage will be tidal influenced while younger terraces will have increasingly more fluvial influence, and 4. document facies and architectural differences between tributive and trunk incised valley deposits.

INTRODUCTION

Incised valley systems, along with their preserved deposits, are known tocontain significant hydrocarbon reserves and may host approximately 25%of all off-structure conventional petroleum traps in clastic reservoirs (Brown, 1993; Boyd et al., 2006). Incised Valleys also provide important clues into the stratigraphic history of the region in which they are found (Ardies et al., 2002; Strong & Paola, 2008; Martin et al., 2011). Understanding the fluvial architecture of incised valley fill deposits can provide important insights into fluid flow of analog reservoirs, channel connectivity, global sea level changes, andclimate and shifts in depositional environments (Zaitlin et al., 1994; Ardies et al., 2002; Wellner&Bartek, 2003; Boyd et al., 2006; Gibling, 2006).

Incised valley systems also play an important role in sequence stratigraphic interpretations as the base and sides of the valley signify an unconformity and, as such, represent an important criterion for the identification of sequence boundaries (Dalrymple et al., 1994).Originally, Sequence boundaries were defined as regional chronostratigraphically significant surfaces (unconformities and their correlative conformity) formed by a fall in relative sea level, which separate facies that are temporally and physically unrelated (Van Wagoner, 1990). This definition has come under considerable debate as studies on sequence boundaries associated with incised valley systems have been shown to be time trangressive (Strong & Paola, 2008; Bhattacharya, 2011; Holbrook & Bhattacharya, in press). Holbrook and Bhattacharya (in press) have suggested that the Ferron consists of falling stage, forced regressive, stepped incised valleys.They also illustrated that rivers continue to widen their valleys as they fill, illustrating that sequence boundaries progress throughout an entire cycle of relative sea level change. This means that when plotted on a Wheeler diagram, incised valleys do not necessarily separate younger rocks from older rocks but may, in fact, separate rocks that are contemporaneous and not completely temporally and physically unrelated (Van Wagoner, 1990; Catuneanu et al., 1998; van Heijst and Postma, 2001; Törnqvist et al., 2003; Strong & Paola, 2008; Bhattacharya, 2011; Martin et al., 2011; Holbrook & Bhattacharya, in press).Recent studies (Li et al., 2010; Li et al., in prep; Holbrook & Bhattacharya, in press) suggest that falling stage valleys may produce stacked falling stage terrace deposits. This means that older, earlier terrace deposits in a falling stage valley may be closer to the shoreline than immediately overlying younger terraces. This means that successive valley fills will show less marine influence if the shoreline is moving away (Strong & Paola, 2008; Holbrook & Bhattacharya, in press; Li & Bhattacharya, in prep). In an effort to resolve these issues, several complex incised valley fills have been identified in the Cretaceous Ferron Sandstone outcrop in Nielson Wash. These incised valleys will be studied in order to help determine the diachronous nature of their correlative sequence boundaries by looking at allogenic and autogenic controls on valley incision and excision and to examine the idea that in a falling stage valley, older terraces show more marine influence.

Incised valley systems can be filled with a complex array of depositional systems that include open marine to estuarine to fluvial environments (Zaitlin et al., 1994; Posamentier 2001).Therefore, current incised valley models often oversimplify their complex nature (figure 1) (Boyd et al. 2006). Also, models associated with incised valley fills are often aimed at the description of the main trunk channel with little to no regard fortributive valley fills. Currently,Plint and Wadsworth (2003) and Kvale and Archer (2007) are some of the few studies aimed directly at addressing the issue of tributive valleys and their fills. Due to the insufficient amount of information on tributive valley fills, more detailed work needs to be done in order to determine, in detail, the fill heterogeneity of tributive incised valley systems. This information will potentially be valuable in helping to determine the size, shape and interconnectivity of sand bodies associated with incised valleys.The Notom delta of the Ferron Sandstone outcrops along Nielson Wash providing an excellent opportunity to study the 3D facies heterogeneity of compound incised valleys that are constituted of fill from both tributive and trunk valleys. Studying this outcrop would be useful in helping to document sedimentological differences between tributive and trunk channels. This research would also be a valuable contribution for the creation of a facies model for tributive valleys.

INCISED VALLEY SYSTEMS

Posamentier(2001) described Incised Valleys as occurring where a river has eroded deep enough into its own floodplain so that even when the river is in its flood stages, it does not overtop the riverbanks. Incised valley systems, which include both the incised valley and its depositional fill, are defined by Zaitlin et al., 1994 as a“fluvially-eroded, elongate topographic low that is typically larger than a single channel form, and is characterized by an abrupt seaward shift of depositional facies acrossa regionally mappable sequence boundary at its base.”Zaitlin et al., (1994) identified several key elements for the recognition of incised valleys in outcrop. Some of these key elements include: an abrupt basinward shift in facies across a sharp erosional contact that can be traced up onto an interfluve for some distance, and stratal truncation and onlap. However, identifying an incised valley based solely on these criteria can be very difficult. In order to aid in the recognition of incised valleys, Bhattacharya and Tye (2004) have developed a quantitative method to distinguish incised valleys from single channels based on the comparison between total depth of incision and calculated bankfull water depth.

Incised valleys typically occur in response to a variety of variables. Some of the more important variables include: sea-level fluctuations, tectonics and climate (Posamentier, 2001). These controls are what drive base level fluctuations, sediment supply and discharge(Shanley& McCabe, 1994; Holbrook et al., 2006). Changes in base level cause changes in both stream slope and velocity, which, in turn, determine whether the fluvial morphology will be straight, braided, or meandering (Zaitlin et al., 1994; Bridge, 2006). Systems tracts have also been identified based on the fluvial architecture of valley fill and their relationship to shoreface stacking patterns as a function of base level (fig 1)(Shanley and McCabe, 1994).The purpose of this study is to examine complex incised valleys within the Cretaceous Ferron Sandstone along Nielson Wash. The four main objectives of this study will be: 1. to extend previous research in the area to determine and examine changes in cut and fill and channel complexity that may occur across the modern valley wall, 2.examine the diachronous nature of the sequence boundary of incised valley systems , 3. determine if older earlier terrace deposits in a falling stage valley may be closer to the shoreline in the same position as younger terrace deposits and 4.document sedimentological differences between tributive and trunk incised valleys.

REGIONAL GEOLOGY

The TuronianFerron Sandstone Member of the Cretaceous Mancos Shale is made up of several fluvial-deltaic wedges associated with the Cretaceous Western Interior Seaway (Bhattacharya and Tye, 2004). These clastic wedges formed in response to an increase in accommodation resulting from the subsidence of the retroarc foreland basin east of the ancestral Rocky Mountains (Peterson and Ryer, 1975; Gardner, 1995; Garrison & van den Bergh, 2004; Zhu et al., in press).The Ferron Sandstone Member of the Mancos Shale Formation is bounded the Bluegate Shale Member above and the Tununk Shale Member below (fig 2) (Garrison & Van Den Bergh, 2004). The Ferron has also been broken into lithostratigraphic units.

The Ferron Sandstone has been divided into several different clastic wedges (fig 3). The most well-known and well-studied of these wedges is known as the Last Chance Delta (Chidse et al., 2004). However, comparatively less focus has been placed on the NotomDelta, which is very well exposed just north of the Henry Mountains in Southern Utah (Fig4).^{40}Ar/^{39}Ar age dates from sanidine crystals found in bentonite beds throughout theNotom Delta indicate that the delta must have prograded into the seaway approximately 91.25 ± 0.77 Ma (Zhu, 2010; Zhu et al., in press). Radiometric age calculations also showed that the Notom Delta was deposited over a period of approximately 620,000 years. This gives an approximate time span of 100,000 years for the deposition of each sequence (Zhu, 2010; Zhu et al., in press).

PREVIOUS WORK

Previous studies by Zhu (2010) and Li et al. (2010) have shown that the Notom Delta is composed of 43 parasequences that are grouped into 18 parasequence sets (figure 5) (Zhu, 2010). These parasequencessets can be grouped into 6 depositional sequences, which display degradational, progradational, aggradational, and retrogradational stacking patterns (Zhu, 2010; Zhu et al., in press). Zhu (2010) also used the sanadine age dates to show that each sequence lasted approximately 100,000 years. The focus of this study will be on the incised valleys from sequence 1 that erode into the marine sandstones and shales of sequence 2 (fig5).

These incised valleys are well exposed in Nielson Wash, which is located approximately 16 kilometers west of Hanksville, UT along Coal Mine Road (fig 4). Campbell (in prep) and Li et al., (2010) have done extensive previous work in Nielson Wash along the eastern face of the wash and have shown that these incised valleys contain a compound valley fill (fig7). Research by both has shown a clear unconformity that exhibits an anomalous juxtaposition of proximal fluvial sandstone on top of more distal marine facies. In addition, they show evidence of terracing. Measurements taken in the field by Campbell (in prep) show that the depth of incision of these incised valleys is over 2x that of the calculated bankfull flow depths.

PROPOSED RESEARCH

Although, much of the geometry of the incised valleys and the nature of the fill material has been elucidated by the research of Campbell (in prep) and Li et al., (2010) further work can be done by mapping the Western cliff faces of the wash. Mapping the western cliff faces will help expose and determinethe 3D nature and orientation of channels across the cliff wall. This will also be useful for determining if the same order of cut and fill and the same compound nature of the channel exists across the valley wall.

In order to accomplish this, data will be collected in the form of measured sections and digital photographs along the western face of Nielson Wash (fig6 & fig 8). The majority of this data will be collected during the summer of 2012 using a hand lens, rock hammer, tape measure, Jacob's staff and compass. Depositional facies and lithological differences will be determined using grain size, sedimentary structures and trace fossils. Valley-fills will be differentiated based on lithofacies, ichnofacies, sedimentary structures, and overall geometry of the units.Figure 8shows an example of the detailed measured sections that will be taken along the western cliff face. These measured sections will then be correlated and compared across the wash to the previous work completed by both Li et al., (2010) and Campbell (in prep) (fig 7).Paleocurrent direction, channel form, and bar height will also be used to determine bankfull flow depth using the methodology described by Bhattacharya and Tye (2004).

In order to assist in the correlation of measured sections that will be gathered, the base of parasequence 4 has been chosen as the datum. This surface can be easily correlated throughout the study area and is readily identified by a relatively continuous transgressive lag and high amounts of the diagnostic *Glossifungites* at the top.

RESEARCH OBJECTIVES & SIGNIFICANCE

Due to the lackof models associated with tributiveincised valleys, studies of extensive outcrop exposures such as that found in Nielson Wash may help in the in the creation of a model for tributive incised valley systems. The exposure that is found within Nielson Wash will also allow for the documentation in sedimentological and facies differences between trunk and tributive incised valleys, of which very little is known.This study will also extend previous work by Campbell (in prep) and Li et al. (2010) and allow for the examination of changes in cut and fill and channel complexity that may occur across the modern valley wall. Outcrop within the incised valleys will also be used to help understand what allogenicand/or autogenic controls are at work during the cut and fill cycles of single channel storeys. This, in turn, will help evaluate if the sequence boundary created by incised valleys is chronostratigraphically significant, or if it is constantly being modified throughout an entire relative sea level cycle. Finally, falling stage terrace deposits within these complex incised valley system will also be examined to determine if the older, more basal terraces experienced more marine influence than younger terraces. This study will not only be of benefit to the scientific community but would also be of benefit to the petroleum industry, as it may improve subsurface interpretation and the production strategy of incised valleys.

References

Ardies, G.W., Dalrymple, R.W., and Zaitlin, B.A., 2002, Controls on the geometry of incised valleys in the Basal Quartz unit (Lower Cretaceous), Western Canada Sedimentary Basin: Journal of Sedimentary Research, v. 72, p. 602–618.

Bhattacharya, J.P., 2011, Practical problems in the application of the sequence stratigraphic method and key surfaces: integrating observations from ancient fluvial-deltaic wedges with Quaternary and modeling studies: Sedimentology, v. 58, p. 120-169.

Bhattacharya, J. P., Tye, R. S., 2004, Searching for modern Ferron analogs and application to subsurface interpretation, *in* T. C. Chidsey, Jr., R. D. Adams, and T. H. Morris, eds., Regional to wellbore analog for fluvial-deltaic reservoir modeling; the Ferron Sandstone of Utah: AAPG Studies in Geology 50, p. 39-57.

Blum, M. D., and Aslan, A., 2006, Signatures of climate vs. sea-level change within incised valley-fill successions: Quaternary examples from the Texas Gulf Coast: Sedimentary Geology, v. 190, p. 177–211.

Boyd, R., Dalrymple, R.W., andZaitlin, B.A., 2006, Estuary and incised valley facies models, *in*Posamentier, H.W., and Walker, R.G., eds., Facies Models Revisited: SEPM, Special Publication 84, p. 171–234.

Catuneanu, O., Willis, A.J. and Miall, A.D., 1998, Temporal significance of sequence boundaries: Sedimentary Geology, v. 121, p. 157–178.

Gardner, M. H., 1995, Tectonic and eustatic controls on the stratal architecture of mid-Cretaceous stratigraphic sequences, central western interior foreland basin of North America, *in* S. L. Dorobek and G. M. Ross, eds., Stratigraphic evolution of foreland basins: Society for Sedimentary Geology (SEPM) Special Publication No. 52, p. 243–281.

Garrison, J. R. Jr., and van den Bergh, T. C.V., 2004, High-Resolution Depositional Sequence Stratigraphy of the Upper Ferron Sandstone Last Chance Delta: An Application of Coal-Zone Stratigraphy, *in* T. C. Chidsey, Jr., R. D. Adams, and T. H. Morris, eds., Regional to wellbore analog for fluvial-deltaic reservoir modeling; the Ferron Sandstone of Utah: AAPG Studies in Geology 50, p.125-192.

Gibling, M. R., 2006, Width and thickness of fluvial channel bodies and valley fills in the geological record: A literature compilation and classification: Journal of Sedimentary Research, v. 76, p. 731-770.

Holbrook, J.M., and Bhattacharya, J.P., 2012, Death of sequence boundary?Reappraisal of the Sequence Boundary in Time and Space: Case and Considerations for an SU (Subaerial Unconformity) that is not a Sediment Bypass Surface, a Time Barrier, or an Unconformity: Earth Science Reviews.

Li, W., 2009, Valleys, facies and sequence stratigraphy of the FerronNotom Delta, Capitol Reef, Utah [unpublished Ph.D. dissertation thesis]: University of Houston.

Li, W., Bhattacharya, J.P. and Campbell, C., 2010, Temporal evolution of fluvial style in a compound incised-valley fill, Ferron ‘‘Notom Delta’’, Henry Mountains Region, Utah (USA): Journal of Sedimentary Research, v. 80, p. 529–549.

Kvale, E. P., and Archer, A. W., 2007, Paleovalley fills: Trunk vs. tributary, American Association of Petroleum Geologists, Bulletin, v. 72, p. 682-687.

Martin, J., Cantelli, A., Paola, C., Blum, M., Wolinsky, M., 2011, Quantitative modeling of the evolution and geometry of incised valleys: Journal of Sedimentary Research, v. 81, p. 64-79.

Peterson, F., and R. T. Ryder, 1975, Cretaceous rocks in the Henry Mountains region, Utah and theirrelation to neighboring regions, *in* J. E. Fassett and S. A. Wengerd, eds., Canyonlands Country: Four Corners Geological Society Guidebook, 8th Field Conference, p. 167-189.

Plint, A. G., and Wadsworth, J. A., 2006, Delta-plain paleodrainage patterns reflect small-scale fault movement and subtle forebulge uplift: Upper Cretaceous Dunvegan Formation, Western Canada Foreland Basin, *in*Dalrymple, R. W., Leckie, D. A., and Tillman, R. W., eds., Incised Valleys in Time and Space: SEPM, Special Publication 85, p. 219-238.

Posamentier, H.W., 2001, Lowstand alluvial bypass systems: Incised *vs.* unincised: American Association of Petroleum Geologists, Bulletin, v. 85, p. 1771–1793.

Shanley, K.W., and McCabe, P.J., 1994, Perspectives on the sequence stratigraphy of continentalstrata: American Association of Petroleum Geologists, Bulletin, v. 78, p. 544–568.

Strong, N., and Paola, C., 2008, Valleys that never were: Time surfaces versus stratigraphic surfaces: Journal of Sedimentary Research, v. 78, p. 579-593.

Törnqvist, T. E., Wallinga, J., Busschers, F. S., 2003, Timing of the last sequence boundary in a fluvial setting near the highstand shoreline—Insights from optical dating: Geology,

v. 31, p. 279-282.

Van Heijst, M. W. I. M., and Postma, G., 2001, Fluvial response to sea-level changes: a quantitative analogue, experimental approach: Basin Research, v. 13, p. 269–292.

Van Wagoner, J.C.,Mitchum JR., R.M., Campion, K.M., and Rahmanian, V.D., 1990, Siliciclastic Sequence Stratigraphy in Well Logs, Core, and Outcrops: Concepts for High Resolution Correlation of Time and Facies: American Association of Petroleum Geologists, Methods in Exploration Series, no. 7, 55 pp.

Wellner, R. W., and Bartek, L. R., 2003, The effect of sea level, climate, and shelf physiography on the development of incised-valley complexes: A modern example from the East China Sea: Journal of Sedimentary Research, v. 73, p. 926–940.

Zaitlin, B.A., Dalrymple, R.W., and Boyd, R., 1994, The stratigraphic organization of incised valley systems associated with relative sea-level change, *in* Dalrymple, R.W., Boyd, R., and Zaitlin, B.A., eds., Incised-Valley Systems: Origin and Sedimentary Sequence: SEPM, Special Publication 51, p. 45–60.

Zhu, Y., 2010, Sequence Stratigraphy and Facies Architecture of the Cretaceous FerronNotom Delta Complex, Southcentral Utah, USA: PhD Dissertation, University of Houston, Houston, 144 pp.

Figures and Illustrations

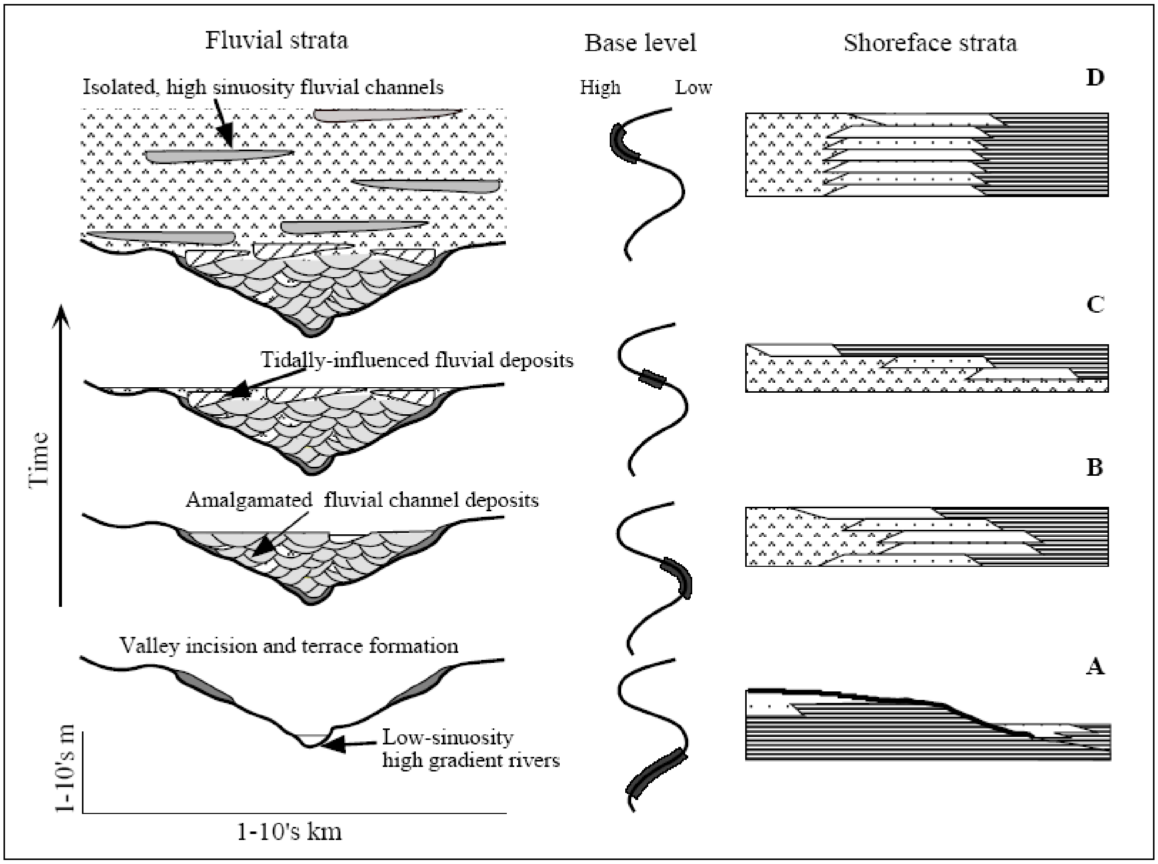

Figure 1.An idealized diagram showing the fluvial architecture of a valley fill and its relationship to shoreface stacking patterns as function of base-level change (from Shanley and McCabe, 1994).

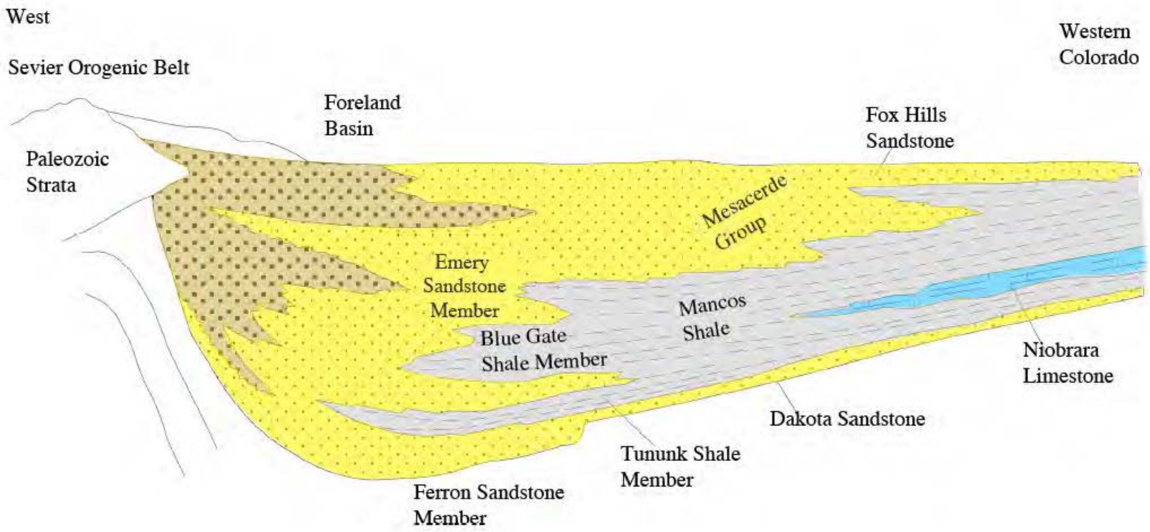

Figure 2. Cretaceous wedge showing the stratigraphic position of the Ferron Sandstone (Modified from Barton et al., 2004 & Hilton, in prep)

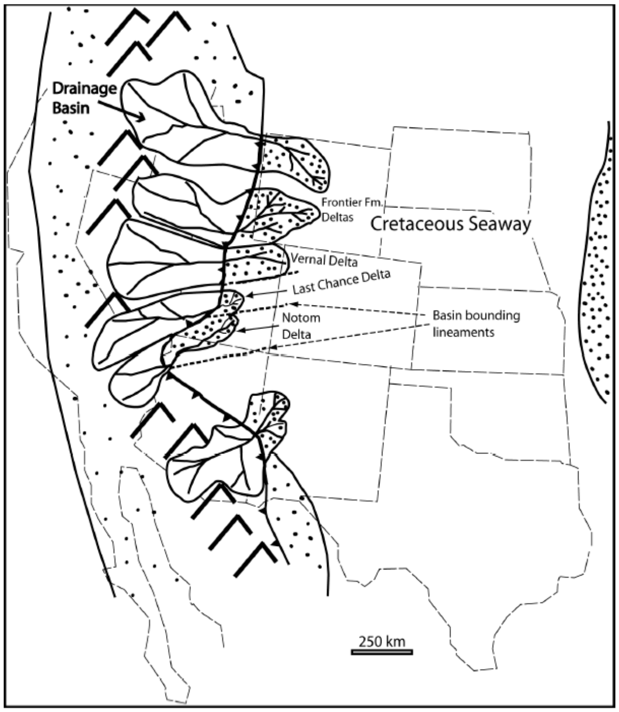

Figure 3. Paleogeographic map of the Cretaceous western margin of North America. Basin bounding lineaments are shown as well as the Notom Delta (from Bhattacharya &Tye (2004), based on Gardner, 1995).

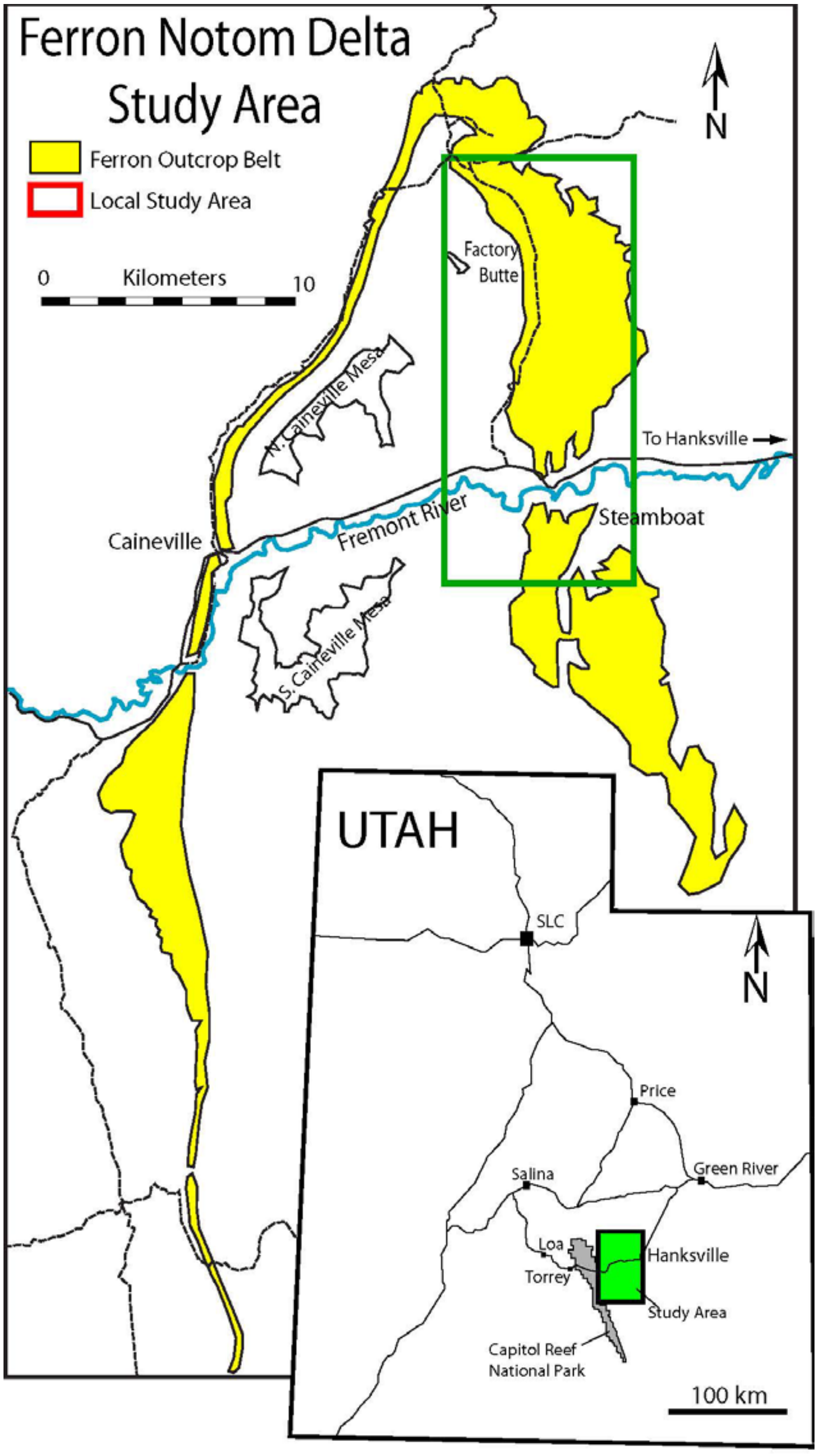

Figure 4. Illustration showing location of Ferron Sandstone outcrop (yellow) along with the location of the study area (red box). (Figure Modified from Zhu, 2010 & Hilton, in prep)

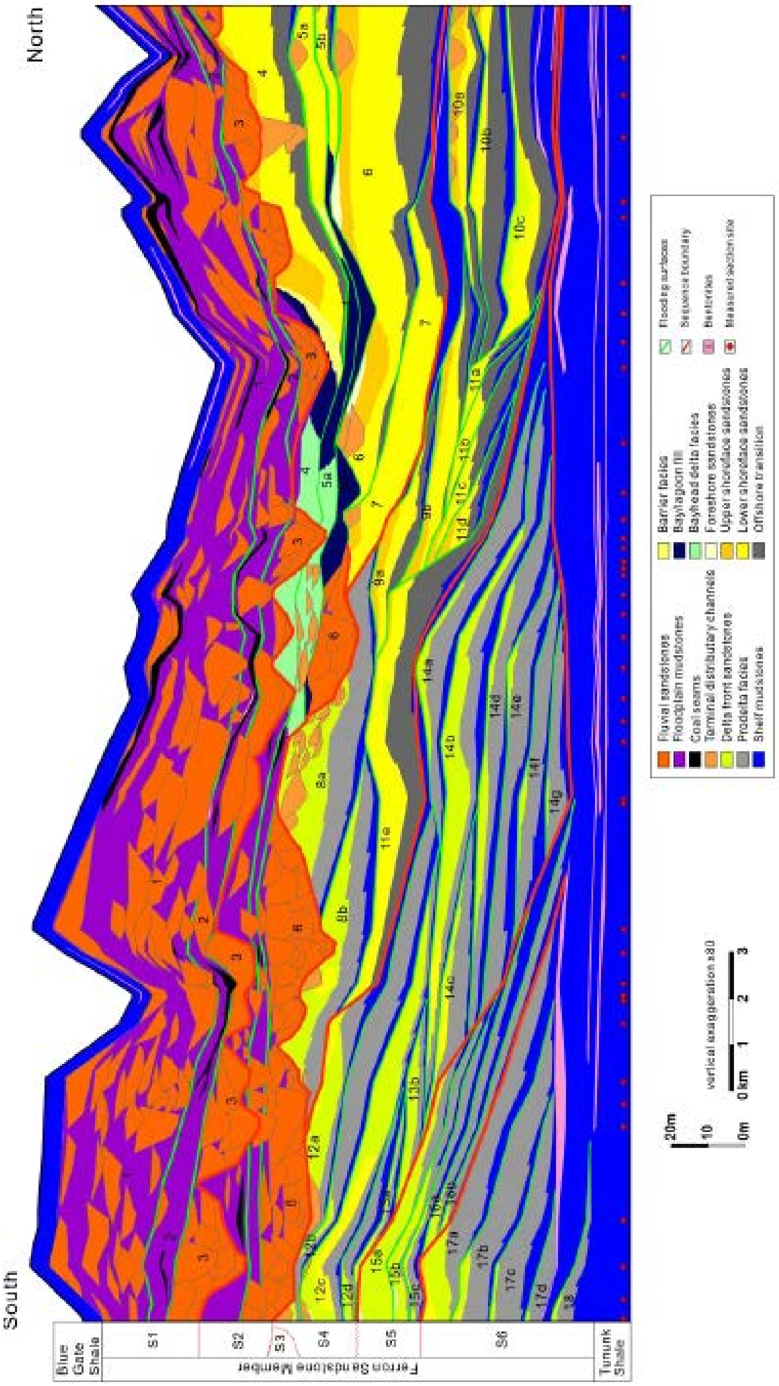

Figure 5. Dip section of the FerronNotom Delta, illustrating the sequence stratigraphy and parasequence sets. (From Zhu, 2010)

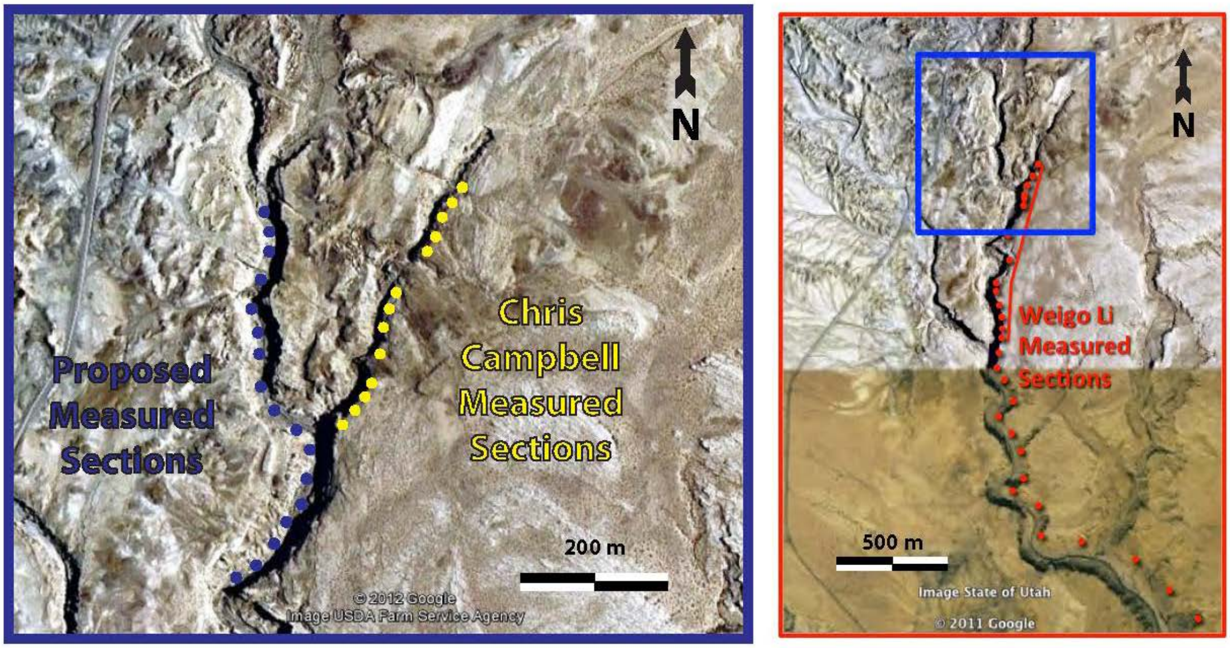

Figure 6. Satellite images from google earth showing Nielson Wash. The figure on the right shows measured sections taken by Weigo Li. The blue box located in the image on the right shows the area displayed in the image on the left. The image on the left shows measured sections taken by Chris Campbell (yellow dots) and proposed measured sections (blue dots).

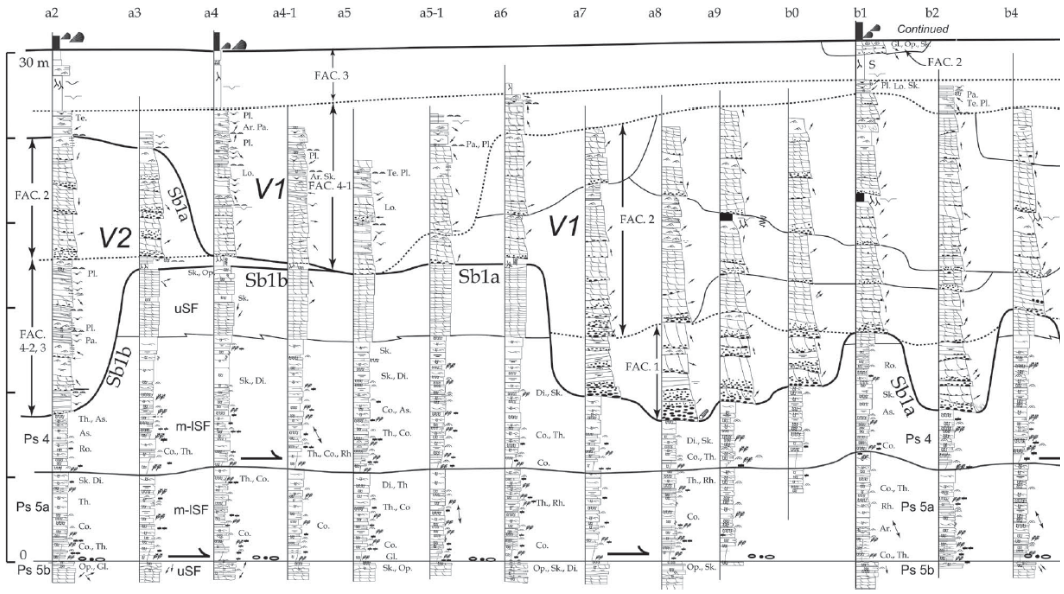

Figure 7. Figure showing measured sections made by Li et al., (2010) along the eastern side cliff face of Nielson wash. Measured sections taken along the western cliff face of Nielson wash will contain the same amount level of detail in order to compare fill patterns and create 3D models.

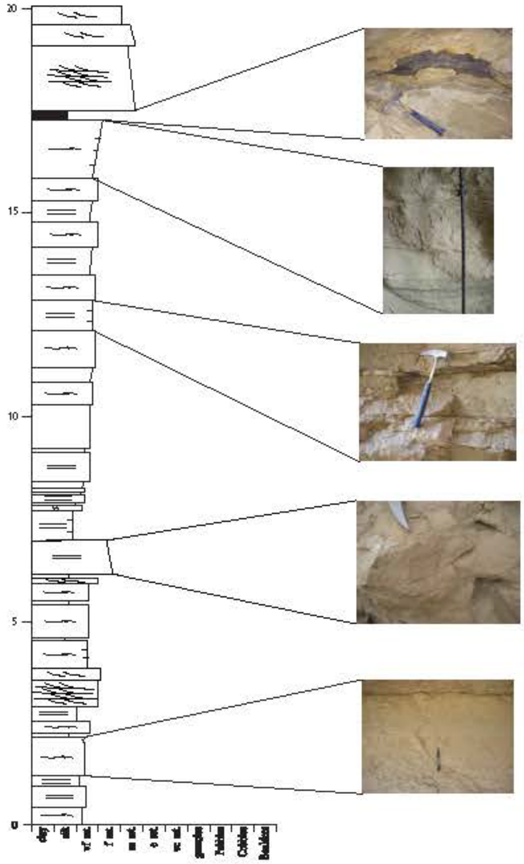

Figure 8. Measured Section taken along the western cliff face of Nielson Wash during Spring Break of 2012.