A REGIONAL ANALYSIS OF THE JURASSIC MORRISON FORMATION IN NORTHEASTERN NEW MEXICO

by

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Chapter One: Introduction

The Morrison Formation covers most of the United States Western Interior and is most famously known for the dinosaur fossils recovered from these strata. Outcropping from New Mexico to Canada, the Morrison Formation covers around 1.2 million km^2 with a latitudinal range of 12 degrees (Maidment and Muxworthy 2019). Owen et al (2015) recently argued that the Salt Walsh Member of the lower Morrison Formation near the Four Corners area is a distributive fluvial system (DFS). Distributive fluvial systems are of interest, partly because they have reasonably predictable trends useful for defining reservoirs, aquifers, and mineral deposits. However, descriptions of the Morrison Formation similar to that available for the Four Corners area of the United States are not available for the eastern exposures of the Morrison Formation. The differences or similarities in characteristics seen in eastern New Mexico will test if the DFS trends seen in the western Salt Wash Member are also seen in the Morrison strata of eastern New Mexico.

The aim for this project is to test whether the deposits of the Morrison Formation in eastern New Mexico are of distributive or tributary fluvial systems. This project will test the distributive fluvial system (DFS) model in eastern New Mexico by identifying architectural variations consistent with this model. This project should test if the eastern Morrison Formation has the same characteristics as the western Morrison Formation, or is potentially a continuation of the DFS seen in the Four Corners area.

1.1) The Morrison Formation

The Late Jurassic Morrison Formation is preserved across the Western Interior of the United States and reaches into southern Canada (Turner and Peterson 2004, Chesley and Leier 2018) (Figure 1). During the Middle to Late Jurassic Nevadan Orogeny, the paleogeography of eastern California and the western most part of Washington was a continental margin where oceanic lithosphere subducted beneath the continental plate to create volcanism and a foreland basin system to the East (Decelles and Giles 1996, Robbins 2009). However, the compressional regime was not consistent throughout the margin. The northern portion experienced an orthogonal compression regime that caused crustal shortening (DeCelles 2004, Owen, Nichols et al. 2015). The south-west margin experienced an almost parallel compressional regime, which resulted in a sinistral strike-

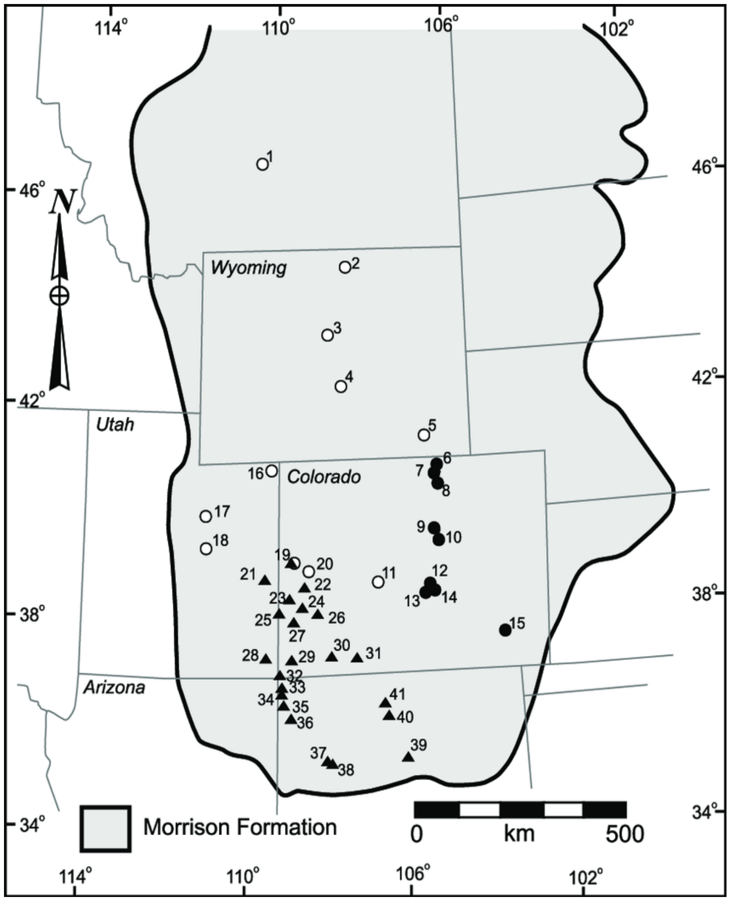

Figure 1. Map showing the geographic distribution of the Morrison Formation across the Western Interior United States based on outcrop exposures and subsurface data. Open circles represent carbonate deposits; dark circles represent carbonate wetland/lacustrine deposits; dark triangles show the Brushy Basin section. https://www.researchgate.net/figure/Map-showing-the-geographic-distribution-of-the-Morrison-Formation-across-the-Western_fig2_223834682

slip intracontinental rifting phase and the Bisbee-McCoy Basin formed (Figure 2) (DeCelles 2004, Owen, Nichols et al. 2015).

With the retreat of the Western Interior Seaway in the Middle Jurassic, clastic sediment was transported from the westernmost highlands to the Morrison Basin. Flexural loading during this event caused the initial development of the foreland basin. This event deposited approximately 200 m of terrestrial sediment during the Late Jurassic

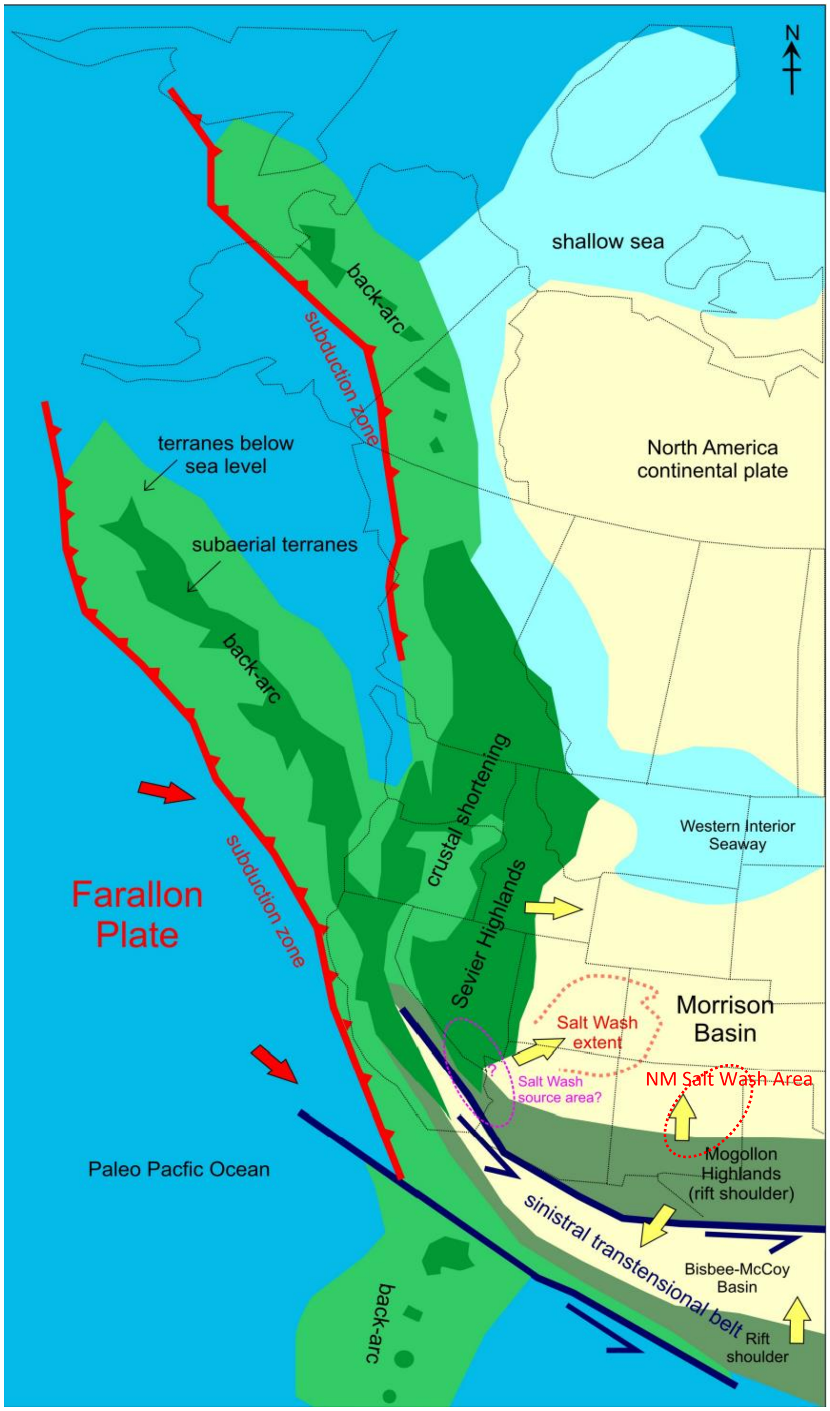

Figure 2. Tectonic reconstruction of North America during the Late Jurassic. Yellow arrows indicate sediment dispersal patterns. Modified from Owen et al. (2015), Blakey (2013) and Turner & Peterson (2004).

as the Morrison Formation (Robbins 2009). Sediment comprising the Morrison Formation derived from the Sevier fold-thrust belt to the west and the Mogollon Highlands to the south, which was deposited in the Cordilleran foreland basin (DeCelles and Currie 1996, Currie 1997, Chesley and Leier 2018). (DeCelles 2004) studied and described the subduction zone to the west that is the controlling factor in creating the initial accommodation space. This process was also responsible for the source area and created a rough north-east migration of sediment into the basin.

The Morrison Formation over most of its southernmost exposure comprises three main members: the lowermost Tidwell Member, the Salt Wash Member, and the uppermost Brushy Basin Member (DeCelles and Burden 1992, Chesley and Leier 2018). The lowermost Tidwell Member is a multicolored mudstone interbedded with sandstone, limestone and gypsum beds. Peterson et al (1988) attributed Tidwell strata to lacustrine, minor eolian, evaporative mudflat, and fluvial environments (see also Kjemperud, Schomacker et al. 2008). The Salt Wash Member of the Morrison Formation is interpreted as being amalgamated meander deposits (Hartley, Owen et al. 2015). The sediment load from the Salt Wash fluvial system in the Four Corners area drained towards the northeast with its sediment load predominantly coming from the Cordilleran Highlands, with a minor contribution from the Mogollon Highlands (Peterson 1984, Robbins 2009). The Brushy

Figure 3. Stratigraphy of the Morrison Formation. Additionally, the Salt Wash Member and Tidwell Member are classified as the Salt Wash DFS (Robbins 2009, Owen 2017).

Basin Member is notably finer grained compared to the Salt Wash Member, and is dominated by overbank siltstones and paleosols. These paleosols are found throughout the Morrison Formation but are very well developed in the Brushy Basin Member (Mullens and Freeman 1957, Tyler and Ethridge 1983, Peterson 1984, Turner and Fishman 1991, Kjemperud, Schomacker et al. 2008, Heller, Ratigan et al. 2015).

The Morrison landscape was dominantly terrestrial with a dry continental climate during the Late Jurassic. Heller et al (2015) notes that the flora of the Morrison Formation was predominantly herbaceous and resembled a savannah with open land and abundant dispersed trees. The climate in the Morrison depositional basin was warm, semi-arid, and seasonal; but became progressively wetter through time, progressing from dry semi-arid in the Kimmeridgian part of the formation to humid semi-arid in the Tithonian. Also, the composition of floras in the Kimmeridgian and Tithonian parts of the Morrison Formation is different, and cannot be viewed as a single vegetational unit over this duration (Heller, Ratigan et al. 2015).

Chapter Two: Processes and Stratigraphy of Distributive vs Tributive Fluvial Systems

Distributive Fluvial Systems (DFS) and Tributive Fluvial Systems (TFS) differ in tangible ways, most fundamentally in their degree of confinement. The degree of confinement of a DFS is much less than that of tributary rivers. Rivers on a DFS are able to shift over relatively wide areas while tributary rivers are commonly confined either within valleys, between DFS systems, or between a DFS and the basin edge (Weissmann, Hartley et al. 2010). These differences cause additional differences in characteristics between rivers on a DFS and those in tributive systems discussed below.

Distributive fluvial systems (DFSs) are arguably the most common of the two styles in modern aggrading sedimentary basins, forming fan-shaped bodies of fluvial sediment in continental basins (Weissmann, Hartley et al. 2010, Chesley and Leier 2018). This system is typical of subsiding continental basins and can be defined by five shared

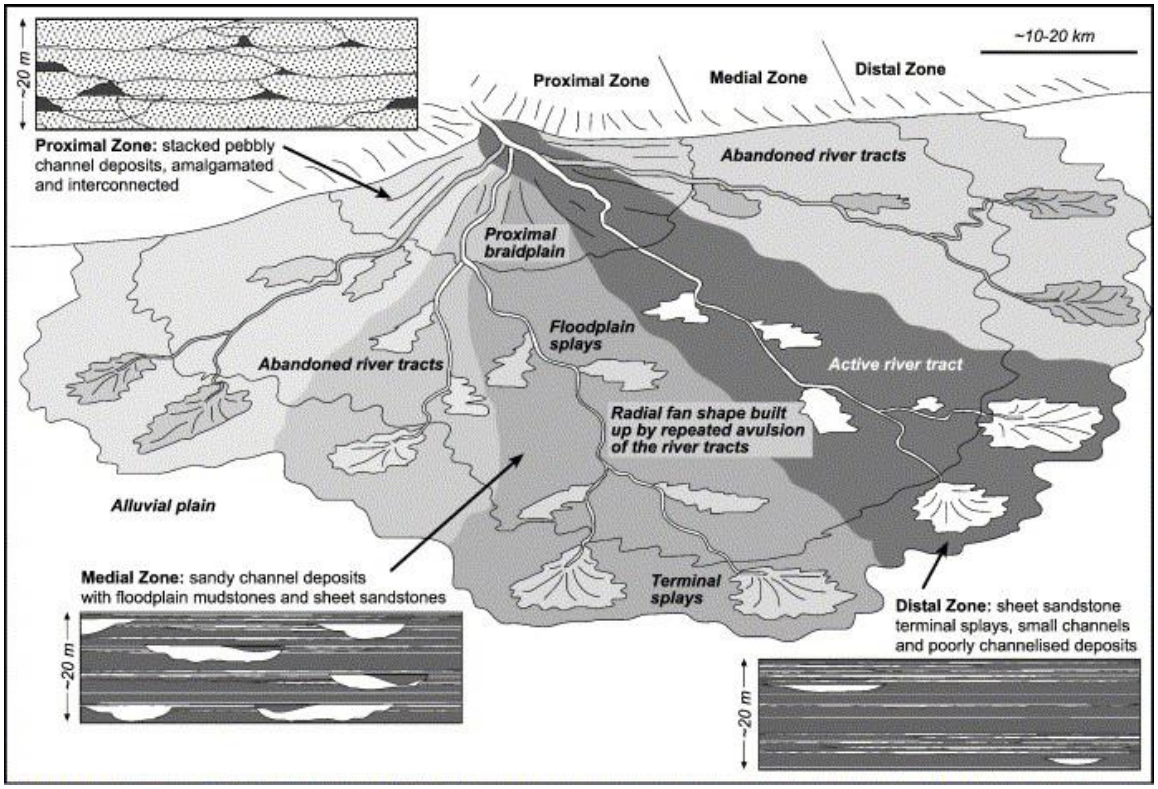

Fig. 4. Development of a fan-shaped body from numerous avulsions of the river channel and architectural elements of the proximal, medial, and distal zones of a fluvial distributary system. Image is from (Nichols and Fisher 2007).

characteristics. DFS systems share 1) channels that radiate from an apex; 2) a decrease in channel size downstream; 3) an increase in preservation of floodplain deposits downstream; 4) a downstream decrease in channel grain size; and 5) a change from amalgamated channel deposits in proximal areas to more separated and smaller channels

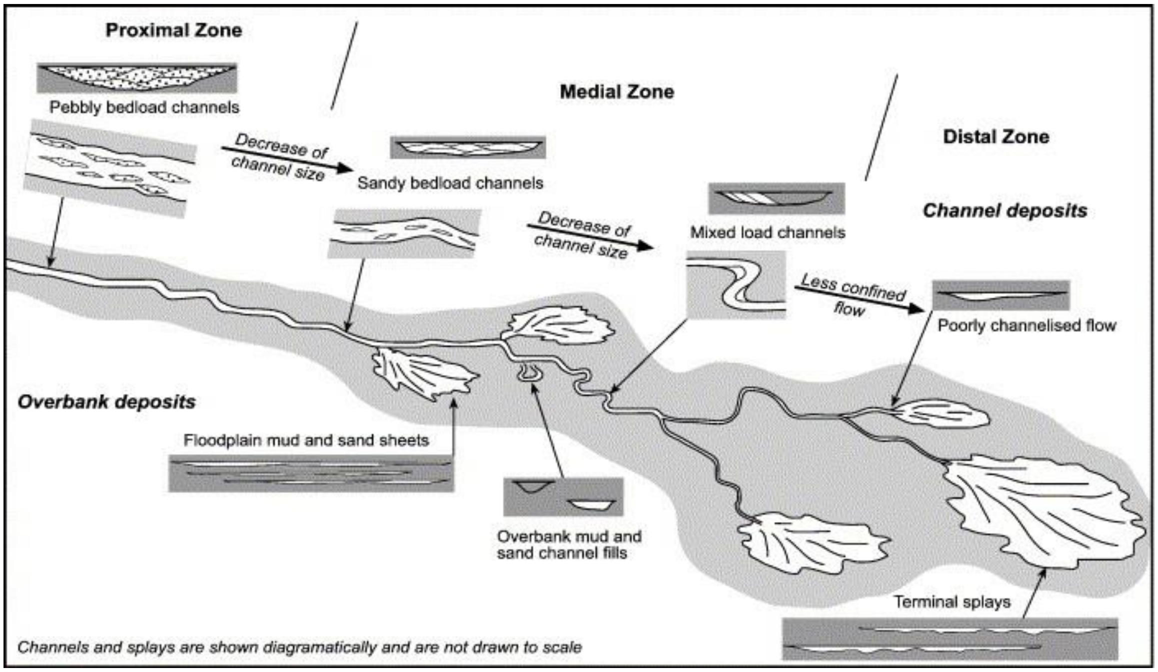

Fig. 5. Proximal to distal trends in channel and overbank processes across a fluvial distributary system: architectural elements, floodplain deposits and overbank deposits. Image from (Nichols and Fisher 2007).

in distal areas (Shukla, Singh et al. 2001, Weissmann, Hartley et al. 2010, Owen, Nichols et al. 2015, Chesley and Leier 2018). Not all channel belts are necessarily active at the same time across the DFS. Rather, the channel belts, both active and inactive, form a radial pattern that distributed sediment across the DFS over time steps (Weissmann, Hartley et al. 2011). These DFSs are typically categorized into three zones: a proximal zone near the apex that is dominated by amalgamated channel-belt deposits; a medial zone with amalgamated channel bodies that are vertically separated by floodplain deposits; and a distal zone comprising predominantly flood-plain deposits and local fluvial channel deposits that rarely amalgamate (Horton and DeCelles 2001, Shukla, Singh et al. 2001, Nichols and Fisher 2007, Weissmann, Hartley et al. 2010, Owen, Nichols et al. 2015, Owen, Nichols et al. 2017). In general, the coarsest deposits occupy the deepest channel fills and are found in the proximal zones. The transition to the medial zone is identified by an increase in overbank facies and decrease in channel-fill facies (Nichols and Fisher 2007). These channel-fill bodies are overall finer grained, consisting mainly of mudrock and thin sheets of sandstone. Channel sheets are amalgamated into sets separated by floodplain deposits (Nichols and Fisher 2007, Owen, Nichols et al. 2017). The distal facies is the most distinctive and is commonly characterized by a high proportion of floodplain facies, with channel-fill deposits encompassing a very small percentage of these strata. Thin sandstone sheets are a distinctive feature of the distal zone, and are commonly of a splay origin. These sheets have sharp, locally erosive bases, suggesting local channelization of flow (Nichols and Fisher 2007).

Long-term preservation of DFS strata requires specific conditions. Nichols and Fisher et al (2007) argued that to preserve a thick succession of fluvial strata the area of deposition needs to have a long history of base-level rise and be generally internally drained. Weismann et al. (2010), however, showed that a DFS does not have to be internally drained and can be exhorheic- as would be the case for the Morrison Formation. Internal drainage is typical in basins which are underfilled and have high rates of

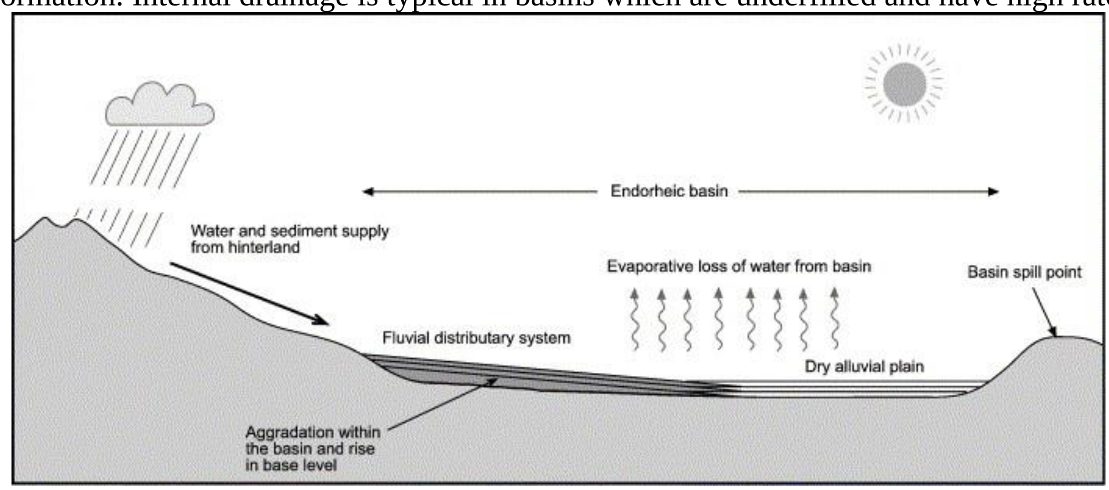

Fig. 6. Tectonic and climate setting for the formation of fluvial distributary systems. Image from Nichols and Fisher 2007.

evaporation. Basins of internal drainage, however, can form in a variety of tectonic settings, such as rift basins and foreland basins. Decelles and Cavazza et al (1990) for instance generalized foreland basin depositional form as comprising megafan deposits, fluvial deposition of inter-megafan rivers that converge to a stream between the megafans, and deposits of an axial fluvial trunk system. The accumulation of a thick succession of fluvial deposits would prevent the development of external drainage (Fig. 6). A moderate water supply is needed to maintain the rivers of the distributary system, otherwise deposits are restricted to smaller fan-shaped deposits. If there is excess water supplied to the basin, a lake will form, and the system will then feed into a lake delta. The rate of sediment supply in distal areas of the basin must exceed the rate of basin-floor subsidence. This ensures base-level will rise in the basin due to the basin filling with sediment, and, therefore, the gradient of the river will be low. The low gradient of the river will promote avulsion and create the fan shaped pattern that many fluvial distributary systems possess (Nichols and Fisher 2007).

Channel bifurcation is a common attribute of a DFS, but not a specific criterion. Bifurcation is where water in a single channel divides into two or more smaller channels, and flow is maintained down the respective anabranches. Bifurcations are found in alluvial fans, braided rivers, lowland rivers, and deltas (Kleinhans, Ferguson et al. 2013). The diversion of water and sediment discharge can be complete, causing a change of direction by diverting the flow into a new course. Many times the flow will enter into an existing channel belt, but other times there will be an avulsion to a new course on the floodplain (Kleinhans, Ferguson et al. 2013). This results in a DFS characterized by distributive channel belts, but with only one or a few hosting an active channel that roughly maintains size down the DFS length. Bifurcations may also be semi-stable, resulting in a DFS with channels of decreasing size but increasing number down the fan length. In both cases, bifurcations generate threads of relatively coarse sediment (Ortiz-Karpf, Hodgson et al. 2015). However, these bifurcations can generate hazards. Bifurcations affect water stability and prompt flooding. A sudden avulsion can cause catastrophic damage – most infamously seen in the lower Yellow River basin in northern China (Shu and Finlayson 1993, Kleinhans, Ferguson et al. 2013).

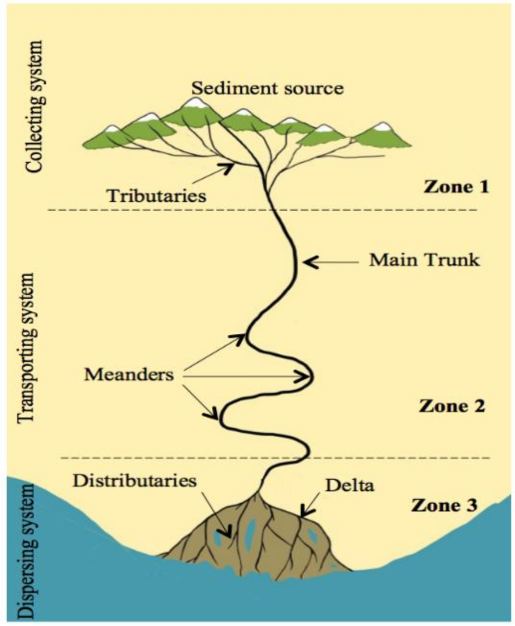

Figure 7. Shows the differences between tributary and distributive fluvial systems. A tributary fluvial system flows into another body of water, while a DFS radiates outward from an apex point.
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A tributary fluvial system (TFS) is defined by flows that do not enter directly into a sea or ocean, but rather flow into another channel. If one river flows into a different river, then the first river is a tributary of the river it flowed into (Figure 7). TFS rivers are typically degradational systems that forms tributaries, as opposed to DFSs that prograde into a basin (Weissmann, Hartley et al. 2011).

Weismann et al (2010) argued for significant differences between tributary and DFS rivers. In an avulsive DFS, channels are not confined within a valley, and radiate outwards from the apex. Channel-belt size only minimally decreases downstream, though this is commonly difficult to observe in the rock record. In DFS systems with stable bifurcations, the river system may bifurcate multiple times down system, creating a large depositional area with abundant vegetated floodplains between each distributary channel belt. In distal areas of the DFS, the individual channels are separated by significant floodplain deposits, resulting in a decrease in channel reworking and increase in preservation of the full channel deposit.

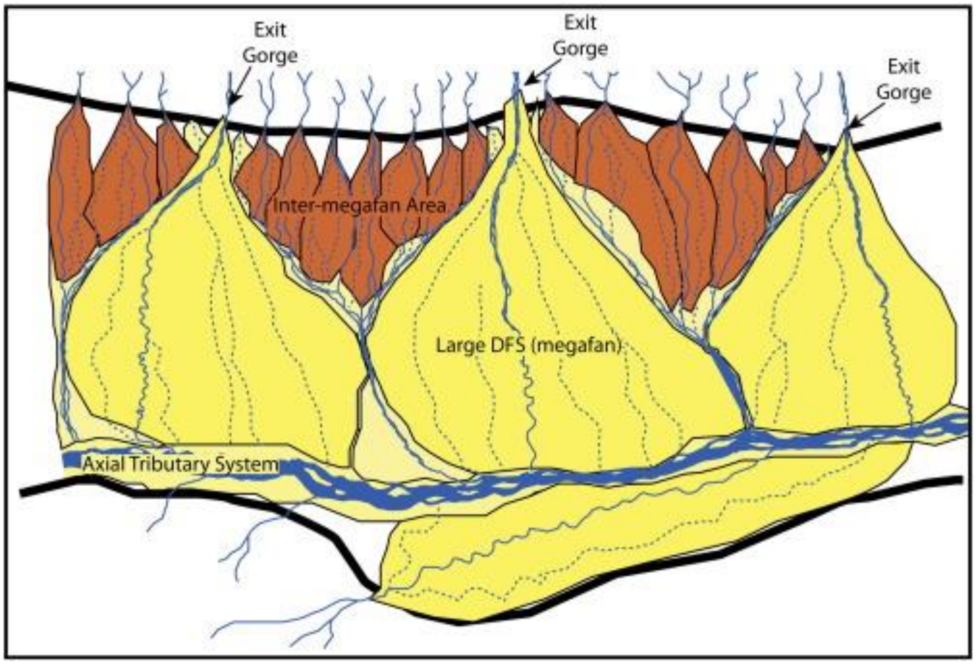


Fig. 8. Diagram showing the geomorphologic elements in a basin. The scale of the features varies with the scale of the basin, but the hierarchical pattern of different DFS sizes will still be present. Image from (Weissmann, Hartley 2011).

Rivers held in the axial position of DFS systems tend to generate amalgamated channel belts. Very little floodplain strata are preserved in this setting, and a coarse-grained, broad channel deposit is preserved (Weissmann, Hartley et al. 2011). Foreland basins with multiple DFS megafans have inter-megafan rivers that converge to an axial fluvial system (Decelles and Giles 1996, Hartley et al. 2011)(Figure 8). The channel-belts within the inter-megafan area tend to increase in size downstream as more streams merge into the axial boundary river. Channel size in this area will be controlled by the number of tributary rivers entering into the basin and the climate (Weissmann, Hartley et al. 2011)(Figure 8). Axial tributary systems can be some of the largest rivers in the world. Large rivers in sedimentary basins are confined between opposing DFS or between a DFS and the basin edge. Axial rivers take on similar form to those in degradational terrains (Weissmann, Hartley et al. 2011). Chute and neck cutoff avulsions, leading to amalgamation, dominate meanders in this position.

Debate remains regarding the dominance of DFS or TFS in basin fill. Weismann et al (2010) suggests that DFS dominate modern fluvial landscapes in subsiding sedimentary basins, while noting that many converge into a trunk system in the basin depocenter. Fielding et al (2010) argue that most of large modern rivers are tributive, and many of them preserve a significant thickness of alluvium beneath and lateral to the modern channel belt. Fielding et al (2010) also argues that the DFS (alluvial/fluvial fans) is more commonly developed on the tilted margins of asymmetric basins (hanging wall of half-grabens, transtensional and foreland basin), and not in the depocenters. He argues that just because DFSs are abundant on the modern landscape does not mean they will be represented well in the ancient. More studies on sedimentary basin fills are needed to test these hypotheses.

2.1) The Morrison Formation of the Four Corners area as a DFS

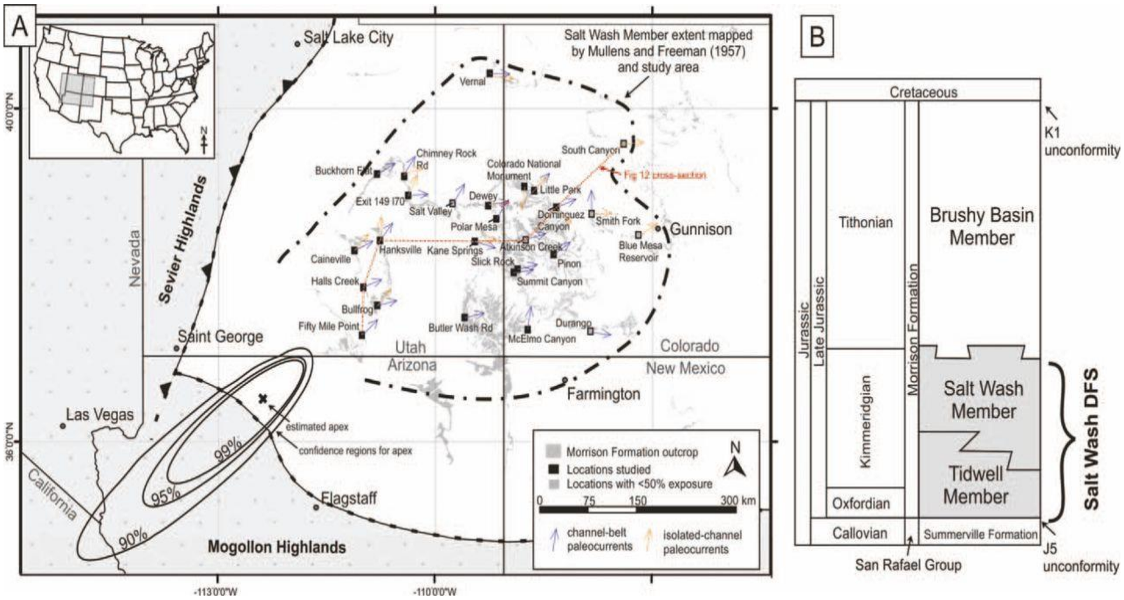


Figure 9. Location of the Salt Wash fluvial system, plus the stratigraphy of the study area. Image from (Owen et al. 2015.)

Owen, et. al. (2015) argued that the Salt Wash and Tidwell members of the Morrison Formation in the Four Corners area collectively record a DFS. The Salt Wash member contains channel deposits that become more dispersed downstream, as well as bearing divergent paleocurrents. This led Owen et al (2015) to conclude that the Salt Wash member preserves channel-belt deposits of a DFS. The Tidwell member comprises a mixture of flood-plain, fluvial channel and lacustrine facies characteristics of distal DFS deposits (Kjemperud, Schomacker et al. 2008, Owen, Nichols et al. 2017). The Salt Wash Member comprises the more proximal areas of the fluvial system and prograded over the more distal Tidwell member (Horton and DeCelles 2001, Turner and Peterson 2004, Kjemperud, Schomacker et al. 2008). Based on these trends, the Salt Wash and Tidwell members are interpreted as deposits of an ancient DFS, which is collectively called the Salt Wash DFS (Weissmann 2013).

The Salt Wash DFS is bracketed by the Summerville Formation and the overlying Brushy Basin member. The base of the Tidwell Member is in a gradational contact with the Summerville Formation. The Summerville Formation was deposited in a shallow-water hypersaline environment during the regression of the Western Interior Seaway (Peterson 1988). According to Owen, et al 2015, the contact between the base of the Salt Wash DFS and the Summerville formation is difficult to define due to the gradational contact. Thus, the base of the Salt Wash DFS is defined as the lowest definitive fluvial deposits (Owen, Nichols et al. 2015). The top of the Salt Wash Member is defined by the integration of recognizable amounts of floodbasin mudstone channel deposits (Peterson 1980, Owen, Nichols et al. 2015). The transition between the Salt Wash and Brushy Basin members can be very approximate. According to Demko 2004, the paleosol unconformity, and the change in color of mudstone from red to green-gray between the Salt Wash and Brushy Basin members, help define a contact for the top of the Salt Wash deposits (Demko, Currie et al. 2004, Owen, Nichols et al. 2015). However, according to (Kjemperud, Schomacker et al. 2008), the Salt Wash Member can occur above the paleosol contact line, making this contact diachronous in some places (Nichols, Owen et al. 2015). It is not known if the Brushy Basin Member is also a DFS. Radiometric dates have not been obtained from the Salt Wash Member. However, the dates obtained from Kowallis et al (1998) indicate that the Salt Wash DFS is one depositional unit but may have occurred as a series of DFS lobes over time (Owen et al 2015).

The groundwork for DFSs on the Morrison Formation has been laid out by Owen et al. (2015) in the Colorado Plateau area. However, there has not been any work to confirm or refute this assertion on these same systems in eastern New Mexico. Nearly all of the work done in eastern New Mexico has addressed stratigraphy and paleoclimate of the area. No extensive research is available on the sedimentary characteristics of eastern New Mexico comparable to that of the Four Corner area. There are sufficient outcrops in this general area to make an evaluation for a DFS and a depositional correlation to other strata in the Western Interior of the United States (Figure 1).

Chapter Three: Objectives and Hypothesis

The objective of this project is to test the DFS model previously described by using lithofacies variations and paleocurrent trends across the eastern Morrison Formation exposures and test if the trends in these rocks match the DFS characteristics like those seen in the Morrison Formation near the Four Corners of the United States. This project will test if these eastern exposures are a separate or related DFS system, or a tributive system. Hypothesis and predictions below will be tested by measuring paleocurrent data, bed thickness, facies characteristics and distribution, grain size measurements, and geomorphologic analysis.

Hypothesis 1

The eastern Morrison Formation is classified as a DFS and has similar characteristics to the Morrison Formation to that seen in the Four Corners area. If so, 1) channels will radiate from an apex; 2) decrease in channel size downstream; 3) increase in preservation of floodplain deposits downstream; 4) channel grain size will decrease downstream; 5) amalgamated channel deposits in proximal areas will transition to more separated and thinner channel fills in distal areas (Weismann 2010).

Hypothesis 2

The eastern Morrison Formation is not a DFS but is a tributive system, unlike the DFS in the Four Corners area. In this case, 1) channels are confined in valleys or central trends and channels systems do not radiate outwards from the apex; 2) preservation of floodplain deposits will decrease downstream; 3) separate channels will amalgamate and generate thicker channel sizes downstream; 4) grain size will be coarse throughout the system and not fine as dramatically down paleodip.

Hypothesis 3

The eastern Morrison Formation is neither a distributive nor tributive fluvial system. In this case, the characteristics observed will have neither of some combination of the traits listed above.

3.1) Methods and Procedures

Representative measured sections were collected across the extent of Morrison exposures on the eastern side of the Rocky Mountains in New Mexico (Figure 10). Outcrops were selected based on exposure quality, and to ensure a representative areal coverage. The overall thickness of the deposit, sand-to-mud ratio, grain size, sedimentary structures, paleocurrents, and bed thickness were measured at each location. The downstream changes in channel belt size were calculated by measuring channel stories, and bar depths at each exposed outcrop. Grain size was estimated in the field by using a grain size card.

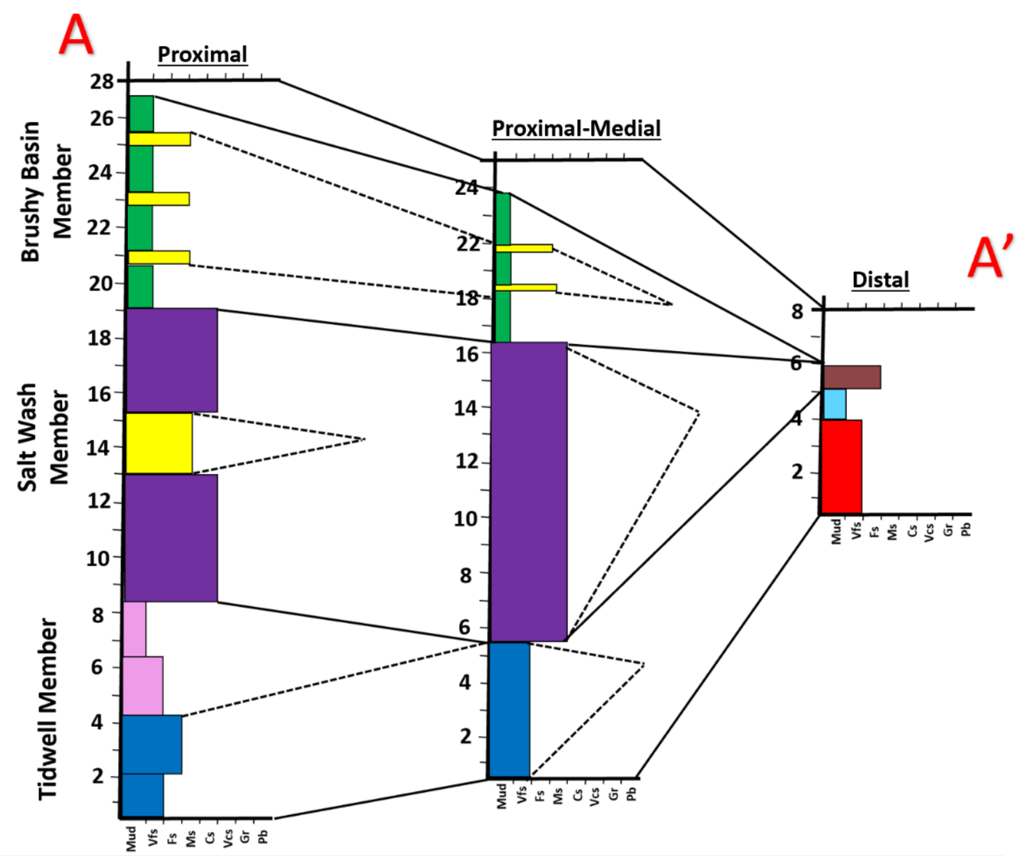
Paleocurrent data were collected from sedimentary structures at three-dimensional surface exposures, and testing for an apex was calculated using the von Mises distribution (Owen et al., 2015). Converging vs. diverging patterns in paleocurrent data define tributive vs distributive flow, respectively. The area of interest of this project ranged from southeast of Tucamcari to the border of New Mexico and Colorado.

Seventeen sites were selected based on exposure quality and areal distribution. Analysis of these sections followed the techniques of Owens et al. (2015) in the Four Corner area. Sand-mud ratios were only calculated for non-covered sections, though covered sections are assumed to be floodplain (Owen, Nichols et al. 2015). Average bed thickness and grain size were only calculated on beds with full exposure. Architectural style is documented in a qualitative manner. Data and interpretations from Totz 2022 were incorporated into this data set.

Chapter Four: Results

4.1) Thickness Trends in the Morrison Formation

The thickness of the Salt Wash Member of the Morrison Formation varies moving downstream. A downstream thickness change in the Salt Wash fluvial system is observed in Figure. 10, with a maximum thickness of approximately 9.8m-12m being recorded in the proximal-medial areas, and a minimum thickness of 3m recorded in distal areas. In Figure 10, the Salt Wash member is thickest in the southwestern zone of the AOI and gradually thins to the northeast. The evidence of amalgamated channel belts with little to no floodplain deposits between channels in the proximal-medial zones indicate true division of these zones was not recorded. A northeastern paleocurrent measurement of the Salt Wash member suggests that the floodplain becomes more dominant in the northeastern edge of the study area. The Tidwell member becomes more prominent in the northeastern area of the study area. As the Salt Wash amalgamated channels thin out, they are replaced by lacustrine deposits. This suggests that a downstream change from Proximal-Medial-Distal is present in the Morrison Formation in northeastern New Mexico. Lateral thickness variations in the Salt Wash member were not recorded, because of lack of complete exposures. A W-E cross-section is shown in Figure 10B for reference, but a true trend along this line was not observed. Sections within the north-western sector are observed to be considerably thinner than sections in the south-eastern



section of the fluvial system. However, measurements of these deposits were not possible because of access to private land.

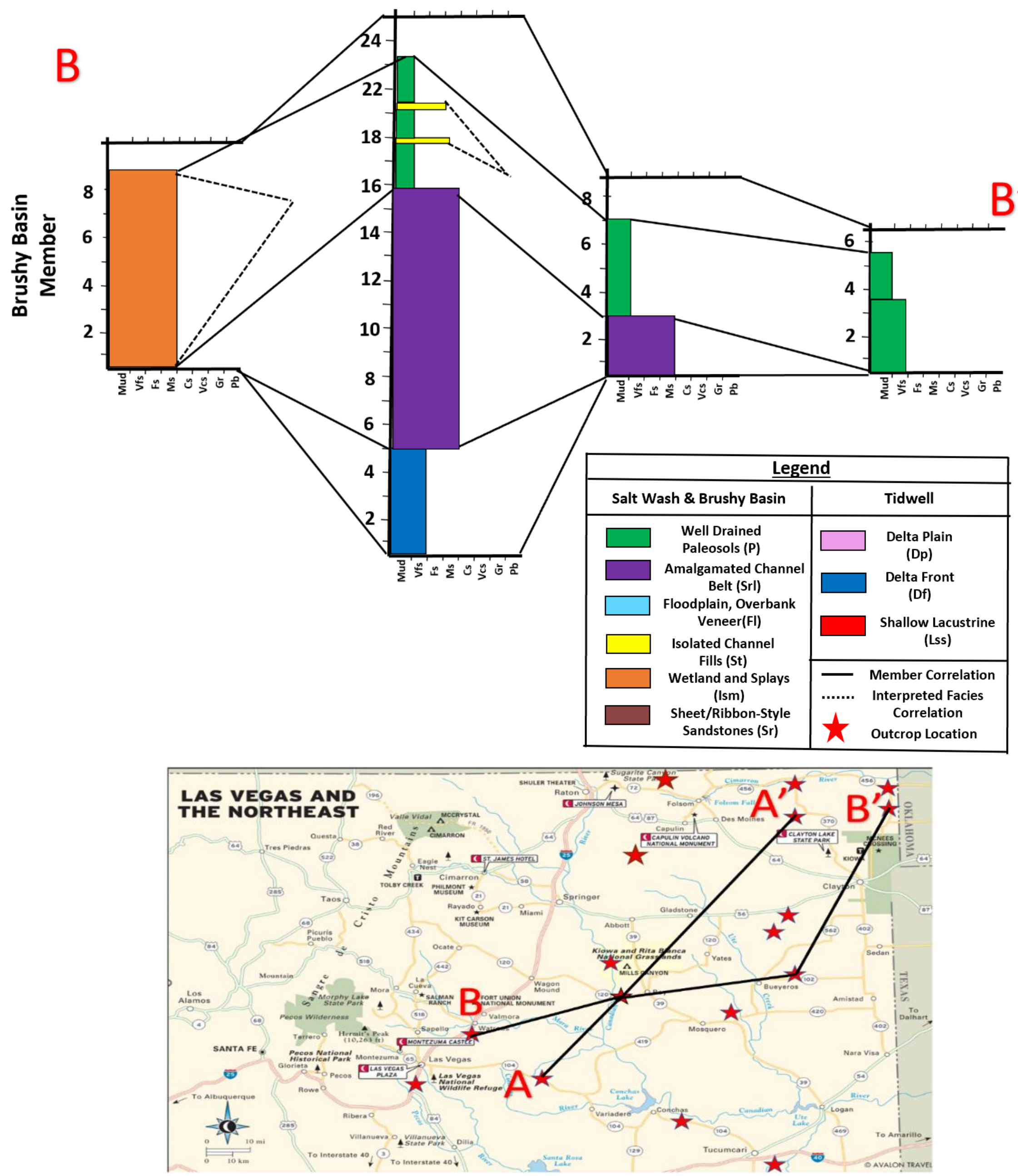
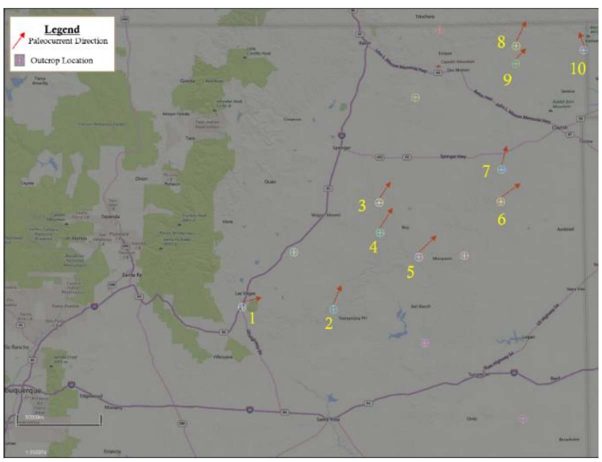


Figure. 10 A-A' and B-B' cross-section show thickness variations of the Morrison Formation in north-eastern New Mexico. A map of the study area with A-A' and B-B' is shown with outcrop locations. Members and lithofacies are drawn to illustrate the thickness variation moving to the northeast and West-East of the study area. Depositional environments and interpretations of facies are listed in the legend. Lithofacies association descriptions can be seen in Table 2.

4.2) Paleocurrent Analysis

The data analyzed is taken from cross-laminations and edges of scours and channels to determine orientation and direction of flow. Paleocurrent readings are averaged from at least twenty-five measurements where data is accessible. The rippled and laminated sandstone (Srl) and planar bedded sandstone (Sr) lithofacies have a linear paleocurrent pattern with a general north-eastern direction. The paleocurrent readings appear to originate from a Mogollan Highland source area. An apex is not derived in this study, as much more data laterally would be needed to lend accurate results. The linear paleocurrent is consistent with a single general vector down a more radial DFS system, but does not confirm a DFS system. More strike-oriented data would be needed to confirm or refute a radial DFS paleocurrent pattern. With the data that is recorded, the paleocurrents confirm down dip was toward the northeast for the Salt Wash fluvial system. A weak subtrend contrasts the southern and northern areas, with that the southern portion recording approximate reading of N30-60E, while the northern portion of the study area is approximately N6-23E.



Outcrop Location	Average Paleocurrent
1	N78E
2	N23E
3	N34E
4	N32E
5	N46E
6	N55E
7	N15E
8	N08E
9	N06E
10	N23W

Figure. 11 Paleocurrent measurements at recorded outcrop locations in north-eastern New Mexico. A general north-eastern trend can be observed. Two potential locations in this study that could change paleoflow. Time and accessibility did not allow for measurements at these spots. **Table 1** Average paleocurrent readings from ten outcrops within the AOI. Measurements are taken from at least twenty-five data records at each outcrop.

4.3) Tidwell Lithofacies Associations

The Tidwell member of the Morrison Formation is lacustrine interbedded sandstone and mudstone. The Tidwell member has contrasting lithofacies with the remaining Morrison Formation, but is conformable beneath the Salt Wash member. The Tidwell is here assigned lithofacies associations:

The following three facies associations were described at the locations in northeastern New Mexico: 1) Lss (Shallow Lacustrine) 2) Dp (Delta Plain) 3) Df (Delta Front) (Figure 12)

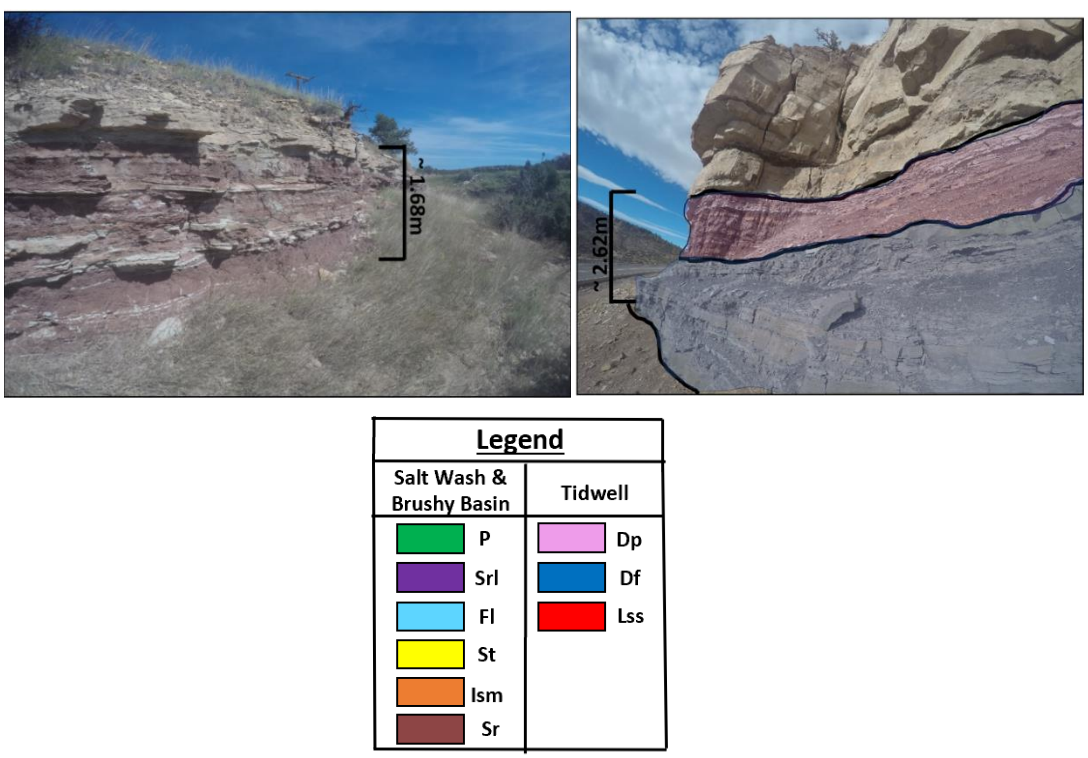


Fig. 12 Measured sections of the Facies Associations of the Tidwell member. To the left is the Shallow Lacustine Association and to the right is the Delta and lower Delta Plain. Highlighted in purple is the Delta Plain and highlighted in blue is the Lower Delta plain.

Shallow Lacustrine (Lss) is defined by its unique red shale and rooting at the top of the section. The Delta plain and lower delta plain are separated by alternating sandstone beds in the lower delta plain. Highlighted in purple is the Delta Plain which is characterized by its very fine sandstone and mudstone layers (10-25 cm) . The Lower Delta Plain is different from the Delta plain because of the cycles that can be seen throughout the section.

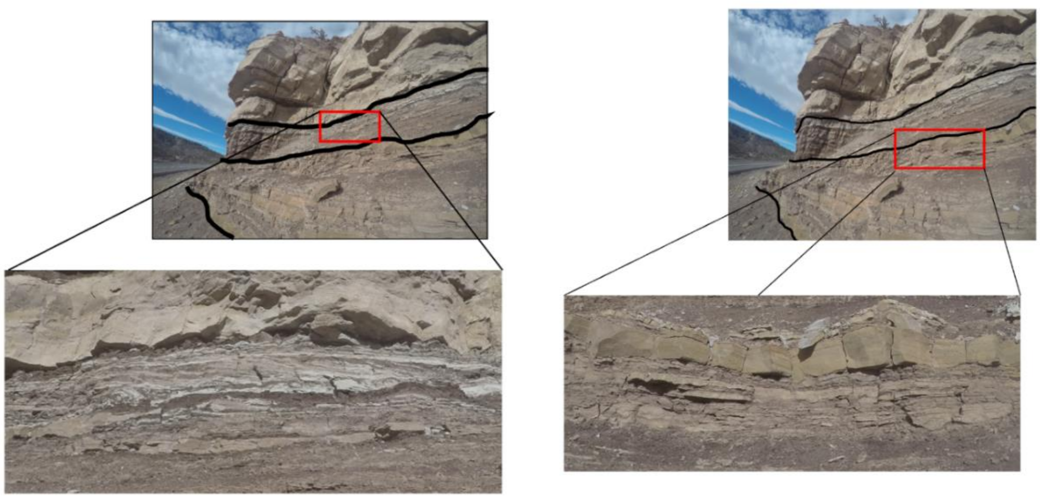


Fig. 13 Differences in the Delta Plain and Delta Front deposits. Very fine cemented sandstones with minor gypsum in the Delta Plain vs. cyclical sands in the Lower Delta Plain

Shallow Lacustrine Association (Lss)

The shallow lacustrine facies association has an undulating to tabular geometry and is less than 1.3m for the largest bed, indicating that this is a minor unit of the Morrison Formation. The primary lithofacies is red horizontally laminated fissile shale with vegetation and rooting recorded at the top of the section (Figure 14). Horizontal laminated shale is approximately 0.2m-0.5m thick and shows faint parallel laminations.

Fig. 14 Shallow Lacustrine Facies Association. Red horizontally laminated fissile shale with vegetation at the top of the unit.

The Shallow Lacustrine facies is commonly associated with the floodplain association. The presence of the floodplain shows that the lake is not a predominant feature of the Morrison and is a temporary deposit throughout the system during wetter periods. The cycles recognized in the deposit could be the result of alternations in lake level, meaning there was a more permanent section of the lake that was controlled by climatic cyclicity (Rogers and Astin 1991). Turner and Peterson (2004) noted that the upper Jurassic mainly exhibited a dry climate. Therefore, these lakes most likely formed in depressions of the floodplain and built-up during flash floods before drying out. These deposits are predominantly found at the base of the Tidwell member, underlying the Salt Wash member.

Delta Plain Association (Dp)

The delta plain facies association predominantly comprises horizontal laminated muds with well-cemented fine sandstones. A general fining upwards trend was also recorded in the Tidwell member.

Fig. 15 Upper section of Tidwell member described as delta plain. Horizontal laminated muds with upper well-cemented sandstones to the Salt Wash.

The upper contact of the Salt Wash consists of very fine sandstone beds.

Alternating down-section are horizontally laminated muds and planar laminated sandstones. The sandstone beds seen are approximately <0.1 m thick, while the laminated mud sections are approximately ~0.3m in thickness.

The very-fine grained sandstones and laminated muds record a calm environment where the extension of the ancient fluvial system met the lacustrine system.

Delta Front (Df)

The lower delta plain comprises fine-grained, rounded to sub-rounded, brown-to-grey weakly confined channel fills (0.2-0.5 m thick) within cyclic parasequences of interbedded mudstone and sandstone beds (8-12 cm) with mud drapes.

These environments are at or near lake level, and the overbank regions received repeated deposits of muds and sands to build up the land surface as the delta subsided below lake level. The presence of alternating sandstone and mudstone beds, and the lack of burrowing, indicates a shallow lacustrine environment.

Fig. 16 Lower section of Tidwell member described as the lower delta front. Wave rippled sandstones alternating with mud deposits.

4.4) Lithofacies Associations– Salt Wash and Brushy Basin

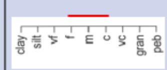
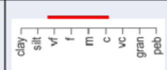
Lithofacies	Lithology	Grain Size	Sorting	Bed Geometry & Structures	Interpretation
Rippled and laminated sandstone (Srl)	Fine-coarse grained, rounded to sub-rounded, grey-brown		Moderately-to-poorly sorted	Bed Thickness: 1.2-3.4m Bed geometry: Lenticular bedded Structures: Current ripple-lamination dominates. Minor Structures: Horizontal planar laminations and mud drapes	Amalgamated channel belt
Planar bedded Sandstone (Sr)	Fine-coarse sand, moderately sorted, sub-rounded, commonly white to brownish in color.		Well sorted	Bed Thickness: .5-2.3m Bed geometry: Tabular bedded Structures: Planar cross-laminations and horizontal laminations	Sheet/ribbon style sandstones
Cross-Laminated Sandstone (St)	Fine-coarse grained, moderately sorted with grains being sub-angular to rub-rounded. White-reddish in color		Moderately sorted	Bed Thickness: 1.2-1.9m Bed geometry: Tabular bedded Structures: Trough cross-bedding, planar cross-laminations, horizontal laminations	Isolated channels fills
Interbedded Sands and Muds (Ism)	Grey-green mudstone with reddish brown sandstone very fine-coarse sand		Poorly sorted	Bed thickness: .2-.5m Bed geometry: Tabular bedded Structures: Horizontal laminations dominate. Mudstone has faint ripple laminations	Wetland, Splays, Overbank
Mudstone with Soil Profile (P)	Red-brown well-drained argillic calcisols. Green–gray. Mixed siltstone and mudstone		Well sorted	Bed thickness: .3-1.8m Bed geometry: Structures: Platy soil structure with burrows and rootlets	Well drained paleosols
Mudstone (Fl)	Grey-green very fine-fine mudstone		Well sorted	Bed thickness: .3-1.8m Bed geometry Structures: Platy soil structure with no burrows or rootlets	Floodplain, overbank veneer

Table 2 Summary of the facies used in this study.

Rippled and laminated Sandstone (Srl)

This lithofacies comprises of fine-to-coarse grained, rounded-to-sub-rounded, grey-brown sandstone beds (Table 2). The wave-rippled laminations match the description given by (Allen 1984). These structures are formed as a result of oscillatory motion within the water column (Bagnold and Taylor 1946). The abundance of ripple-laminations within fine sandstone indicates that a relatively low energy regime existed where entrainment stress was sufficient to sediment but not beyond ripple-forming conditions (see Owen et al. 2015; and (Mckee and Middleton 1965). The local thin mud drapes suggest that flow velocity dropped low enough for the settling of mud, which can be seen throughout the Salt Wash unit. The co-existence of current ripple-lamination and horizontal laminations within beds indicate that flow was dominantly in one direction.

Horizontal laminations, as noted by Owen 2015, can form under two different flow conditions. (Allen 1964) studied variations of plane beds within the Lower Old Red Sandstone and experimentally demonstrated the horizontal laminations forming as part of upper flow regime conditions. However, horizontal-laminations can also be produced under lower flow regime conditions, as noted by (McBride,1974). In this study it is suspected that well defined horizontal laminations are the product of upper flow regime conditions, with the contrary being that less defined laminations are the byproduct of lower flow regime conditions. The presence of rippled laminations and horizontal laminations indicates there were minor fluctuations in flow velocity during deposition within and between beds.

Figure. 17 A) small ripple-laminations within the Srl facies. B) Poorly defined horizontal

The Srl facies is commonly seen in the proximal areas of the Salt Wash. The Srl facies is interpreted to be fill of amalgamated channel belts, with channels ranging in thickness from 1.5-2.5m in thickness. Multi-story amalgamated channels give the insight that this is a high energy environment that is likely to be located more proximal to the sediment source.

Planar Cross-Laminated Sandstone (Sr)

This facies comprises of sediment that ranges from veryfine-to-medium sand, where normal grading is common within the beds (Table 2). The presence of cross-lamination suggests that the deposition of units occurred from a bedload deposit in which there was a unidirectional dune flow conditions within a lower flow regime. Based on the classification from (McKee and Weir 1953), the planar-bedding cross-stratification can be termed as tabular cross-lamination owing to the asymmetric, straight, cross-strata that is interpreted to have been formed from small scale sand waves (Yeganeh, Feiznia et al. 2012). Cross-sets observed were deposited in a relatively homogeneous flow within the lower flow regime. As discussed in the previous section, horizontal laminations could represent upper or lower flow regime conditions, meaning that there were either increases or decreases in flow velocity during the depositional processes.

Normal grading suggests that there was a decrease in flow velocity or there was a

Figure. 18 Planar cross-stratification. Planar upper surface with asymmetric, straight, tabular nature of cross-strata underlying it.

decrease in sediment supply. The sharp lower contact indicates deposition onto previous deposits with little to no incision.

The Sr facies is commonly recorded in the distal portions of the Salt Wash. The Sr facies is interpreted to be ribbon/sheet style sandstone beds, with the channel thickness approximately 1.07 m. Sr lithofacies is found in the distal portions of the study area.

Tabular Sandstone (St)

The St lithofacies comprises of fine-to-coarse grained sand and is moderately sorted with grains being sub-angular to sub-rounded (Figure 13).

The St facies is interpreted as isolated channels fills and overbank sheet sandstone beds. The channel belt sandstone beds are commonly seen in the proximal units of the Brushy Basin, while the sheet sands are more common in the medial to distal parts of the Brushy Basin Member (Figure 19). Sam Totz attributes these channels as single-story and are similar in nature to fixed, anastomosing, or meandering river channels, also noted by

(Kjemperud, Schomacker et al. 2008, Owen, Nichols et al. 2015, Maidment and Muxworthy 2019).

Figure. 19 Tabular sandstone, isolated channel fills, and sheet sandstones. Interpreted to be overbank sheet sand deposits

Interbedded Sandstone and Mudstone (Ism)

The Ism facies records splay deposits in a wetland environment. It consists of thin sheet sandstone beds, and small confined channel fills with interbedded mudstones (Figure 20). The horizontal laminated sands could represent upper or lower flow regime, as discussed before, that temporarily decreased in velocity enough for mud to settle out and deposit with the channel fill sands. This lithofacies is commonly recorded in the medial portions of the Brushy Basin. The Ism facies is ribbon/sheet-style sandstones, with the channel thickness approximately 1.07 m thick.

Figure. 20 Interbedded sand and mud. Interpreted as wetland or splay deposits.

Floodplain Facies (P and Fl)

Facies P and Fl are similar (Table 2), but with a few key differences. The P lithofacies is defined by well-drained and poorly drained floodplain soils. This facies is very identifiable by highly developed paleosols with a distinct red-green color. Fl lithofacies are identified by green-grey siltstone-to-mudstone beds with a higher occurrence of sand sheets than P. Lithofacies Fl is also identified by its grayer color and lesser rooting, with less soil development noticeable. The two lithofacies are thus gradational with each other, contingent on the degree of pedification.

The P lithofacies is predominantly mud dominated with some minor and regionally dispersed sandstone beds. Sandstone abundance is attributed to the proximity of the channel, the sediment supply, or the magnitude of floods (Pizzuto 1987, Guccione 1993, Owen, Nichols et al. 2015). The floodplain association in NE New Mexico generally lacks the “red, to red-brown well-drained calcisols” seen in the Four Corners area. The floodplains on which these calcisols formed underwent intermittent periods of low accommodation and low sediment supply (Maidment and Muxworthy 2019). This allowed the paleosols in lithofacies P to be exposed to the surface for long periods of time and to develop distinct soil horizons. This exposure allowed well-drained paleosols to produce more oxidized, reddish mudstones, where the poorly drained floodplains produced green mudstones through less oxidation (Totz, 2022).

Lithofacies Fl differs from lithofacies P in its lack of distinct soil profiles. Fl comprises the green-gray mudstone but lacks well-developed rooting or burrowing. It was deposited during a time when sediment supply approximately equaled accommodation, and distinct soil horizons did not form (Maidment and Muxworthy 2019). This Fl lithofacies is interpreted as aggrading floodplain overbank mud veneer.

4.5)Architecture Analysis of the Salt Wash Member of the Morrison Formation

Figure. 21 A) Mudstone with no soil profile (Fl). B) Mudstone with soil profile (P)

Salt Wash Architecture and Facies – Proximal

The up-dip/proximal zone of the Salt Wash is represented by the Trujillo Hill outcrop. The proximal zone of the Salt Wash in this study is rippled and parallel laminated sandstone beds (Srl) with minor pockets of tabular sandstone beds (St) (Figure 22). The Delta plain (Dp) is mostly continuous within the Tidwell member along the bottom contact of the Srl unit. Two out of the main six lithofacies are represented in this outcrop. Srl is common throughout the outcrop as both channel-fill and sheet sands. St is present as thin sheet sands within floodplain silts and muds.

The Trujillo Hill outcrop (Figure 11) exposes amalgamated upper and lower channel belts, separated by an interval of mixed channel fill sands and floodplain deposits between. The upper and lower channel belts range from a thickness of 1.4m - 4.3m thick and are laterally continuous. Sandstone beds contain clearly defined parallel and ripple

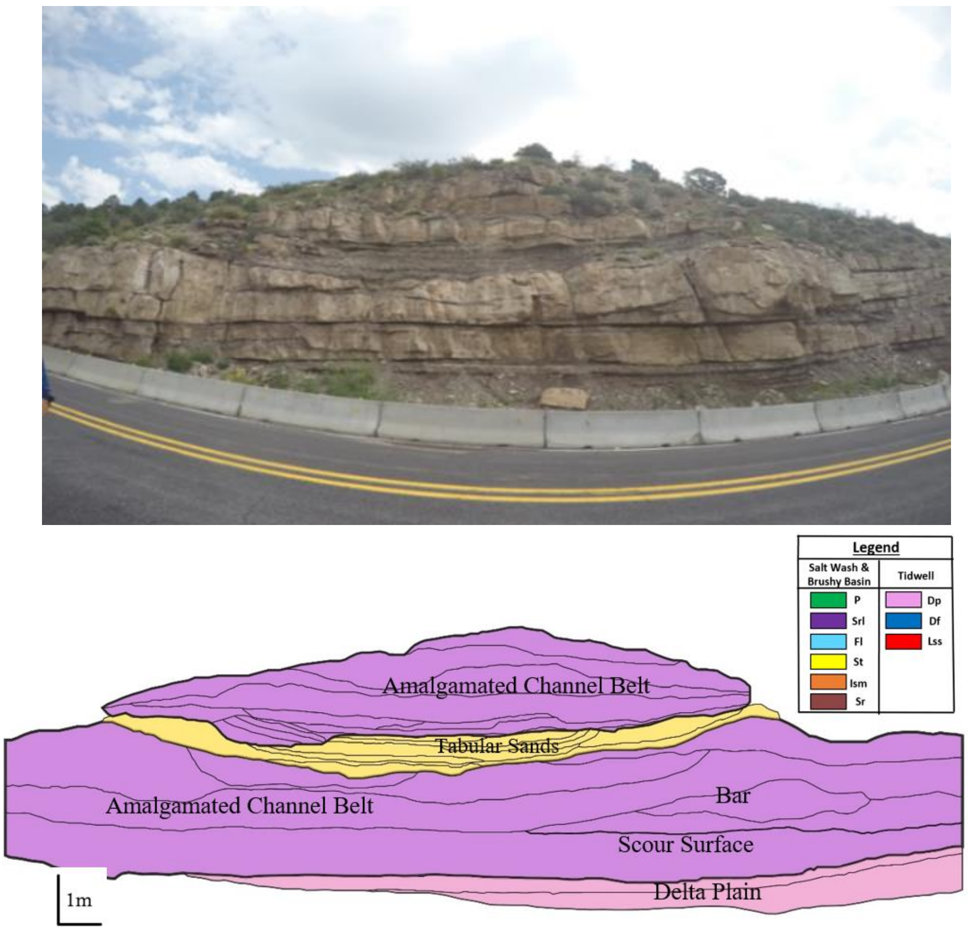


Figure. 22 Salt Wash outcrop at Trujillo Hill. The thicker outer lines are denoting channel belts, while the thinner lines are showing the channels within the belt. The image to the left is the initial outcrop image to the right. The image to the right is a lithofacies assemblage with architecture work.

laminations of lithofacies Srl. In the center of the outcrop (Figure 22) there are alternating sand and mud layers, which are approximately <.1m in thickness each. The lower channel belt architecture of this sandstone is relatively complex, with multiple vertically and laterally stacked, amalgamated fluvial channel stories. Sam Totz completed similar architectural work on the Salt Wash Member at Canadian River Ranch and Mills Canyon and noticed a network of first and second-order bedding surfaces within the amalgamated deposit, similar lithofacies being present within the channel belt (Srl and St), and was in the proximal-to-medial zone of the study area.

Salt Wash Analysis - Proximal Zone

Influx of sediment supply caused avulsion and amalgamated vertically stacked channels creating mappable scour surfaces near the underlying deltaic facies (Figure 22). St lithofacies deposited during reworking of channels, limiting preservation for floodplain materials. An average paleocurrent direction of N23E was recorded at this unit, and a notable thinning of both deposit thickness and channel body thickness is noted moving to the northeast. The proximal zone is different from the proximal-medial zone by the thickness of both the amalgamated channel belts and channel sizes.

Salt Wash Architecture and Facies - Proximal-to-Medial Zone

The medial zone is characterized with amalgamated channel bodies that are commonly vertically separated by floodplain deposits. The medial zone is not discretely defined in this study area, and is more a transitional phase from proximal-medial zones instead.

The Mills Canyon outcrop was mapped out by Samuel Totz, since a drone was the only accessible way to capture images of this outcrop. This outcrop is located on a cliff face in Kiowa National Grasslands, and exposed due to weathering of the western side of the canyon (Totz, 2022). This outcrop is predominantly composed of Srl with minor St deposits. The amalgamated channel deposits contain horizontal and ripple laminations of lithofacies Srl. Below the scour surface, channels are highly amalgamated and reveal little to no sedimentary structures. Above the scour surface, fluvial channel elements are

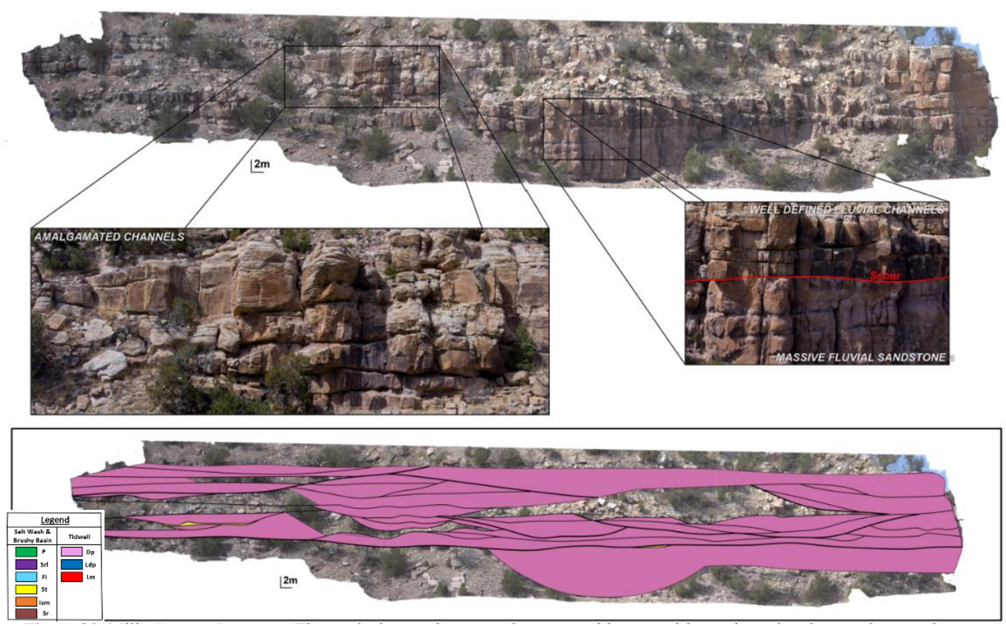


Figure. 23 Mills Canyon outcrop. The top is the non-interpreted outcrop with zoomed in sections showing amalgamated channels and a mappable scour surface. The bottom shows the lithofacies and mappable surfaces. Image from Totz 2022.

visible (Totz, 2022). Mills Canyon predominantly contains amalgamated channel and bar deposits. The amalgamated channels here contain horizontal and ripple laminations similar to those seen at the Trujillo location.

Totz noted that the channel fill deposits have a lensoidal geometry and are frequently incised by the channels above them. Furthermore, the sheet sands contain horizontal laminations, and bar accretion surfaces that onlap channel bottoms. Channel-belt sands are notably smaller in total thickness compared to the more proximal Trujillo outcrop.

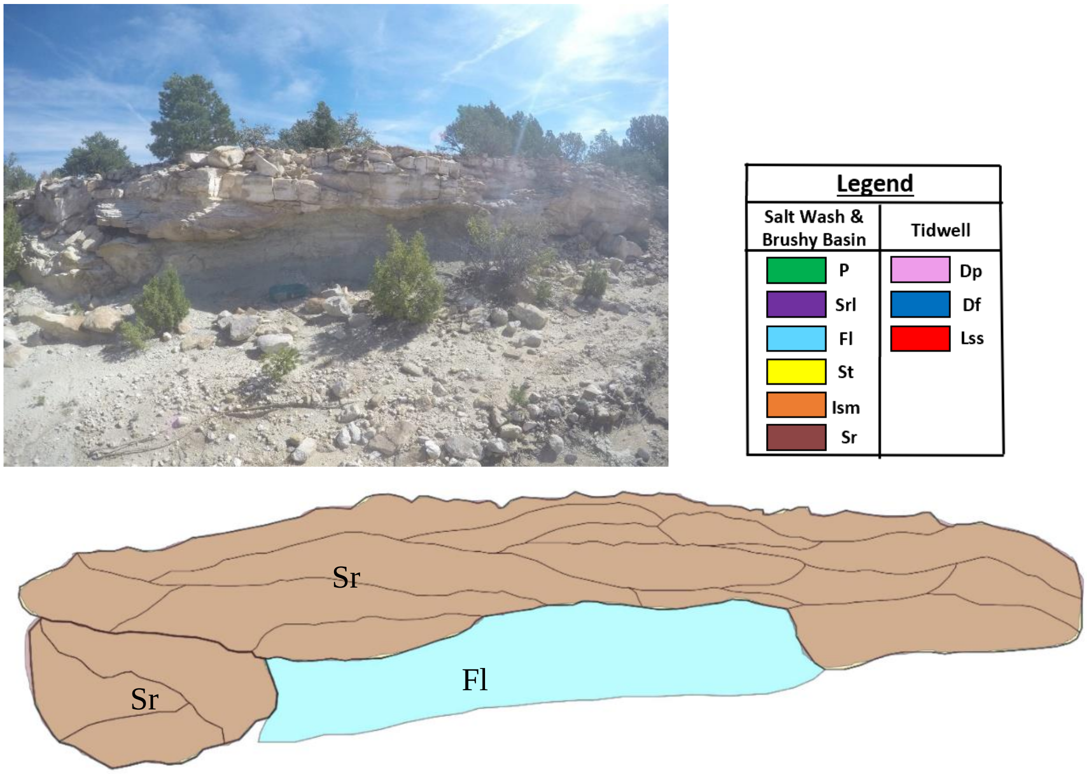
Salt Wash Analysis - Proximal-to-Medial Zone

The proximal-to-medial zone form channel bodies that are still amalgamated and form discrete packages of channel-belt sands. Connectivity of sandstone bodies are still recorded in the medial section, but thicknesses of channel sands decrease from the proximal zone. A lack of lacustrine deposits in this zone could be due to the low ratio of load accommodation to sediment supply. A complete distinction of the proximal zone to the medial zone is hard to observe and not as differentiated as in the equivalent deposits of the Four Corners. Due to the lack of exposed outcrops in this area, a well-defined medial zone is difficult to define. Low accommodation and high sediment supply can still be inferred in the medial zone based on limited outcrops, but not as definitively as in the Colorado Plateau. With limited outcrops being measured in the proximal-medial zone, a radial pattern paleocurrent was not recorded in the area. With the medial section of the Salt Wash being only seen in one example, interpretations that the Salt Wash traveled a large distance and the medial section only deposited in pulses along the ancient fluvial system.

Salt Wash Architecture and Facies – Distal Zone

The distal zone is characterized by a high proportion of floodplain facies, with channel-fill deposits encompassing a very small percentage of these strata. Thin sandstone sheets are a distinctive feature of the distal zone, and are commonly of a splay origin. These sheets have sharp, locally erosive bases, suggesting local channelization of flow. The distal zone outcrop is located in the northern portion of the study area as location 8 seen in Figure 11. This unit comprises of the Salt Wash and Tidwell members of the Morrison Formation. Two out of the six lithofacies are represented at this outcrop. Sr is observed at the uppermost part of this outcrop, while Fl is at the bottom of the section. Sr sandstone beds are making sheet/ribbon-style channel cuts. Fl is identified by its gray color, little to no rooting, and lack of internal structure.

Sr lithofacies in the North Exposure outcrop contain discrete parallel laminations. At the top of the outcrop (Figure 24) there are several <.5m thick ribbon-style channels comprising Sr lithofacies. The internal structure is relatively simple, with parallel laminations being abundant with some minor cross-laminations. In the bottom left of the outcrop there is a bar form that is cutoff from the original outcrop. The lower portion of the outcrop is floodplain material with little to no internal structure.



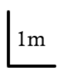


Figure. 24 Top photo is the non-interpreted North exposure Salt Wash Unit. Sandstone ribbon channels, approximately 0.32m - 0.75m in thickness, onlapping onto a bar form. Thin lines are showing an interpreted representation of laterally extensive channels.

Salt Wash Analysis – Distal Zone

The floodplain association dominates the northern exposure of the Morrison Formation, along with minor ribbons style sandstones and sheet sandstones. Little to no amalgamation is noted in the distal zones. Channel belt deposits are absent, floodplain material dominates with sparse ribbon channels scattered throughout the zone. It is possible that the change in architecture downstream is due to it becoming the dominant fluvial form, rather than actually increasing in presence, since the amalgamated channel-belts reduce in size from the proximal to medial zones (Owen, Nichols et al. 2015). An abrupt thinning of the fluvial units is noted in the distal zone. For example, the fluvial section at Trujillo is approximately 9.8m thick, yet the system at the northern edge of the AOI is approximately 1-1.5m thick. Despite the obvious proximal to distal thickness variations, the medial section is less pronounced in thickness disparity.

4.6) Salt Wash – Discussion

The architecture for the Salt Wash varies vastly across the study area. The proximal-to-distal trends seen in northeastern New Mexico can be illustrated in Figure 25. The three outcrops discussed show a downstream change in architecture, where there is progradation of the Salt Wash fluvial system from the Mogollan Highlands to the northeast. The paleocurrents discussed before have

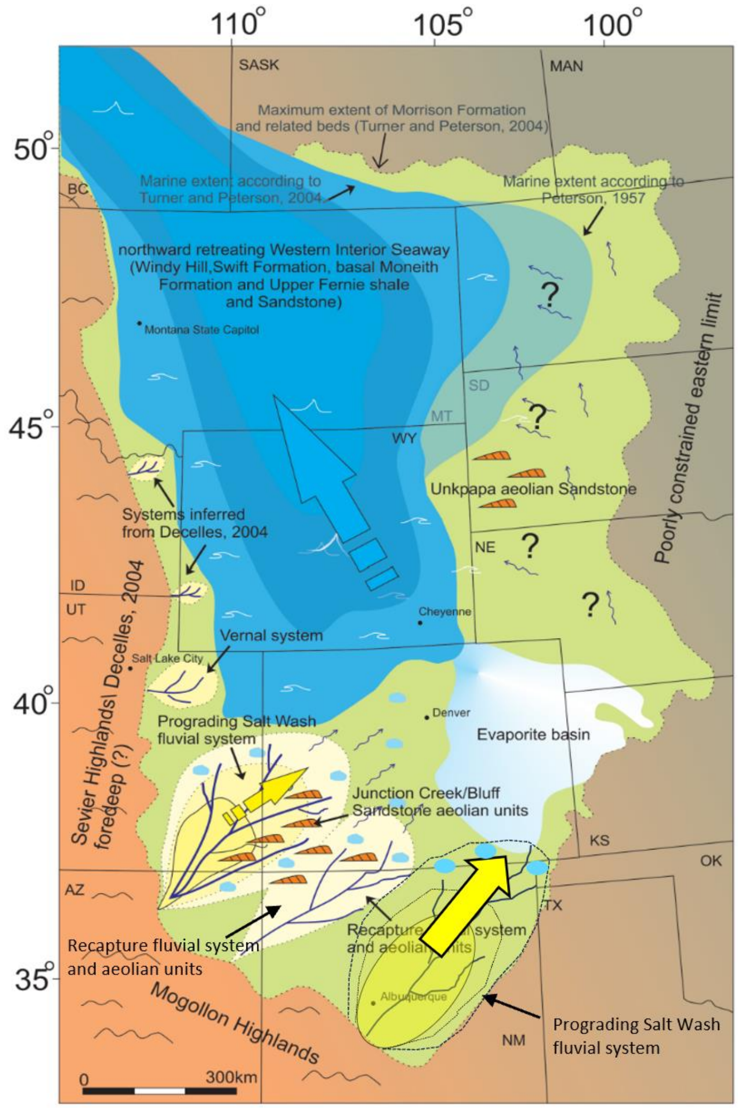


Figure. 25 Summary cartoon of the Salt Wash and Recapture fluvial systems. As the seaway retreats north-west, fluvial systems such as the Salt Wash DFS prograde into the basin. Black dotted outline indicates projected Salt Wash fluvial system in this study. Green depicts alluvial facies which are predominately muddy facies with minor fluvial and lacustrine environments which are interpreted to be wetlands by Turner & Peterson (2004). Edited from Owen et al. (2015).

measurements originating from the Highlands and continue to the northeast. Additionally, a downstream decrease in channel thickness is observed and is consistent with a typical prograding DFS system that is described by Weismann 2011. The lateral extent of the Salt Wash fluvial system will need further work, however, the downstream changes in this study illustrate the architectural changes of the Salt Wash Fluvial system.

In the proximal areas, the outcrops are composed of laterally extensive and vertically amalgamated channel belt sandstones. Channel belts are amalgamated, and channel fills forming between amalgamated deposits. The characteristics in proximal areas of the Salt Wash indicate a system with low accommodation to sediment supply ratio, with a fluvial system that was mobile enough to allow crosscutting of fluvial channels during avulsions. The proximal-to-medial zone form channel bodies that are still amalgamated and form discrete packages of channel-belt sands. Connectivity of sandstone bodies are still recorded in the medial section, but thicknesses of channel sands decrease from the proximal zone. Larger channels belts, higher sand percentage, and amalgamation percentage lead to the interpretation that the proximal and medial zones of the Salt Wash member seem to interfinger with one another. The lack of radial pattern paleocurrent measurements in northeastern New Mexico does not disprove a potential DFS. The paleocurrents recorded in the study area could be tracking on one path of a radial pattern. Future studies are needed to confirm this claim. A system of higher accommodation and less sediment supply can still be inferred for the proximal-to-medial zone.

Distal deposits are characterized by isolated ribbon style sandstones with a higher W:T ratio than the previous two zones described. Little to no amalgamation was observed between sandstone bodies. Floodplain deposits become dominant, with sheet sands depositing within the unit. A system with a high ratio of accommodation to sediment supply is inferred, with little reworking of channel systems.

Salt Wash DFS Paleogeography and Tectonic Setting

The Salt Wash fluvial system is reported to interact with several other different depositional units (Craig et al. 1955; Turner and Peterson, 2004; Owen et al. 2015). A look at how the Recapture system interacts with the Salt Wash DFS will help reconstruct the depositional environment in the Late Jurassic.

Recapture System

According to (Craig 1955), the Recapture Member is found at the base of the Morrison Formation in NW New Mexico and smaller parts of Utah and Colorado, and can coexist within the Morrison deposits. Craig et al. (1955) also mentioned that the Recapture Member comprises of fluvial channels and overbank deposits. The Recapture Member and the Salt Wash fluvial system both have similar architecture that is recorded in northeastern New Mexico. Amalgamated channel belts in the proximal zone that thin in the distal zones to floodplain muds and sandstone stringers. The Recapture System and the Salt Wash fluvial system are interpreted to interfinger with one another in the Four Corners area (Craig 1955, Mullens and Freeman 1957, Turner and Peterson 2004, Owen, Nichols et al. 2015). Where these systems have similar depositional environments, it has been recorded that they have two different paleocurrent indicators, with the Recapture System believed to have been sourced from further east in the Mogollan Highlands in west-central New Mexico (Craig 1955). Still farther to the east along the Mogollan Highlands, the Salt Wash fluvial system outcrops again. Therefore, it can be seen that lateral to the Salt Wash fluvial system another fluvial system was also present (Fig. 25).

It is not certain that the two systems were deposited coevally as absolute dates are not available for the Recapture system. However, the fact that the two are stratigraphically equivalent and are both found at the base of the Morrison Formation gives probable reason that they were coeval (Owen et al. 2015).

Filling of the Foreland Basin: Salt Wash Member and Recapture System

The tectonic setting and filling of the foreland basin still remains in question in the Late Jurassic. The initial thrusting of the Sevier thrust belt and the timing of flexural loading is an important factor when looking at the deposition of the Salt Wash member of the Morrison Formation. The tectonic history of the Morrison Formation around the Colorado Plateau, northeastern New Mexico, and also the Recapture System illustrates how these formations were sourced and deposited as they are today. Interpretations from this study and others will show how the three distributive fluvial systems deposited into the foreland basin.

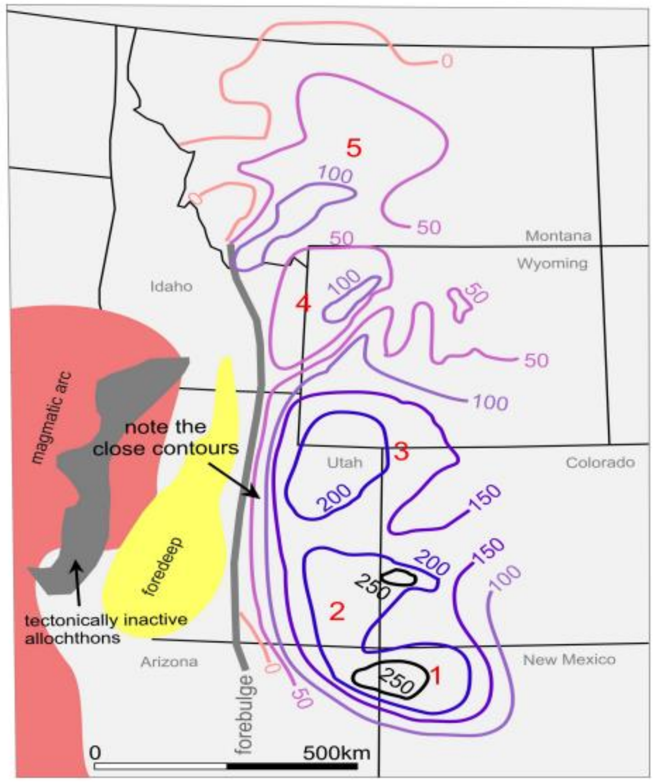


Figure. 26. Morrison thickness contour map, modified from Decelles (2004) and Owen (2015). Numbers depict the presence of separate possible fluvial systems 1=Westwater/Recapture system, 2= Salt Wash DFS, 3= Vernal system

As discussed before, flexural loading generated accommodation for the Morrison Basin. The Salt Wash fluvial system is thickest in the southwest and thins to the northeast, as discussed in the thickness analysis section above, providing evidence that an asymmetrical fill is present within the basin. This matches the conclusion that Owen et al. 2015 recorded in the Four Corners area as well. From the work of Decelles 2004, an isopach map of different DFS systems shows that there is asymmetric filling across the basin (Figure 26). The western margin of the Morrison Basin (Figure 26) shows that there is an initial thin strip being positioned closely to the mountain front, with deposits first thickening and then thinning towards the basin center. Looking at the initial thinning seen towards the mountain edge, it can be noted that the basin does not display a true asymmetric thickness pattern, as noted by Decelles (2004). However, the initial thickening from West to East is abrupt, and it is therefore contested whether such a minor anomaly should discount against the overall asymmetric pattern (Decelles 2004, Owen et al. 2015).

The argument for the timing of the development of a foreland basin continues. Owen et al. (2015) argues that the presence of a backbulge and foredeep parts of the foreland basin is questioned, particularly during the timing of Salt Wash deposition. The authors noted that the forebulge was not always a prominent feature, which is recorded in Fosdick et al. (2011) who documented a suppressed forebulge with Cenemanian-Turonian basin fill in southern South America, rather than a prominent feature such as the present Andean foreland basin. Current paleogeographic maps suggest a paleoflow coming from the southwest and the Mogollan highlands (Figure 24). With the speculation that the forebulge not being a prominent feature, and having evidence of the forebulge becoming fully developed within the Cretaceous (Figure 27), this suggests that the thrust system at this point was in its infancy, with the load only being sufficient enough to create low accommodation during Salt Wash deposition (Owen et al. 2015). In this respect the initial thrusting caused the accommodation but was insufficient to produce a forebulge (Owen 2015). The increased subsidence and accommodation will be noted in the Brushy Basin section, but there are large fluvial channels with more accommodation that are seen within the Brushy Basin member compared to the Salt Wash (Figure 30). It is at this stage, with more load being created, that the forebulge becomes developed within the Cretaceous, as can be seen in (Figure 27).

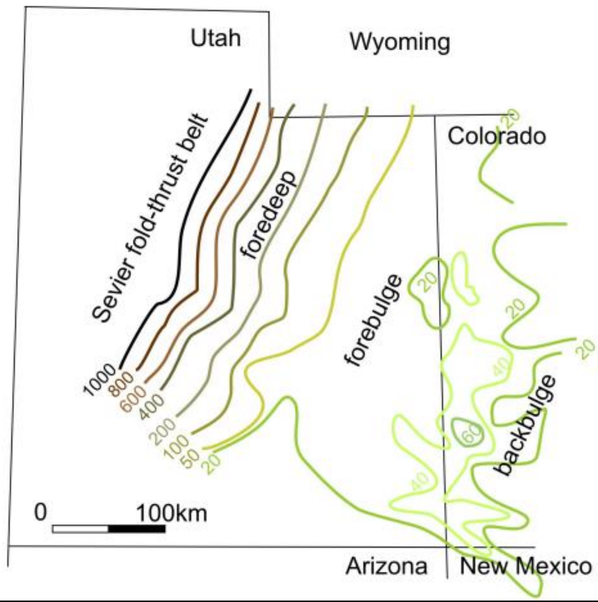


Figure. 27. Contour map of the Lower Cretaceous. Contour intervals in meters. Modified from Decelles and Giles (1996) and Owen et al. (2015)

The analysis from this thesis agrees with Owen et al. (2015), where the low accommodation of the Salt Wash could represent the initial formation of the foreland basin. A summary cartoon from Owen et al. 2015 can be found in Figure 28 to visualize this scenario.

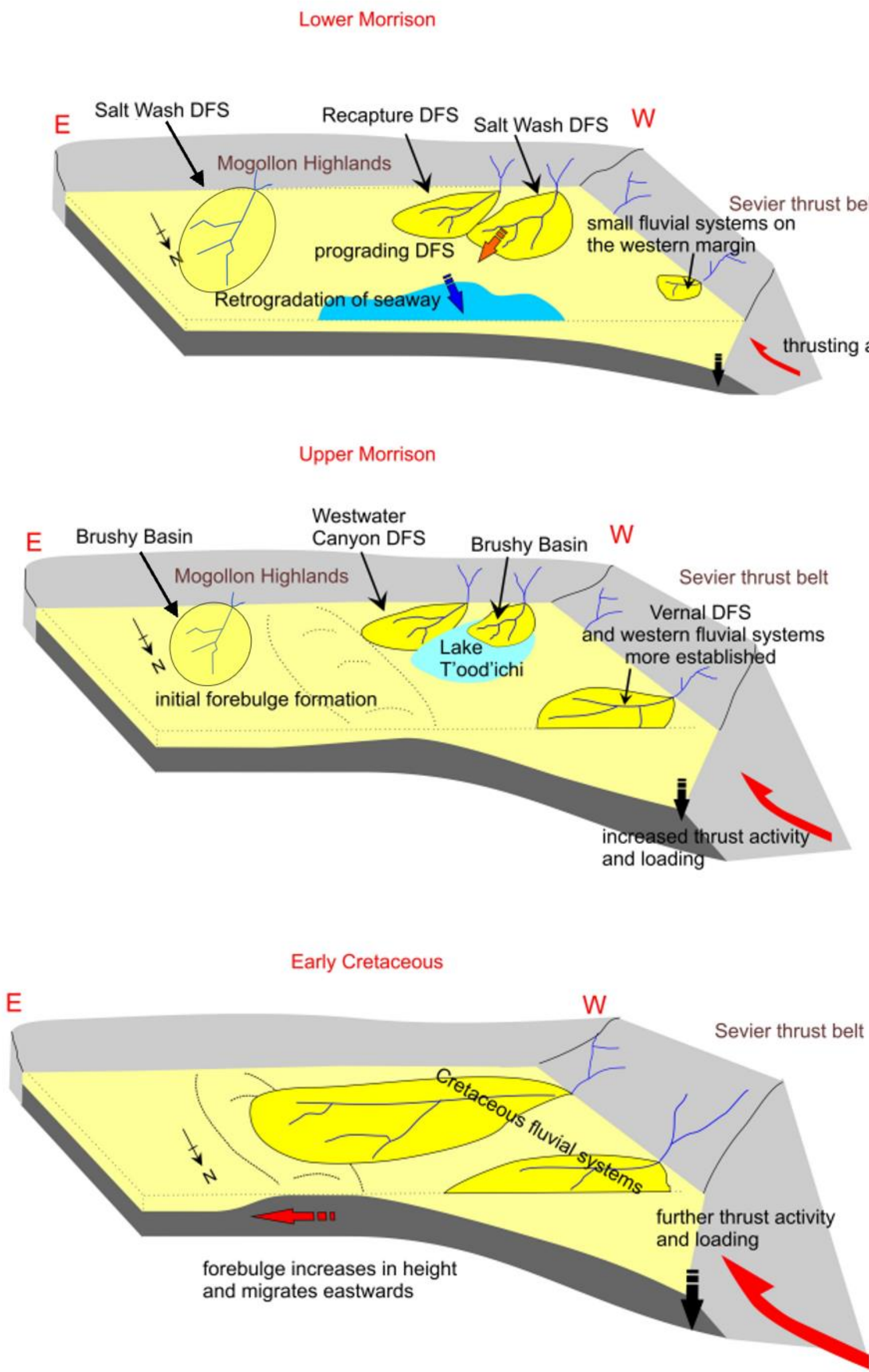


Figure. 28. Cartoon illustrating the hypothesized formation of the foreland basin system from early Morrison through Early Cretaceous. Modified from Owen et al. (2015)

With two different fluvial systems likely being deposited coevally from two different source mechanisms, there is evidence that the eastern Salt Wash fluvial system in northeastern New Mexico was never being sourced by the Sevier Highlands (as in the Four Corners area) but rather the Mogollan Highlands in the South. With the paleocurrent indicators collected in the study area, there is reason to believe that there are two different sourcing mechanisms for the Salt Wash member in the Colorado Plateau and the study area in this thesis. However, a future study of the Mogollan Highlands and a proper source to sink study will be needed to confirm this conclusion.

Salt Wash Depositional Model

The Salt Wash fluvial system is prograding into the basin after the retreat of the Western Interior Seaway to the north-west. The fluvial system is being sourced from the Mogollan Highlands and creating a proximal to distal system that has been recorded in the hypothesis set forth by Weissmann et al. (2013). Northeastern trending paleocurrents, along with the infancy of thrusting in the foreland basin, show strong correlation that the Salt Wash member in northeastern New Mexico is being sourced from the Mogollan Highlands.

(Ethridge, Wood et al. 1998) noted that observing key controlling factors for sedimentary sequences can be a challenge because different factors may produce the same signature, or it may be that several controlling factors could be involved for the characteristics seen within a system. This is evident when studying the Salt Wash as it appears that several factors, such as sediment supply, accommodation, and tectonic activity, could be responsible for the progradation of the system. Possible causes of progradation have been discussed with a combination of factors that include tectonic activity and changes in the accommodation and sediment supply ratio (Decelles 2004, Owen et al. 2015).

The strongest downstream trend observed is within the Srl unit of the Salt Wash. Downstream, the amalgamated channel belts become less dominant, and become entirely absent in the distal areas (Figure 10). A higher energy environment in the proximal zones allowed for the development of a delta plain that would deposit sediment into a lacustrine environment. As the energy decreases in the fluvial system, the lacustrine unit outcrops in the distal zone. A downstream decrease in energy, along with channel bifurcation, seems to be the most likely mechanism to the trends observed. (Kukulski, Hubbard et al. 2013) noted that the Salt Wash fluvial system is deemed to be an upstream fluvial system, and that it should be controlled primarily by upstream processes (influx of sediment and discharge rate). However, (Robinson, McCabe et al. 1998) showed vertical trends that the Salt Wash unit reflects base-level changes within shrinking and expanding lacustrine systems. Since the lacustrine system in the Morrison Formation is inferred as a minor feature, and is highly unlikely to control such a large system that the Salt Wash creates, the Salt Wash fluvial system will be deemed as an upstream fluvial system.

Architectural styles have been discussed in previous sections and it is concluded that the proximal-medial zone has amalgamated channel belts and the distal zone has smaller, more separated channels. The Salt Wash depositional model can be seen in (Figure 29), which can be compared to the similar paleogeography described from Weissmann 2013. The Salt Wash fluvial system should be analyzed by the hypothesis set forth by (Weissmann, Hartley et al. 2013) when describing a prograding system: 1) channels that radiate from an apex; this study did not estimate or predict an apex but suggests that a potential apex could be from the Mogollan Highlands. 2) Channel size decrease downstream; channel sizes decreased downstream from approximately 1.4-4.8m to .7-1m in the distal area. 3) an increase in preservation of floodplain deposits downstream; floodplain deposition increases as the fluvial system moves downstream. 4) a decrease downstream in channel grain size; an in-depth analysis of grain size is not recorded in this study; however, grain size is recorded to decrease as the channels become smaller ribbon style channels in the distal areas. 5) a change from amalgamated channel deposits in proximal areas to more separated and smaller channels in distal areas.

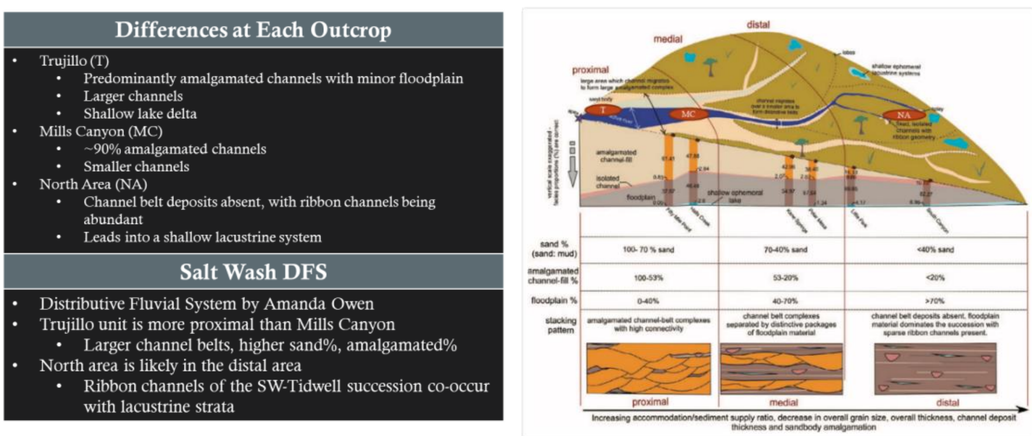


Figure. 29 Diagram illustrating the differences between each outcrop and how they fit in to the Salt Wash DFS system that Amanda Owen described around the Colorado Plateau. DFS Diagram from (Owen, 2015).

4.7) Architecture Analysis of the Brushy Basin Member of the Morrison Formation

Brushy Basin Architecture and Facies – Proximal Zone

The proximal zone of the Brushy basin is represented by the Roy outcrop and comprises of St channel belts with P separating the fluvia l channels (Figure 30). Lithofacies P contains paleosols with moderate pedogenic development. The outcrop also contains lithofacies St, which show little-to-no amalgamation. Channel thickness ranges from 0.7m and decreases up-section of the deposit. Paleocurrent indicators were lacking entirely in the Brushy Basin member, with outcrop exposures not available for accurate measurements.

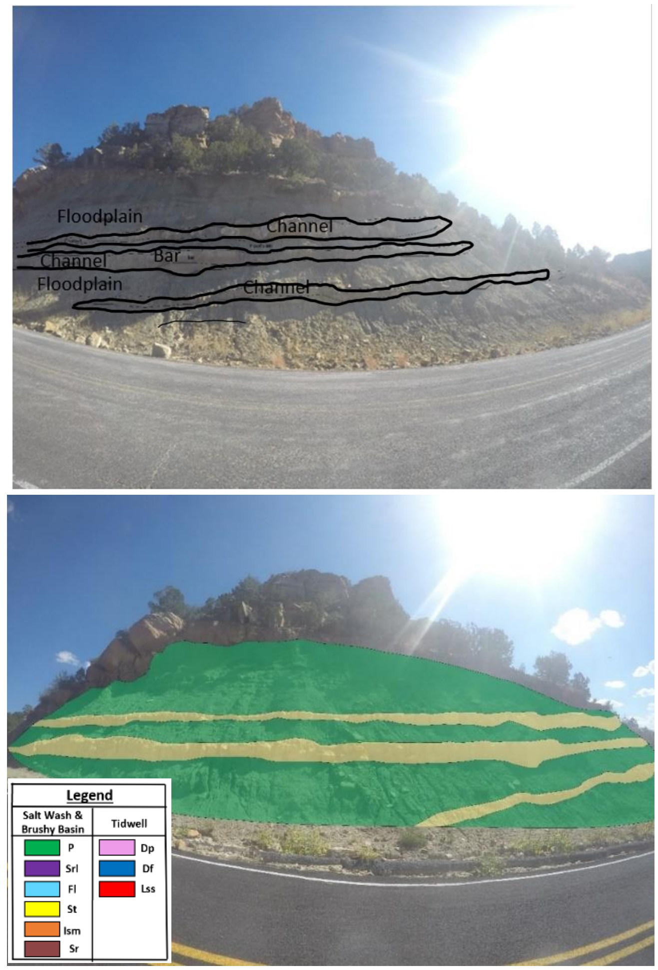


Figure. 30 A proximal zone Brushy Basin outcrop near Mills Canyon. Small channel belt sands separated by floodplain muds and silt. Low frequency avulsions creating scour surfaces.

Brushy Basin Analysis – Proximal Zone

The Brushy Basin member follows a similar paleoflow as the Salt Wash unit. (Craig 1955) also suggests that the Salt Wash and Brushy Basin come from a similar source. This assumption is based on the characteristics that Weismann et al. (2010) described when characterizing downstream deposits in modern continental basins. Bar forms are seen above scour surfaces in the proximal zones of the Brushy Basin. This shows that even though amalgamation is low between fluvial deposits, there was still mobile reworking of fluvial systems in this zone. Low amalgamation of channel belts leads to higher pedogenic development, which is seen between fluvial channels (Figure 30). Gradual thinning of channel belt deposits shows a transition into the medial section. Large fluvial channels with more accommodation are seen within the Brushy Basin member compared to the Salt Wash (Figure 28). An increase in subsidence and accommodation is a potential reason why this is being deposited here, which is further explained in the discussion section of the Recapture and Salt Wash fluvial system.

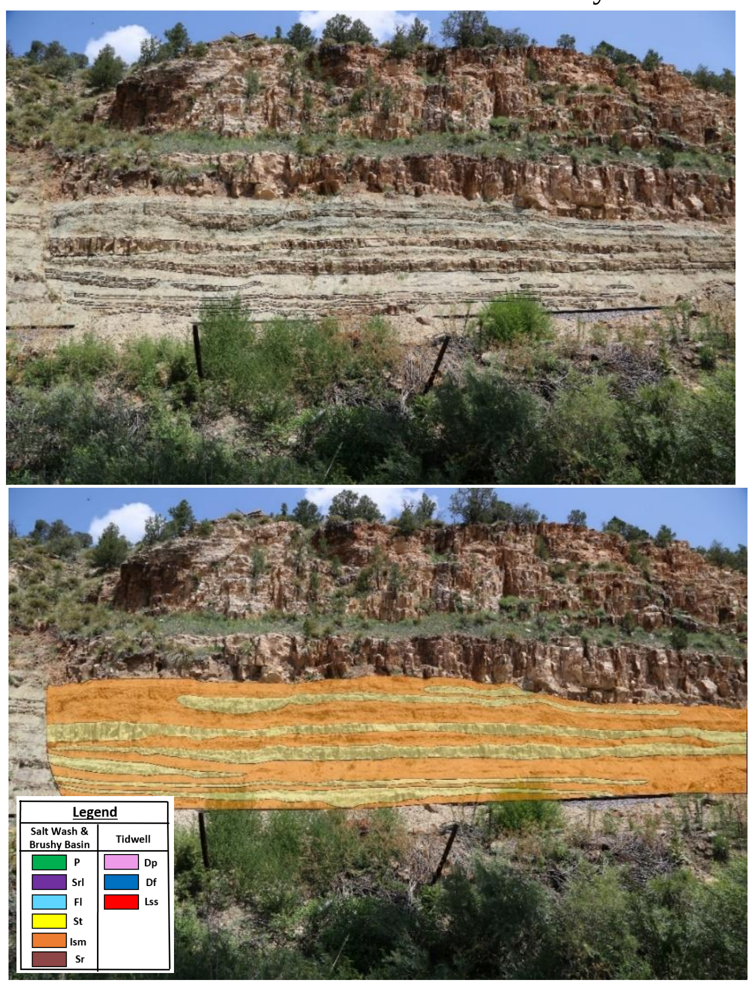


Figure. 31 Medial zone of the Brushy Basin. Illustrates St channel cuts of the Brushy Basin member. Lower section is showing lithofacies of the outcrop section.

Brushy Basin Architecture and Facies – Medial Zone

The medial zone of the Brushy Basin is characterized by thin channel sandstone sheets interbedded with floodplain mudstones. This outcrop of the Brushy Basin is located between Wagon Mound and Las Vegas, New Mexico. The

Brushy Basin outcrop predominantly comprises Ism with St channel cuts (Figure 31). The sandstones are much thinner and amalgamate more with the surrounding mudstone (Figure 29). The mudstone and sandstone show the highest amalgamation rate out of the outcrop sections discussed. Channel sheets range from 0.2m to 0.5m in thickness.

Brushy Basin Analysis – Medial Zone

Evidence for high discharge rate is recorded by extensive lateral channel-fill complexes (Figure. 31). The sporadic preservation of overbank elements suggests that the fluvial system is still being reworked by avulsion and laterally shifted channels. The outcrop is also characterized by the increased occurrence of sheet sandstones (Figure 31), occurring as laterally extensive, mainly tabular, vertically separated channel units (Figure 31). The occurrence of sheet sandstone beds within the medial region is best explained by (Field 2001), where channel capacity is progressively reduced when high-magnitude and low-magnitude flooding events occur due to aggradation and channel bed elevation, resulting in channels only being able to accommodate repeated floods of smaller magnitude. In contrast, larger floods spill into adjacent floodplain areas. With channels not being able to accommodate, the magnitude of a flooding event required for overbank channels decreases. With that, the level of discharge is highly variable and is dependent between high-magnitude and low-magnitude flooding events (Field 2001). The channels and surrounding mudstone have a higher sand percentage than those seen in the northern area of the study area and Mills Canyon, suggesting that deposition is at the medial portion of the fluvial system (Weissmann, Hartley et al. 2013).

Brushy Basin Architecture and Facies – Distal Zone

This outcrop is location 10 in the northernmost portion of the study area (Figure 11). The distal association is predominantly comprised of mudstone and siltstone with poorly drained paleosols. The distal zone for the Brushy Basin in this study is comprised of mudstone with soil profile (P), interbedded sand and mud (Ism), and pulses of tabular sandstone (St) throughout outcrop. Small sheet sandstones are approximately 0.1m-0.3m and are located at the base of the deposit. Tabular channel sandstone sheets are laterally continuous throughout the floodplain mudstone. Distinct interbedded sandstone and mudstone are at the top of the outcrop section. Floodplain mudstones have distinct purple soil horizons (Figure 32) that lack internal structure.

Figure. 32 Distal zone Brushy Basin outcrop. Upper image is showing lithofacies assemblages, while the lower is showing outcrop architecture. Predominantly dominated by floodplain and interbedded sands and muds.

Brushy Basin Analysis – Distal Zone

The North Exposure outcrop is defined by the poorly drained paleosols in the distal zone, which suggest an interaction with springs or coming in contact with the spring line. The thin sheet sands have no correlation with progradation into the basin, as these thin sheets are likely a part of a pulsing depositional pattern downstream rather than a linear proximal to distal trend. The transition from medial zone to the distal zone is indicated by the presence of lithofacies P and a decrease in laterally continuous sand sheets. The architectural elements of this environment are indicative of a significant decrease in downstream fluvial discharge.

Brushy Basin – Discussion

The architecture for the Brushy Basin member is highly variable and sporadic across the study area. In this study, the Brushy Basin will be compared to the work of Sam Totz

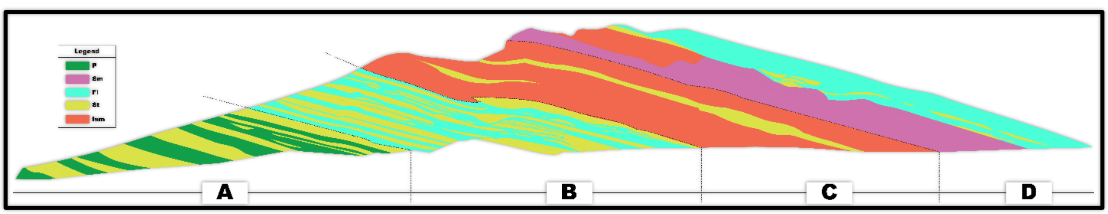


Figure. 33 Proximal-Medial-Distal zones of the Brushy Basin. A→D shows the progression of the Brushy Basin on a terminal fan model. Proximal facies include large sheet sands with no amalgamation; the medial facies are thinner sheet sands with little amalgamation; the distal facies have the thinnest sand sheets and highest preservation of floodplain. Image from Samuel Totz

detailed work at selected outcrops in the area. Totz (2022) interpreted proximal, medial, and distal zones in a vertical section based on architecture and lithofacies associations. Totz 2022 zones are applied in this study and are extrapolated across the northeastern New Mexico study area. Proximal-medial-distal zones will be classified based on the work done near Las Vegas, New Mexico (Figure 33).

In the proximal areas, outcrops include floodplain muds and silts that separate channel belt sand sheets. Little to no connectivity is recorded in this zone, however, scour surfaces similar to those seen in the Salt Wash proximal zone are shown in outcrop as well. The characteristics seen in this unit suggest a system of high accommodation with a moderate sediment supply.

In the medial zone, floodplain muds turn into interbedded sandstone and siltstone with small, confined channels. Some minor connectivity was seen, indicating higher avulsion frequency as channels define a new path from the high-energy channel belts from the proximal zone. As Sam Totz notes in his detailed look at the Brushy Basin, the thinner sand sheets correspond to the reworking of high-energy channels avulsing and establishing a new active fan lobe.

The distal association is predominantly composed of mud and silt with poorly drained paleosols. Floodplain deposits become dominant, with sheet sands depositing within the unit. A system with a high ratio of accommodation to sediment supply is inferred, with little reworking of channel systems.

The downstream system trends suggest that the Brushy Basin fluvial system lacks a regional trend. With a non-linear depositional pattern throughout the area, it is highly likely that the Brushy Basin proximal and medial zones are areas where sediment influx is greater than accommodation, where high discharge fluvial systems fed the upper portion of the Morrison Formation (Weissmann, Hartley et al. 2013). With paleocurrent data not being recorded in the study area due to exposure quality, it is assumed that the Brushy Basin has a similar progradation pattern as the Salt Wash due to the increased accommodation space and percentage of sheet sands downstream. However, the Brushy

Basin deposits possess a distinctive red, purple, and green coloration and contain smaller discrete channels than those observed in the Salt Wash fluvial system. To the northeast of the AOI, distal facie deposits characterize the Salt Wash fluvial system, where channels decrease in size and presence, and the floodplain facies become more dominant. With the work of (Craig 1955), it is known that the Salt Wash and Brushy Basin are deposited from a similar source. It is inferred from this information, and the fact that there is a gradational contact between the Salt Wash and Brushy Basin in many locations, that the Brushy Basin system is a continuation of the Salt Wash fluvial system.

There are a number of reasons that could explain the difference in appearance between the two members. The Brushy Basin is far more mudstone-rich than the Salt Wash system, with discrete ribbon style sands being far more abundant than channel belt sandstones. The difference in characteristics between the two members simply implies that the Brushy Basin system was deposited under a much higher A/S ratio than that of the Salt Wash system. This would suggest that the coarser sediments simply aggraded in the proximal regions and never reached the upper-portion of the Morrison, or that the Brushy Basin was starved of coarser grained sediment (Owen, Nichols et al. 2017). (Owen, Nichols et al. 2015) explains that the Brushy Basin could also be tapping into a more mud-rich source rock, either by tectonic activity, or by a result of it being sourced from a different area to the Salt Wash fluvial system. There are a few speculative studies over tectonic activity having a factor in creating more accommodation space in the Salt Wash-Brushy Basin transition, but those studies are highly speculative and more detailed work on the depositional system of the Brushy Basin will be needed to clarify similarities and differences.

The Brushy Basin Member of the Morrison Formation lacks a regional trend to fit it in the DFS story of the Salt Wash member. With a lack of quality outcrops for paleocurrent data, it is difficult to determine the true downdip direction. There are architectural changes in the Brushy Basin that are defined within the proximal-medial-distal zones, however, these changes do not follow any specific trends that were recorded during this study. A larger study area or a more detailed comparison with other studies will be needed to continue the evaluation of the Brushy Basin DFS.

Chapter Five: Conclusions

This study illustrates and quantifies proximal-to-distal trends across the Salt Wash and Brushy Basin members of the Morrison Formation. An overall decrease in deposit thickness downdip, a change in grain size from coarse sand to mud and silt, and a gradual change from amalgamated channel belts to floodplain deposits is recorded across the study area. When present, average channel belts ranged from 4.3m in proximal zones to <1m in distal zones. The architectural style of the deposits distinctively changed, with proximal regions being dominated by stacked amalgamated channel-belts, and distal regions dominated by floodplain muds, lacustrine deposits, and sheet sandstones with little to no amalgamation of channel deposits. The lacustrine units recorded in this study are extensive and are seen across the plains across New Mexico and farther North across the Colorado border. These unit were not recorded in this study because of the study area limits.

The Salt Wash tectonic setting and its filling of the foreland basin is a critical component of analyzing the depositional history. The initial thrusting caused the accommodation, where the accommodation was low during Salt Wash deposition and increased during Brushy Basin deposition. The paleocurrent measurements recorded in this study show that the sourcing mechanism of the Morrison Formation is from the Mogollan Highlands, rather than the Sevier Highlands. The Salt Wash DFS in northeastern New Mexico is parallel to the Recapture System and the Salt Wash DFS that is seen in the Four Corners area. The lateral extent of the northeastern Salt Wash DFS is still needed to see the radial pattern of the ancient fluvial system.

The Brushy Basin member lacks a true trend throughout the study area. The pulsing depositional pattern recorded throughout the study area shows that the Brushy Basin member lacks a regional trend and does not fit the DFS that the Salt Wash member shows.

The Tidwell member was evaluated as its own separate section because of the varying lithofacies and the depositional story associated with it. Additional studies of the Tidwell will be needed to fully complete the story of the Morrison Formation in northeastern New Mexico.

Those trends that are not quantified, such as grain size and architectural styles, are put in a qualitative state and are still important to analyzing the controls on the system. A decrease in energy downstream, corresponding to how the flow of rivers enter a basin, channel bifurcation and avulsion, are interpreted to be key controls on the ancient fluvial system.

The downstream facies trends provide a basis to compare to other fluvial systems deposited in different conditions, which may lead to better similarities and differences across ancient fluvial systems.

References

Allen, J. R. L. (1964). "Primary Current Lineation in the Lower Old Red Sandstone (Devonian), Anglo-Welsh Basin." Sedimentology **3**(2): 89-108.

Allen, J. R. L. (1984). Sedimentary structures, their character and physical basis. New York;Amsterdam;, Elsevier.

Bagnold, R. A. and G. Taylor (1946). "Motion of Waves in Shallow Water. Interaction between Waves and Sand Bottoms." Proceedings of the Royal Society of London. Series A, Mathematical and Physical Sciences **187**(1008): 1-18.

Chesley, J. T. and A. L. Leier (2018). "Sandstone-Body Variability in the Medial–Distal Part of an Ancient Distributive Fluvial System, Salt Wash Member of the Morrison Formation, Utah, U.S.A." Journal of Sedimentary Research **88**(5): 568-582.

Craig, L. C. (1955). Stratigraphy of the Morrison and related formations, Colorado Plateau region, a preliminary report. Bulletin.

Currie, B. S. (1997). "Sequence stratigraphy of nonmarine Jurassic–Cretaceous rocks, central Cordilleran foreland-basin system." GSA Bulletin **109**(9): 1206-1222.

Decelles, P. and K. Giles (1996). "Foreland Basin Systems." Basin Research **8**: 105-123.

DeCelles, P. G. (2004). "Late Jurassic to Eocene evolution of the Cordilleran thrust belt and foreland basin system, western U.S.A." **304**(2): 105-168.

DeCelles, P. G. and E. T. Burden (1992). "Non-marine sedimentation in the overfilled part of the Jurassic-Cretaceous Cordilleran foreland basin: Morrison and Cloverly Formations, central Wyoming, USA." **4**(3-4): 291-314.

DeCelles, P. G. and B. S. Currie (1996). "Long-term sediment accumulation in the Middle Jurassic–early Eocene Cordilleran retroarc foreland-basin system." Geology **24**(7): 591-594.

Demko, T. M., B. S. Currie and K. A. Nicoll (2004). "Regional paleoclimatic and stratigraphic implications of paleosols and fluvial/overbank architecture in the Morrison Formation (Upper Jurassic), Western Interior, USA." Sedimentary Geology **167**(3): 115-135.

Ethridge, F. G., L. J. Wood, S. A. Schumm and G. Kocurek (1998). Cyclic Variables Controlling Fluvial Sequence Development: Problems and Perspectives. Relative Role of Eustacy, Climate, and Tectonism in Continental Rocks, SEPM Society for Sedimentary Geology. **59:** 0.

Field, J. (2001). "Channel avulsion on alluvial fans in southern Arizona." Geomorphology **37**(1): 93-104.

Guccione, M. J. (1993). Grain-Size Distribution of Overbank Sediment and Its Use to Locate Channel Positions. Alluvial Sedimentation**:** 185-194.

Hartley, A. J., A. Owen, A. Swan, G. S. Weissmann, B. I. Holzweber, J. Howell, G. Nichols and L. Scuderi (2015). "Recognition and importance of amalgamated sandy meander belts in the continental rock record." Geology **43**(8): 679-682.

Heller, P. L., D. Ratigan, S. Trampush, A. Noda, B. McElroy, J. Drever and S. Huzurbazar (2015). "Origins of Bimodal Stratigraphy In Fluvial Deposits: An Example From the Morrison Formation (Upper Jurassic), Western U.S.A." Journal of Sedimentary Research **85**(12): 1466-1477.

Horton, B. K. and P. G. DeCelles (2001). "Modern and ancient fluvial megafans in the foreland basin system of the central Andes, southern Bolivia: implications for drainage network evolution in fold-thrust belts." **13**(1): 43-63.

Kjemperud, A. V., E. R. Schomacker and T. A. Cross (2008). "Architecture and stratigraphy of alluvial deposits, Morrison Formation (Upper Jurassic), Utah." AAPG Bulletin **92**(8): 1055-1076.

Kleinhans, M. G., R. I. Ferguson, S. N. Lane and R. J. Hardy (2013). "Splitting rivers at their seams: bifurcations and avulsion." **38**(1): 47-61.

Kukulski, R. B., S. M. Hubbard, T. F. Moslow and M. K. Raines (2013). "Basin-Scale Stratigraphic Architecture of Upstream Fluvial Deposits: Jurassic–Cretaceous Foredeep, Alberta Basin, Canada." Journal of Sedimentary Research **83**(8): 704-722.

Maidment, S. C. R. and A. Muxworthy (2019). "A chronostratigraphic framework for the Upper Jurassic Morrison Formation, western U.S.A." Journal of Sedimentary Research **89**(10): 1017-1038.

McBride, E. F. (1974). "M. D. Picard & L. R. High 1973. Sedimentary Structures of Ephemeral Streams. Developments in Sedimentology, vol. 17. xvi + 223 pp., 139 figs, 16 tables. Elsevier Scientific Publishing Company, Amsterdam, London, New York. Price Dfl. 75.00. U.S. $26.30." Geological Magazine **111**(6): 570-570.

Mckee, E. D. and G. V. Middleton (1965). Experiments on Ripple Lamination1. Primary Sedimentary Structures and Their Hydrodynamic Interpretation, SEPM Society for Sedimentary Geology. **12:** 0.

McKee, E. D. and G. W. Weir (1953). "Terminology for Stratification and Cross-Stratification in Sedimentary Rocks." Geological Society of America bulletin **64**(4): 381-390.

Mullens, T. E. and V. L. Freeman (1957). "Lithofacies of the Salt Wash Member of the Morrison Formation, Colorado Plateau." GSA Bulletin **68**(4): 505-526.

Nichols, G. J. and J. A. Fisher (2007). "Processes, facies and architecture of fluvial distributary system deposits." Sedimentary Geology **195**(1): 75-90.

Ortiz-Karpf, A., D. M. Hodgson and W. D. McCaffrey (2015). "The role of mass-transport complexes in controlling channel avulsion and the subsequent sediment dispersal patterns on an active margin: The Magdalena Fan, offshore Colombia." Marine and Petroleum Geology **64**: 58-75.

Owen, A., G. J. Nichols, A. J. Hartley and G. S. Weissmann (2017). "Vertical trends within the prograding Salt Wash distributive fluvial system, SW United States." **29**(1): 64-80.

Owen, A., G. J. Nichols, A. J. Hartley, G. S. Weissmann and L. A. Scuderi (2015). "Quantification of a Distributive Fluvial System: The Salt Wash DFS of the Morrison Formation, SW U.S.A." Journal of Sedimentary Research **85**(5): 544-561.

Peterson, F. (1984). "Fluvial sedimentation on a quivering craton: Influence of slight crustal movements on fluvial processes, upper Jurassic Morrison formation, western Colorado plateau." Sedimentary Geology **38**(1): 21-49.

Pizzuto, J. E. (1987). "Sediment diffusion during overbank flows." **34**(2): 301-317.

Robbins, M. (2009). Sedimentology and sedimentary tectonics of the Salt Wash Member, Morrison Formation, western Colorado M.S., Boston College.

Robinson, J. W., P. J. McCabe and G. Kocurek (1998). Evolution of a Braided River System: The Salt Wash Member of the Morrison Formation (Jurassic) in Southern Utah. Relative Role of Eustacy, Climate, and Tectonism in Continental Rocks, SEPM Society for Sedimentary Geology. **59:** 0.

Rogers, D. A. and T. R. Astin (1991). Ephemeral Lakes, Mud Pellet Dunes and Wind-Blown Sand and Silt: Reinterpretations of Devonian Lacustrine Cycles in North Scotland. Lacustrine Facies Analysis**:** 197-221.

Shu, L. and B. Finlayson (1993). "Flood management on the lower Yellow River: hydrological and geomorphological perspectives." Sedimentary Geology **85**(1): 285-296.

Shukla, U. K., I. B. Singh, M. Sharma and S. Sharma (2001). "A model of alluvial megafan sedimentation: Ganga Megafan." Sedimentary Geology **144**(3): 243-262.

Turner, C. E. and F. Peterson (2004). "Reconstruction of the Upper Jurassic Morrison Formation extinct ecosystem—a synthesis." Sedimentary Geology **167**(3): 309-355.

Weissmann, G. S., A. J. Hartley, G. J. Nichols, L. A. Scuderi, M. Olson, H. Buehler and R. Banteah (2010). "Fluvial form in modern continental sedimentary basins: Distributive fluvial systems." Geology **38**(1): 39-42.

Weissmann, G. S., A. J. Hartley, G. J. Nichols, L. A. Scuderi, M. E. Olson, H. A. Buehler, L. C. Massengill, S. K. Davidson, S. Leleu and C. P. North (2011). Alluvial Facies Distributions in Continental Sedimentary Basins—Distributive Fluvial Systems. From River to Rock Record: The preservation of fluvial sediments and their subsequent interpretation, SEPM Society for Sedimentary Geology. **97:** 0.

Weissmann, G. S., A. J. Hartley, L. A. Scuderi, G. J. Nichols, S. K. Davidson, A. Owen, S. C. Atchley, P. Bhattacharyya, T. Chakraborty, P. Ghosh, L. C. Nordt, L. Michel , N. J. Tabor, S. G. Driese and L. C. Nordt (2013). Prograding Distributive Fluvial Systems—Geomorphic Models and Ancient Examples. New Frontiers in Paleopedology and Terrestrial Paleoclimatology: Paleosols and Soil Surface Analog Systems, SEPM Society for Sedimentary Geology. **104:** 0.

Yeganeh, B., S. Feiznia and A. v. Loon (2012). "Sedimentary environment and palaeogeography of the ?Palaeocene-Middle Eocene Kashkan Formation, Zagros fold-thrust belt, SW Iran %J Geologos." **18**(1): 13-36.

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ABSTRACT

A REGIONAL ANALYSIS OF THE JURASSIC MORRISON FORMATION IN NORTHEASTERN NEW MEXICO

By Preston Louis Dupree, M.S., 2023

Department of Geological Sciences

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The geoscience community has neglected exposures of the Upper Jurassic Morrison Formation in northeastern New Mexico compared to that of the western Colorado Plateau. This study uses methods such as lithofacies associations, regional stratigraphic mapping, and architectural analysis to record an overview of the fluvial processes that deposited the Morrison Formation as it is today. Results from this study were compared to published literature on the Morrison Formation, which identified similarities and differences in the regional depositional pattern that is recorded at outcrops in New Mexico from those on the Colorado Plateau. The results and conclusions of this study, which identifies a new sourcing mechanism in northeastern New Mexico, will be a fundamental component for future studies.

A REGIONAL ANALYSIS OF THE JURASSIC MORRISON FORMATION IN NORTHEASTERN NEW MEXICO

By

Preston Louis Dupree

Thesis approved:

Major Professor

For the College of Science and Engineering