Possible counter point bars in a coarse-grained meandering fluvial system in the Jurassic Morrison Formation, South-Central Utah

By: Petter Dischington

Research Supervisor: Dr. Janok Bhattacharya

Research Committee: Dr. William Dupre

Research Committee: Dr. Brian Willis

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Abstract

Fluvial deposits in the Tithonian Brushy Basin Member of the Morrison Formation will be studied in order to create a facies architectural diagram of the outcrop. This study will represent a rare study of a coarse-grained meandering fluvial system, and possibly the first description of an ancient counter point bar in outcrop. Seven measured sections across a slightly curved outcrop will be correlated on a photomosaic, creating bedding diagrams showing facies architecture and grain size variations. Flow parameters will be determined by using relationships between cross-set and bar thickness measurements and total depth, and paleocurrents will be measured from foreset dip direction. The channel belt geometry will be reconstructed using the bedding diagrams, incorporating additional measured sections that were along the same sandstone horizon laterally distant from the main outcrop. Initial results show the main outcrop to represent a single meander loop, where the channel bend is on the north side of the outcrop, the eastern side of the outcrop shows north-moving paleocurrents and the western side south moving paleocurrents. Four main facies are expected to be present based on previously published studies. Preliminary results indicate the presence of a silty, mud-rich floodplain facies, a sandy, trough-cross-stratified channel facies and a silty, mud-rich counter point bar/flood drape facies. Counter point bars (CPBs) originate as a meander scroll migrates laterally and encounters an obstacle in the form of an erosion-resistant substrate, forcing it to begin longitudinal translation. Thus the CPB is always located on the distal end of the point bar, preceding the cutbank. Inclined heterolithic stratification (IHS) interpreted to be flood drapes, and counter point bar facies are predicted to be of similar composition. Determination of clay content in the counter point bar and flood drape sediment will be done through petrographic study. The main channel facies show a fining up succession from gravel to medium-grained sand, and is overlain by the fine sand and silt-sized sediment of the upper point bar.

Introduction

This study will describe a possible counter point bar deposit (CPB) in the Brushy Basin Member of the Morrison Formation. While former studies have focused on modern and Pleistocene counter point bar deposits (Page and Nanson, 1982; Woodyer, 1985; Hickin, 1986; Hickin, 1979; Makaske and Weerts, 2005; Smith et al., 2009), this will be the first outcrop study of a counter point bar. The purpose of this project is to provide a thorough description of the fluvial deposits, and divide them into respective facies architectural elements. Furthermore a reconstruction of the channel will be attempted, with the result to be compared to the theoretical models by Willis and Tang (2010), which shows meandering fluvial channels with point bars and CPBs of various sinuosity values and translation patterns. Three possibilities are introduced:

1) The inclined stratification seen in the outcrop represents mud-rich rocks deposited on top of point bars by floods.

2) The mud-rich deposit near the center of the outcrop, representing a significant amount of the total interpreted channel deposit depth, is interpreted to be a counter point bar.

3) The outcrop represents a cross-section through a coarse-grained meander loop.

Counter point bar deposits are significant as they are similar to point bar deposits, but the portion of clay and silt-sized sediments of the CPB would occlude the porosity and permeability of deposits that would be presumed to be sand-rich if no CPB was present. The presence of CPBs could explain discrepancies in porosity and permeability compared to predicted values in meandering fluvial deposits (Smith et al. 2009).

Methodology

The channel deposits were walked out in order to assess the total extent of the outcrop. Measured sections were then recorded along correlatable exposures, using rappelling gear where the terrain deemed it necessary. Lithological descriptions, grain size and sedimentary structures were recorded. Paleocurrent measurements were taken from cross-set dips taken in three dimensional outcrops, alongside the recording of cross-set thicknesses. To estimate the amount of smectite in the deposits, the sediments have been exposed to liquid to check if the clays swell, and the sand to silt ratio has been checked through chewing the rocks and feeling their grittiness.

Photomosaics will be created in order to document the outcrop and allow for correlation between measured sections. Bedding diagrams will then be constructed to incorporate measured sections and paleocurrent measurements, and will display facies transitions and grain size variations through the outcrop. The continuity of the lower parts of the sandstone bodies will be assessed by trenching through the covered areas. From the data and interpretations acquired through the above procedures, a reconstruction of the channel belt will be attempted. The datum to be used in this restoration will be a cluster of three to four thin beds showing soft-sediment deformation, that are laterally continuous across the main outcrop. This datum cannot be correlated away from the main outcrop, so the additional laterally more distant measured sections are confirmed to belong to the same stratigraphic horizon through walking out the outcrop. By taking the photomosaic and displaying it on a 3d representation of the outcrop where the strike direction of each face of the outcrop is shown, one can generate a representation of the outcrop that shows its three-dimensional geometry. Assuming the inclined strata to be of constant depth, one can derive the dip angle of inclined stratification by using a three-point problem. Using these results, the channel belt will be reconstructed, which cannot be done with good accuracy from a two dimensional outcrop (Willis, 1989).

A detailed description of facies will be made through field and hand sample measurements, and through qualitative petrographical assessment of samples collected in representative sections of the outcrop, focusing on grain size and clay content.

Geological Setting

The Morrison Fm. is Jurassic in age, and stretches across the US from east of the Rockies through Utah, and from New Mexico to Montana (fig. 1).

The outcrop is within the Brushy Basin member of the Morrison Fm. In the area, the Morrison Fm. consists of three members, the Tidwell, the Salt Wash and the Brushy Basin (fig. 2). The bulk of the member is Tithonian in age, as shown by fission track dating with age ranges of around 144 ma. and younger, which were made very close to the study area. Brushy basin rocks from the Kaiparowits plateau and Dinosaur National Monument were dated using 40AR/39AR methods and show the rocks to be 153-145 ma. to the south and 135 ma. to the north (Kowallis, 1991). Brushy Basin rocks sampled near Hanksville were recently dated to 147 ma using U/Pb dating of zircons (Kowallis, 2007). Many authors have described the Brushy Basin Member, it is overlain by the Buckhorn Conglomerate and the Cedar Mountain Fm. (Currie, 1997; Roca and Nadon, 2007), but Kowallis et al. (1991) points out the absence of the Buckhorn conglomerate in the Notom area. Robinson and McCabe (1997) place the younger Dakota Formation directly above the Brushy Basin, bounded by an erosional unconformity. The Brushy Basin Mbr. is sandier at the bottom, with a transition from lowermost interpreted braided deposits to fluvial sandstones of an interpreted meandering origin. These deposits are interspersed with significant amounts of fine-grained floodplain sediment towards the top of the Brushy Basin Member (Currie, 1997).

The Morrison Fm. was deposited in the foreland basin developed during the commencement of the Sevier orogeny (fig. 1). Locally, the Brushy Basin Member was deposited in the Henry Trough, which was located at approximately the same area as the current Henry Mountains. The basin was fed from the eastern Monument plateau and the southwestern Black Mesa (fig. 3) (Peterson, 1986).

Studies of the sequence stratigraphy of the upper Triassic to the Cretaceous completed north of the study area shows that the Brushy Basin overlies the upper Salt Wash Member, which was deposited within a falling stage systems tract, and is wholly contained within what Currie (1997) calls the Upper Jurassic 2 sequence. The lower Brushy Basin is thought to represent a transitional systems tract, while the upper, fine-grained section shows an aggradational fluvial style interpreted as a high stand systems tract.

Climate in the area during the time of deposition was considered to be hot and dry, as assessed from the large amount of red clay-rich found in the Jurassic of the western US (Brenner, 1983), but recent paleosol studies at dinosaur dig sites in the Brushy Basin Mbr. near the outcrop location indicate moisture-rich deposits, either from a more humid climate or from bank overspill (VanDeVelde et al., 2006).

Study area

The study area is located 4.5 miles west of Hanksville, Utah (fig. 4), and the outcrop is positioned approximately east west with local variations, and measures about 300 meters in length (fig. 5).

Outcrop description and interpretation

The interpreted channel deposits of interest measure four to six meters in height, with the total height of the outcrop averaging 20-25 meters. Additional fluvial deposits are located laterally to the main outcrop at the same stratigraphic depth. Bidirectional downlap of the point bar/counter point bar deposits are seen across the outcrop (fig. 6). On the eastern side the inclined strata dip eastward, while on the west side they dip westwards. The system is interpreted to be a meandering fluvial deposit, as opposed to a braided deposit, due to paleocurrent directions being to the north on the western side and to the south on the eastern side of the outcrop.

Counter Point Bars

Counter point bars (CPBs) are described as a fine-grained, concave deposit on the distal end of a point bar (Makeske and Weerts, 2005). CPBs occur as a meandering river encounters an erosion-resistant substrate as it migrates laterally, and is forced to initiate longitudinal downstream migration. Such erosion-resistant substrates can be incised valley margins, oxbow lakes, abandoned channel fills or older counter point bars (fig. 7) (Smith et al., 2009; Makaske and Weerts, 2005). In older literature, these deposits are described as concave-bench deposits, and were thought to only form where the fluvial channel bent in a hairpin tight curve, related to flow separation as well as eddy currents (Page and Nanson, 1982; Woodyer, 1985; Hickin, 1986; Hickin, 1979). Eddy generated counter point bar deposition would generate an erosional scour on the base of the channel. CPB deposition can also initiate as stream power is very low, and barely exceeds the energy required for erosion (Nanson and Page, 1983). The term counter point bar was first used by Smith (1987b), describing a different kind of deposit where deposition of coarser than point bar sand and gravel material is transported over the point bar in chutes, and deposited distally to the front of the point bar.

CPB deposition occurs from a variety of processes, including fluvial terrace deposits and tidally influenced fluvial deposits. They are predicted to have the greatest amount of preservation potential if deposited in near coastal environments (Makaske and Weerts 2005). The paleogeography of this area shows it being far from the coast (Dickinson and Gehrels 2009), and there is a complete absence of indicators of marine or tidal influence. No bioturbation is seen in the deposits, and there are no lamina-scale sand-clay couplets that would indicate tidal influence.

A gradual transition from counter point bar deposits to muddy deposits draping regular point bars is apparent, indicating a very similar origin. Thickness of fine-grained deposits compared to the total thickness of the channel appears to be the main differentiation between the two types of deposits (Makaske and Weerts, 2005). There is one deposit in the middle of the outcrop that is preliminarily assumed to be a counter point bar deposit, the muddy inclined strata could also be flood drapes referred to by the descriptive term inclined heterolithic stratification (IHS) by Thomas et al. (1987), which is closely related to the older concept of epsilon cross-strata (fig. 8; fig. 9). Some examples of IHS in Thomas et al. (1987), where clay-rich beds are superimposed to form a thicker clay-rick package, have later been interpreted to be CPB deposits (Smith et al., 2009). Corbeanu et al. (2004) describe IHS as a result of tidal influence upon point bars, with the muddy parts of the deposit showing burrows from marine influence.

Most previous studies of counter point bars are from modern rivers, as well as from cores of sub-recent fluvial terrace deposits (Makaske and Weerts, 2005). Additionally, one study describes CPBs from high-resolution shallow seismic data of the Cretaceous McMurray Fm. in Alberta (Smith et al., 2009). The above mentioned study appears to be the only published study describing ancient CPBs.

Coarse grained meandering fluvial systems

Meandering fluvial systems are ordinarily thought of as fine-grained systems, and the suspended sediment load of all meandering rivers largely consists of fine sediment. Even rivers described as coarse bedload rivers typically have suspended fine sediment load of over 80% (Bridge, 2003). There are many studies of modern coarse-grained meandering fluvial systems, while descriptions of ancient coarse-grained meandering rivers are less common. Studies of deposits from Quaternary gravelly meandering rivers include Ori (1982) and Campbell and Hendry (1987). Kostic and Aigner (2007) used GPR to describe a coarse-grained deposit showing trough-shaped deposits interpreted to be braided rivers, which were superpositioned by laterally accreting coarse-grained deposits interspersed with sand. The upper deposits are interpreted to be from meandering fluvial deposits. McGowen and Garner (1970) compared coarse-grained meandering fluvial deposits of the modern Colorado River in Texas and the Amite River in Louisiana, with Pleistocene deposits of the Colorado River and the Eocene Simsboro Formation in Texas.

Facies

Miall (1985) describes eight fluvial architectural elements: Laminated sands (LS), overbank fines (OF), sand bedform (SB), foreset macroform (FM), sediment gravity flows (SG), channels (CH), gravel bedform (GB), and lateral accretion (LA). This study will tie these elements with the description of the outcrop. Architectural element LA forms the basis for this deposit, where the outcrop shows east and west dipping accretion across the outcrop. No clear cutbanks are seen, however, trenching has shown the western deposits of the outcrop to be discontinuous with the channel deposits further west, so no CH element is apparent. OF is seen throughout the floodplain, alongside sparse LS. GB is seen at the bottom of the channel deposits, overlain by SB. FM is present, but in most cases very faint and not visible until the covering sand-mud mixture is removed.

In preliminary studies of the outcrop, four facies are predicted: Floodplain, channel, counter point bar and point bar deposits. The CPB facies is thought to consist of siltstone with an inclusion of clay minerals, as well as occasional coarser sediments, up to granule sized material. These are deposited in inclined strata, which are very similar to fine-grained storm or flood derived draping mud deposits. The main difference between them is the ratio of the total depth of the deposits related to total channel depth. CPB deposits are more common towards the distal edges of the meanderbelt (Makeske and Weerts, 2005).

Inclined Heterolithic Strata (IHS) describes a larger than dune scale inclined stratification of alternating clay-sand lithology, earlier described as epsilon cross-stratification. The dipping beds can be the result of storm or flood events, or tidal influence, which leave a fine-grained drape upon the tops of regular point bar surfaces (Thomas et al., 1987). Some of the alternating lithology seen in this outcrop could be from IHS and not CPB deposition as the clay-rich deposits only cover the surface of the point bar.

The channel facies are thoroughly cross stratified, with sediment of medium to pebble grain sizes, alongside occasional mudclasts. Channel fills display a fining up succession, with the top of the point bar showing either ripple scale cross-stratification, or if clay-rich can show either parallel laminations or massive deposits.

The floodplain facies consist mainly of silt-sized sediments, with various amounts of smectite, which is probably of a volcanic origin. Thin, laterally continuous sandstones composed of very fine to fine grain size showing soft-sediment deformation are thought to originate from overbank splays. Roots and slickensides are not abundant, but occurrences do indicate paleosols (Bridge, 2003).

Flow Estimation

To estimate the flow depth, cross-set thicknesses will be measured. Using the Leclair and Bridge (2001) method, cross-set thickness is representative of one third of total dune height, and total flow depth is 4-20 times dune height, with 6-10 times being more common. The resulting data will be compared to the total bar height, which represents 80% of flow depth (Bridge, 2003). Flow velocity will be estimated using a crossplot of the bedforms vs. flow depth, as well as grain size (fig. 10) (Rubin and McCulloch, 1980). Incorporating channel width measurements with flow velocity will give an estimate of discharge.

Conclusion

This study will describe an ancient coarse-grained meandering fluvial deposit, including the counter point bar deposits contained therein. A facies architectural model will be created from gathered data, which will assist in reconstructing the channel belt geometries. Flow depth and direction will be assessed from the deposits. The study will determine whether clay-rich inclined strata are part of IHS or counter point bar deposition. Counter point bar deposits can appear similar to flood draped tidally influenced IHS, as seen in cross-section C-C' of figure 6, where the boundary between point bar and CPB deposits is not straight. A preliminary interpretation of the outcrop would be that the deposits represent one meander loop, where the east side of the outcrop has paleocurrent directions going to the south and the western side of the outcrop shows paleocurrents moving northwards, and the bilaterally downlapping inclined stratification shows the loop being on the northern side of the outcrop, which would give a westward translation of the entire meandering fluvial system. The results of the reconstruction will be validated with the theoretical model of point bar interconnectivity described by Willis and Tang (2010).

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Figures:

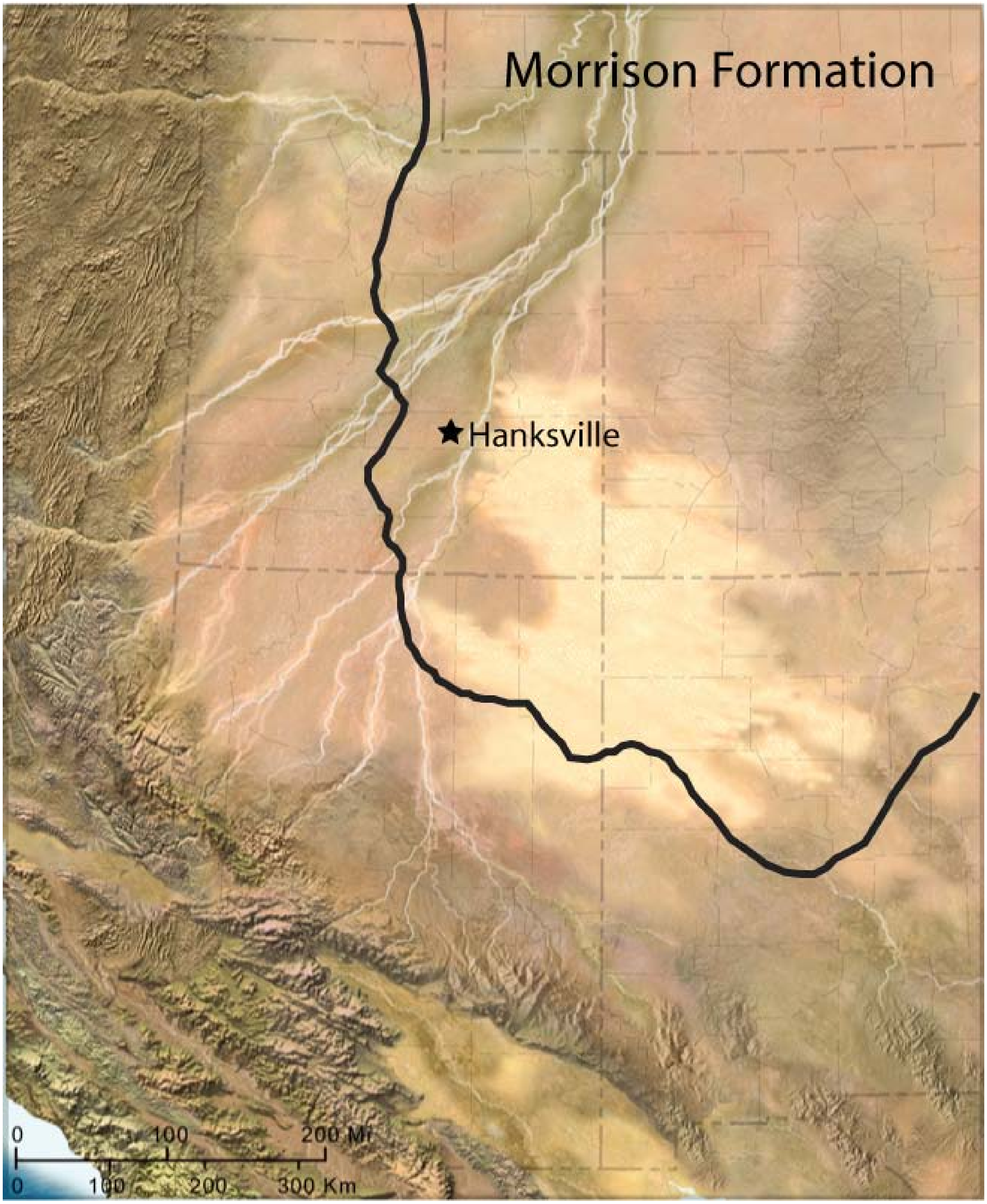

Figure 1. Paleogeographic map of the Colorado Plateau during the Late Jurassic. The Sevier orogeny is shown to the west, with rivers feeding sediments to the foreland basin on the east side of the map. Deposits of the Morrison Fm. are found within the black line. (Modified from Hasiotis, 2004 and Blakey, 2010)

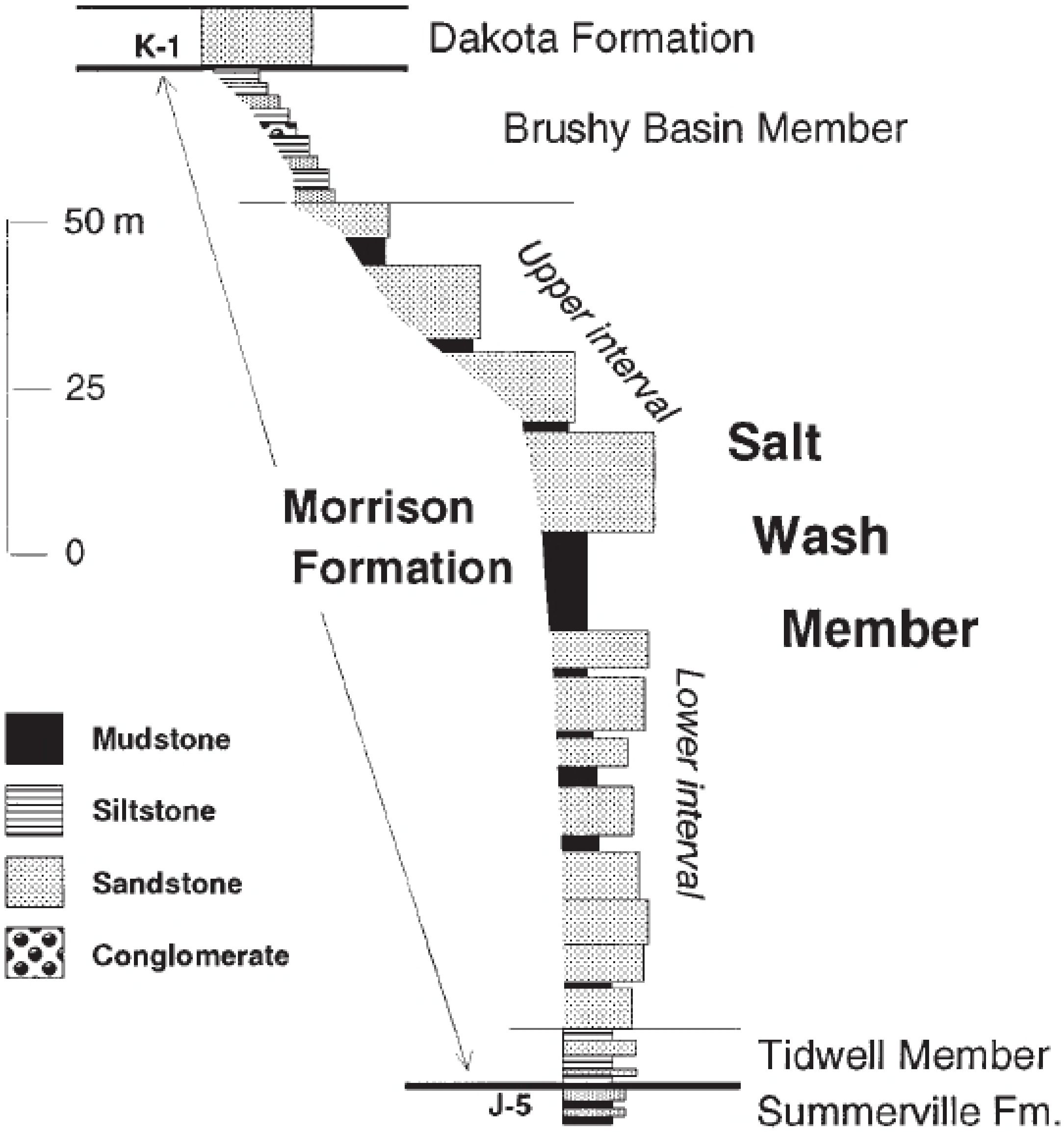

Figure 2. The Brushy Basin member of the Morrison Fm. conformly overlies the Salt Wash member. Notice the sandy to finer grained alteration of the Brushy Basin deposit. The Cretaceous Dakota Fm. overlies the Brushy Basin across a major erosional unconformity (Modified from: Robinson and McCabe, 1997).

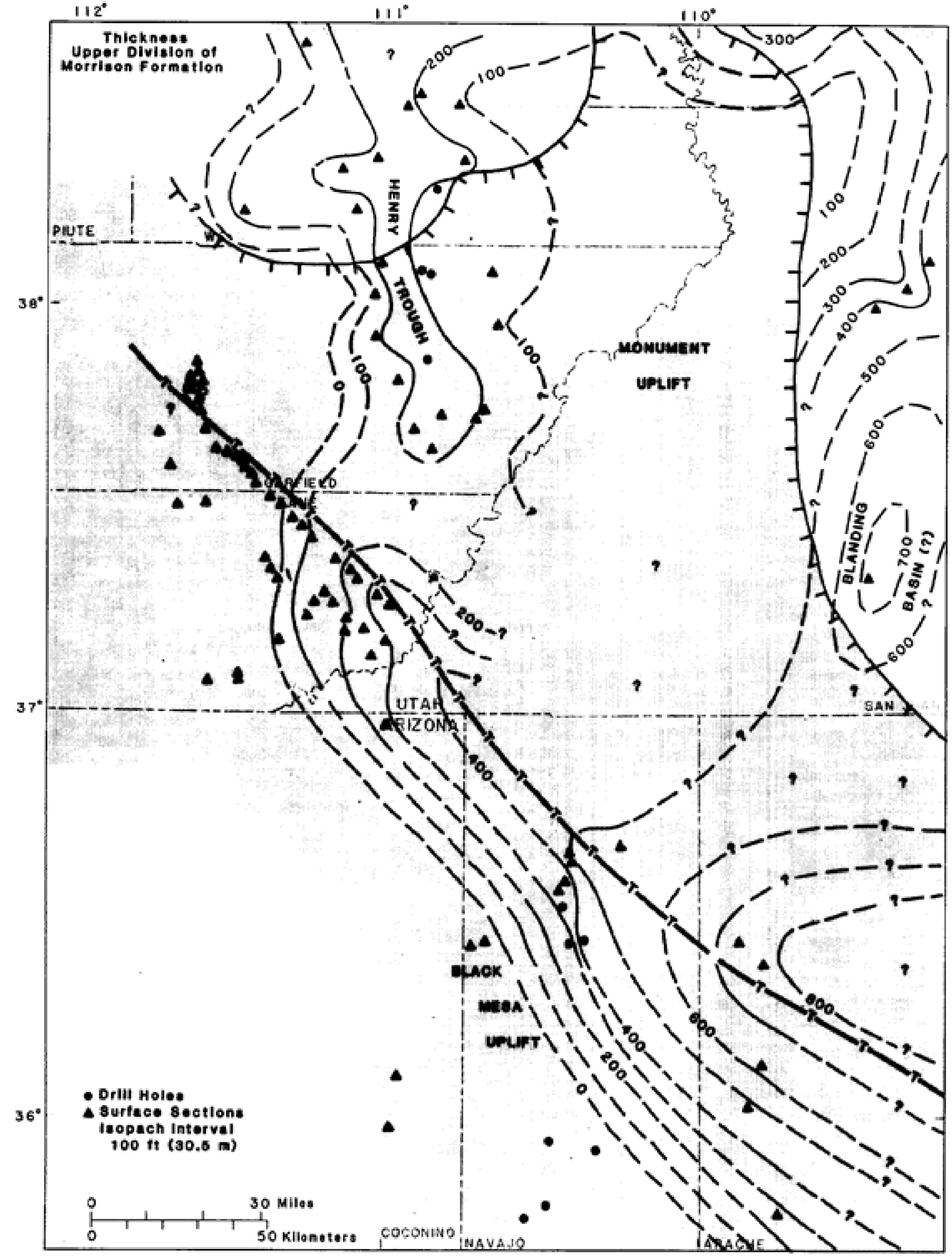

Figure 3. Isopach map of the Brushy Basin Member, showing the Black Mesa to the south and the Monument Uplift to the east, as well as where the Brushy Basin is deposited within the Henry Trough. Morrison Fm. deposits reach thicknesses of up to 800 meters to the southeast (From Peterson, 1986).

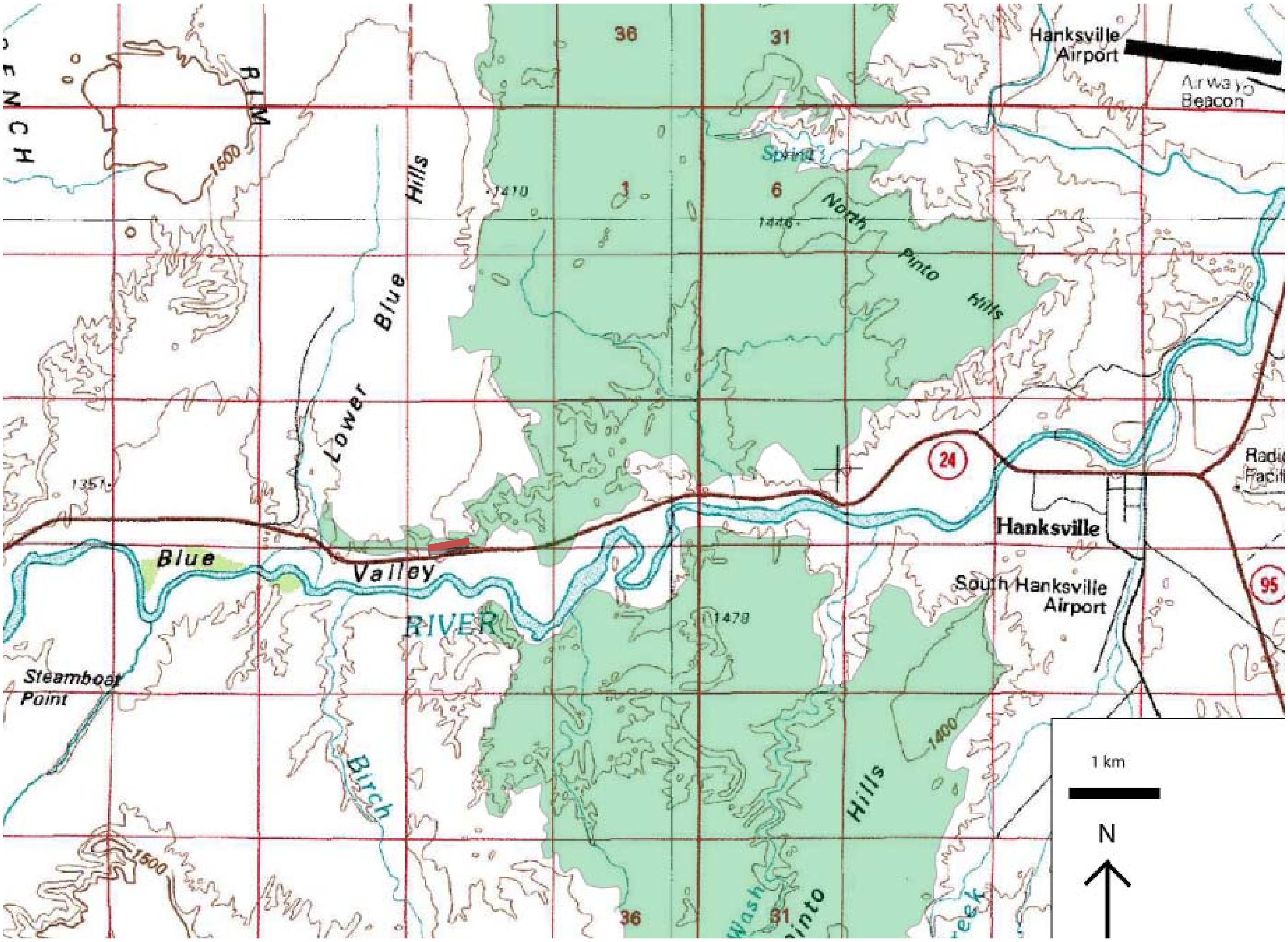

Figure 4. Map showing exposure of the Brushy Basin and Salt Wash Members of the Morrison Formation in green. Outcrop location marked by red line (modified from USGS Hanksville Utah, 1:10000 Topographic map; Williams and Hackman, 1971; Patterson et al., 1985; Google Earth).

Figure 5. Satellite view of outcrop. Red line equivalent to red line in figure 1, and denotes the total outcrop length of 200m. Notice the slight three-dimensionality of the outcrop (from Google Earth).

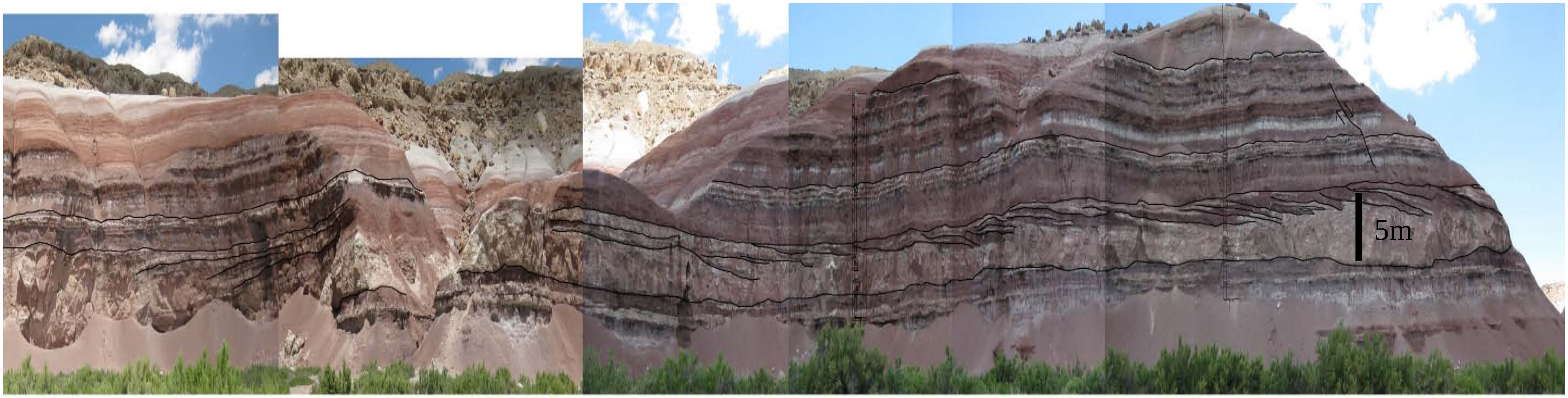

Figure 6. Basic bedding diagram showing bidirectional downlap of inclined strata, where the eastern side of the outcrop has east-dipping inclined beds, and the west side shows west-dipping beds. 200% vertical exaggeration

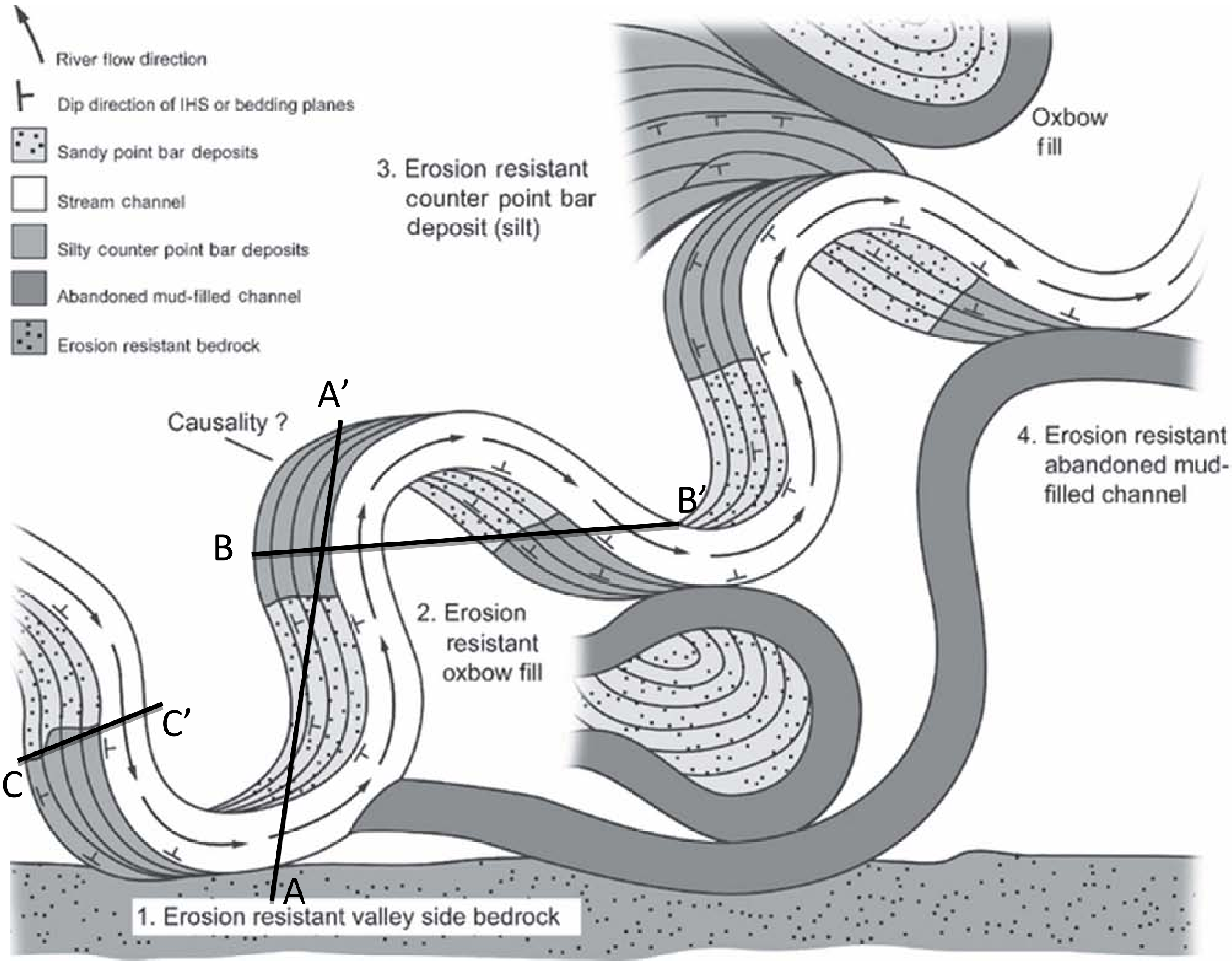

Figure 7. Diagram showing CPB deposition as the fluvial channel encounters the valley margin, oxbow lake fills, older counter point bars and mud-filled channels, and is forced to move from lateral to longitudinal downstream translation. Also notice the concave shape of the CPBs, and their location distally to the point bars. (Modified from Smith et al., 2009)

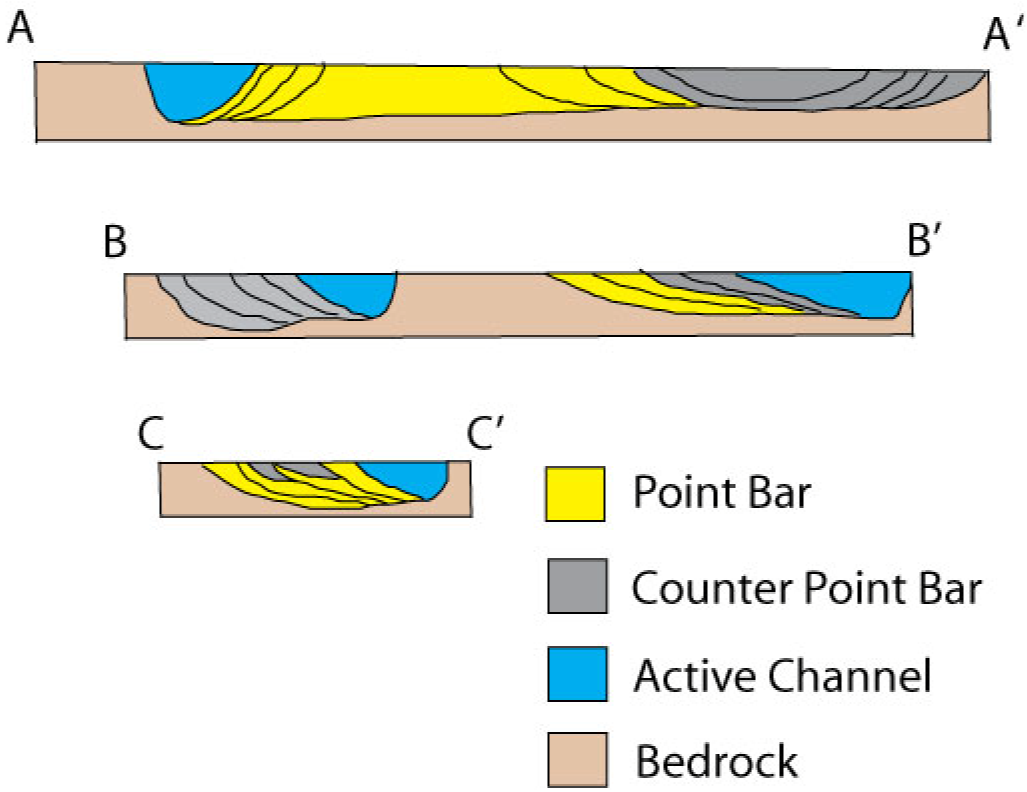

Figure 8. Cross-sections through figure 5 as shown above. A-A' shows a transect near parallel to the channel. Notice transition from point bar to counterpoint bar deposit, and the thickness of the counter-point bar deposits. Cross-section B-B' is directed at an angle across a meanderloop. It shows transition from counter-point bar to channel, and again from point bar to CPB to channel. In C-C', deposits from one reach of a meander is shown. This particular cross-section is interesting due to the boundary from CPB to point bar being wavy in map view, resulting in CPB deposits covering the tops of point bars.

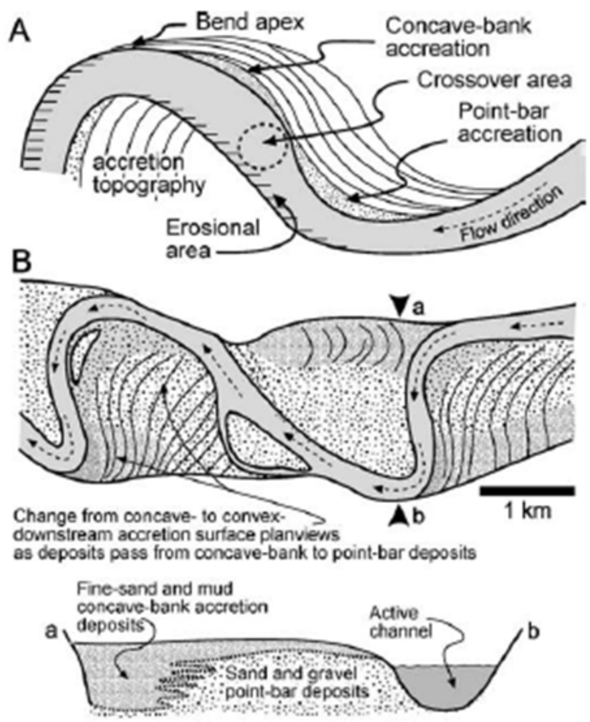

Figure 9. Diagram showing transition from point bar to counter point bar deposits. Notice interfingering of deposits in cross-section a-b. (From Willis and Tang, 2010, after Makeske and Weerts, 2005)

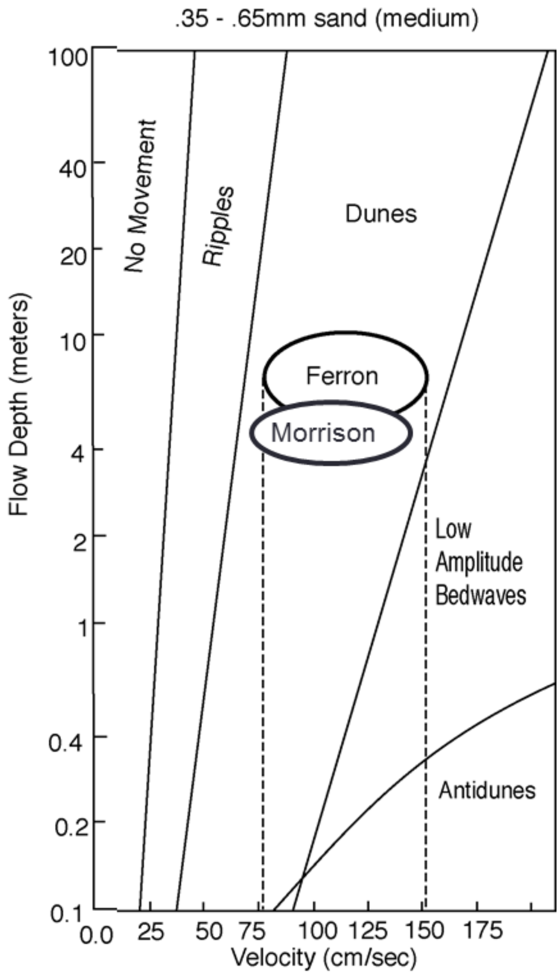

Figure 10. Diagram showing the flow velocity of the outcrop rocks derived from bedform, flow depth and grain size. Resulting velocity is 50-125 cm/s, but accuracy could be impacted by the coarser-grained deposits of the Brushy Basin Member outcrop. (Modified from 2010 Quantitative Sedimentology Consortion field trip guide, after Rubin and McCulloch, 1980)