A LATE HOLOCENE MEANDER-BRAID TRANSITION

OF THE LOWER MISSOURI RIVER VALLEY

by

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ABSTRACT

A LATE HOLOCENE MEANDER-BRAID TRANSITION

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Historically, the Lower Missouri River is known for being a temperate river that constantly and quickly reworks its floodplain with a braided network of channels; however, the river only recently became braided. Ox-bow lakes and landscape features resembling highly sinuous meandering loops mark the floodplain of the lower Missouri River Valley as scars of what was once a fully meandering Missouri River. The unanswered question then is, when did the lower Missouri River system change from meandering to braided? To answer this question we compared a series of newly created allostratigraphic maps of the lower Missouri River valley floor to establish a record of river pattern from types of channel loops and their cross-cutting relationships. In addition, OSL samples were strategically collected in order to date the last channel loops created by the meandering system and the first braids that formed after the transition completed. This study is focused on the lower Missouri River between Yankton, SD and Omaha, NE. The data suggest that the last change from meandering to braided in this section of the Missouri River occurred abruptly approximately 1600 +/- 200 yr B.P. Down-dip, from Kansas City, MO to the confluence with the Mississippi River, previous work done by Holbrook et al. (2005, 2006) in the lower reach of the river dates the meander-braid transition

from 3400-1200 yr B.P. Both shifts from meandering to braided appear to reflect changes in water and sediment supply because of climate change. We speculate the cause of the early transition onset down-dip to be due to changes in tributary inputs just south of the up-dip area caused by severe drought conditions.

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CHAPTER 1

INTRODUCTION

The Missouri River Basin drains ten US states and two Canadian provinces (Figure 1.1). Historically, the Missouri River is an actively changing river carving out the present Missouri River Valley through constant aggrading and incising of the river. Prior to channelization by the Army Corp of Engineers in the early 1900's, the untamed Missouri River had a history of changing its channel pattern from a highly sinuous meandering system to a fully braided system (Hallberg et al., 1979). Evidence of this change is still present today as meander scars and abandoned braided channels imprinted on the valley floor. This thesis will investigate the last substantial natural change in channel morphology/geometry over the valley reach from Yankton, South Dakota to Mondamin, Iowa (Figure 1.2). This investigation will be based upon allostratigraphic maps of this portion of the lower reach of the Missouri River and samples of bar sand collected for optically stimulated luminescence (OSL) dating.

The purpose of this investigation is to determine when the Missouri River changed from meandering to braided and to determine if it was an abrupt change or if there was an extended period of transition. The results of this investigation will then be discussed and compared with recent work done by Holbrook et al. (2005, 2006) in the lower reach of the river between Kansas City, Missouri and Overton Bottoms, Missouri (Figure 1.2). Mapping and dating the landforms and allostratigraphic units left by the Missouri River have provided a better understanding of the behavior of this understudied fluvial system.

Figure 1.1 Missouri River Basin
(Modified from *Missouririvermap.jpg*. Digital image. *Wikipedia*. Web. 1 Apr. 2012.
<http://en.wikipedia.org/wiki/File:Missouririvermap.jpg>.)

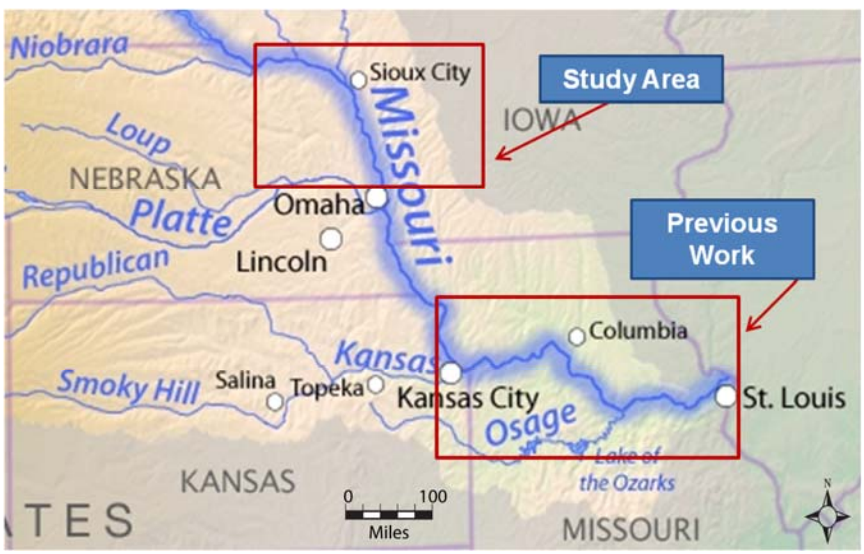


Figure 1.2 Location Map. Current Study Area and Previous Work Area (Holbrook et al., 2005, 2006)
(Modified from *Missouririvermap.jpg*. Digital image. *Wikipedia*. Web. 1 Apr. 2012.
<http://en.wikipedia.org/wiki/File:Missouririvermap.jpg>.)

CHAPTER 2

BACKGROUND

2.1 The Missouri River

The Missouri River is one of the longest in North America and is responsible for draining one-sixth of the conterminous United States. Nicknamed “The Big Muddy” for the unusually high suspended sediment load it carries (Figure 2.1). The muddy waters of the Missouri River begin their journey in Three Forks, Montana at the confluence of the Gallatin, Jefferson, and Madison Rivers. From there, the river flows 2,341 miles to its confluence with the Mississippi River in St. Louis, Missouri (Laustrup and LeValley, 1998). Draining 10 US states and the southern reaches of Alberta and Saskatchewan, Canada, the Missouri River Basin encompasses 529,350 square miles and experiences an elevation drop of approximately 13,600 feet from its headwaters to the Mississippi River confluence (Laustrup and LeValley, 1998). Today, the Missouri River no longer flows naturally. In the early 1900’s, the United States government straightened and channelized a large portion the river in order to control flooding and create a navigable channel (Table 2.1, Figure 2.2) (Hallberg et al.,1979, Laustrup and LeValley, 1998). Before channelization, the Missouri River carried around 320 million tons of sediment per year. After channelization, the sediment load dropped 75%, to around 80 million tons of sediment per year. At present, only one-third of the modern Missouri river length remains substantially unaltered by humans (Laustrup and LeValley, 1998).

Table 2.1 Summary of Changes in the Missouri River from 1879-1976 Due to Channelization (Modified from Hallberg et al., 1979)

Time Period	River Miles		Sinuosity		Channel Area		Water Area		Island Area		Bar Area	
	Miles	% Diff.	Ratio	% Diff.	Acres	% Diff.	Acres	% Diff.	Acres	% Diff.	Acres	% Diff.
1879-1890	+3.7	+2%	1.50-1.52	+1%	-9,086	-11%	-21,140	-37%	-3,986	-41%	+14,671	+99%
1890-1923	-14.3	-7%	1.52-1.42	-7%	+5,240	+7%	+9,031	+25%	+5,075	+98%	-9,496	-32%
1923-1976	-18	-9%	1.42-1.30	-8%	-61,652	-80%	-30,228	-66%	-11,513	-99.9%	-19,911	-9.9%

Figure 2.1 Color difference indicates a change in sediment contents, showing the high suspended load carried by the Missouri River. (a) (Top) Missouri River/Mississippi River confluence, true color. (b) (Bottom) Missouri River/Mississippi River confluence, false color. (Missouri River/Mississippi River Confluence. Digital image. *Google Earth*. Web. 5 May 2011.)

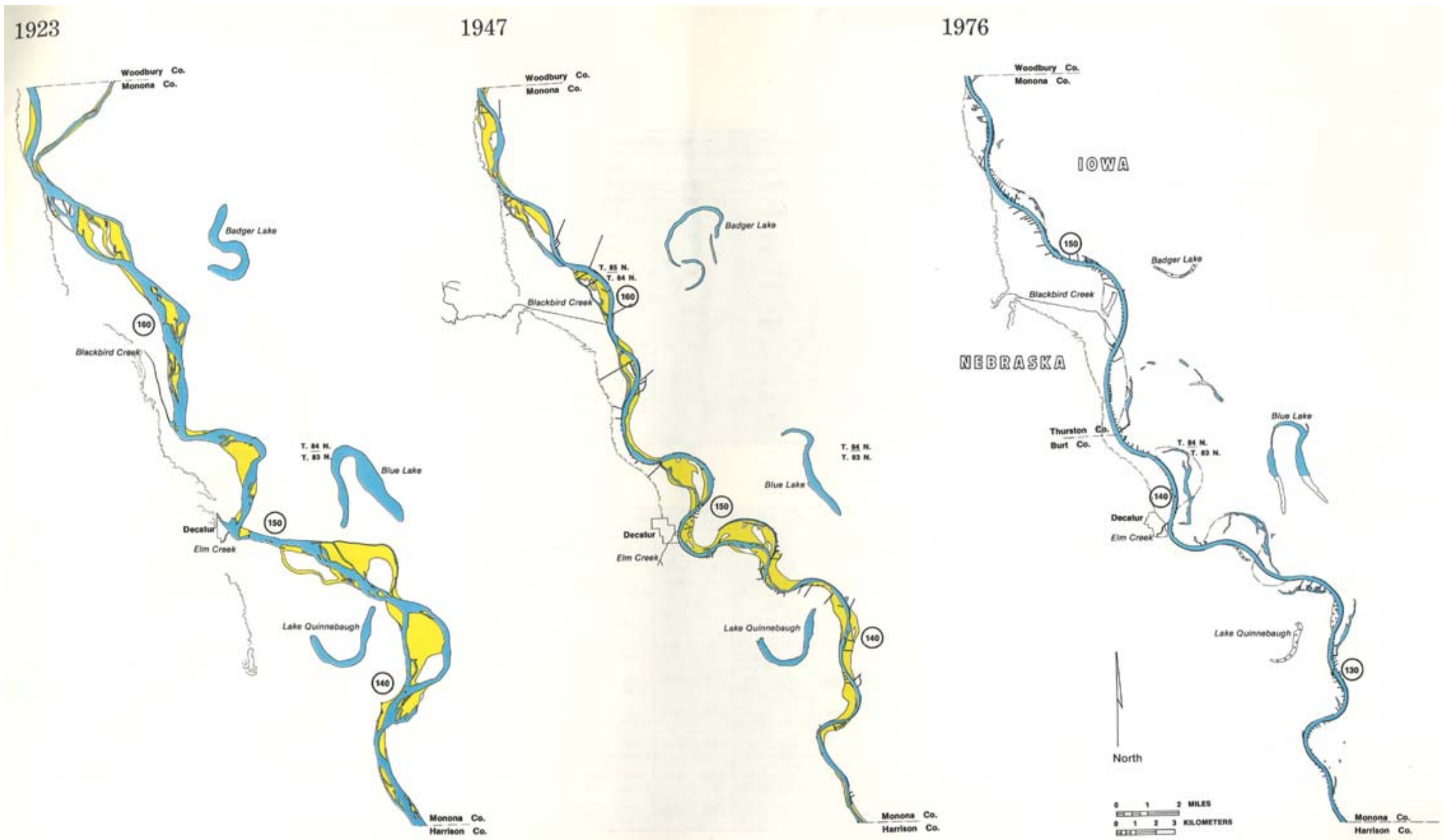


Figure 2.2 Progression of morphological changes in the Missouri River, Monona County, IA due to channelization; 1923-1976. (Hallberg et al., 1979)

2.1.1 Previous Work

The Missouri River is one of the largest in the United States but it is also one of the least geologically researched, especially when compared to the Mississippi River (Blum and Törnqvist , 2000, Jacobson and Oberg, 1997, Saucier, 1974, 1994, Smith and Winkley, 1996). Most of the scientific research conducted on the Missouri River is focused on archaeology (Ahler et al., 1974, Wedel 1967) or biology/ecology (Jacobson et al., 2010, Braaten et al., 2010). There have also been numerous studies, done by or in cooperation with The University of Nebraska-Lincoln, on the glacial loess deposits that cap the valley walls of the Missouri River Basin (Lugn, 1962, Schultz and Frye, 1968).

Research on the river itself is scarce, but does exist. One of the first maps of the Missouri River was created by Meriwether Lewis and William Clark during the Lewis and Clark Expedition of the Louisiana Purchase from 1804-1806 (Figure 2.3). Lewis and Clark were among the first to document and describe the Missouri River (Moody et al., 2003). In the early 1900's, prior to the channelization of the river, there were also several evaluations of geologic history, flood behavior, and channel patterns of the Missouri Basin (e.g. Condra, 1908, Duncanson, 1909, Todd, 1914). More recently, a study by Hallberg et al. (1979) through the Iowa Geological Survey documents the changes in the Missouri River from Sioux City, IA to Nebraska City, IA during the period 1879 – 1976 (Table 2.1, Figures 2.2 and 2.4) and some of the river's geologic history.

Most valuable to this project is the recent research conducted by Holbrook et al. (2005, 2006) who mapped a series of quadrangles along the lower part of the Missouri River between Kansas City, Missouri and Overton Bottoms, Missouri, closer to its confluence with the Mississippi River. OSL samples were acquired to determine the onset of the change from meandering to braided patterns. Results from those studies showed that the river in this area began the transition around 3400 yr B.P. and ended 1200 yr B.P.

Figure 2.3 Portion of a historic map from the Lewis and Clark Expedition of the Missouri River in 1804 showing the river's braided pattern (Moody et al., 2003)

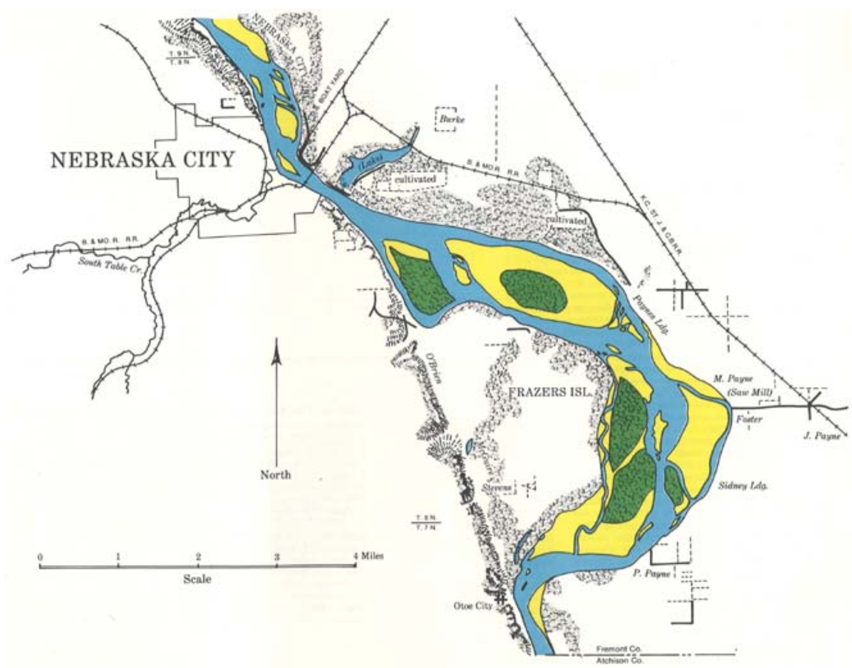


Figure 2.4 Portion of the 1890 Missouri River Commission map sheet 21. Channel area shown in color; blue-water, yellow-sand bar, green-vegetated island (Hallberg et al., 1979)

2.2 Holocene Climate

The Holocene is preceded by a period of late Pleistocene cooling and glaciation. The Last Glacial Maximum (LGM) is the coldest period of the last glacial advance, occurring approximately 24,000 years ago during the Pleistocene Epoch (Anderson et al., 2007, Roberts, 1989). During this time, glaciers reached their peak extents and sea levels were as much as 100 m lower than they are today (Roberts, 1989). Temperatures slowly rose until around 13,000 yr B.P. when the Late Glacial Maximum warming event occurred, causing accelerated glacial melting. The Late Glacial Maximum continues until the Pleistocene ends and the Holocene epoch begins around 11,500 yr B.P. During the early Holocene, glaciers continued to retreat and the Earth's crust began an isostatic adjustment as the weight of glacial ice was removed. In the mid-Holocene, around 6000 yr B.P., sea level began to stabilize rising only slightly to reach present day levels (Roberts, 1989). The late Holocene was not stable climatically. Climate proxies for this time period show shifts occurring regionally and rapidly (Valero-Garcés et al., 1997, Laird et al., 1998, Baker et al., 2000, Denniston et al., 2007, Nordt et al., 2007).

2.2.1 Holocene Climate in the Missouri Basin

Holocene climate studies in the Great Plains region indicate that climate shifted back and forth from cool/humid conditions to warm/arid conditions many times over the Holocene, punctuated with intermittent periods of extreme drought (Valero-Garcés et al., 1997, Laird et al., 1998, Baker et al., 2000, Denniston et al., 2007, Nordt et al., 2007).

Approximately 9000 – 6000 yr B.P., plant macrofossils and pollen in southeast Nebraska show a decline in upland forests replaced by prairie plants and grass, indicating that climate in the Great Plains region was gradually shifting from cool and humid to warm and dry (Baker et al., 2000). Using a combination of pollen, diatoms, and stable isotopes ($\delta^{18}O$ and $\delta^{13}C$), a study in the northern part of the basin at Moon Lake in North Dakota showed similar results: a shift to more arid conditions, reaching a maximum Holocene aridity around 6500 yr B.P. (Valero-Garcés et al., 1997). Between 5800 yr – 3100 yr B.P., arid conditions persisted but were on the decline. Pollen and macrofossils from southeast Nebraska show an increase in riparian forests and a continuing prominence of prairie lands indicating a slight shift to cooler humid conditions but still experiencing periods of drought (Baker et al., 2000). In addition to evidence from lake levels in the northern Great Plains indicating an overall increase in moisture (Valero-Garcés et al., 1997), temperature records taken from stable isotopes ($\delta^{13}C$) of buried soil organic matter (SOM) in this region indicate a slight decrease in temperature during this time as well (Nordt et al., 2007). Alternatively, further south near central Missouri, $\delta^{13}C$ values collected from stalagmites indicate a period of aridity from 3500 yr – 2600 yr B.P. (Denniston et al., 2007). Optical and radiocarbon dating of dune deposits in north-central Kansas suggest that dune fields in the eastern Platte River valley were active 4300 - 3500 yr B.P. indicating severe drought conditions (Hanson et al., 2010).

By 3000 yr B.P. the Great Plains experienced a cooling trend with landscape vegetation becoming similar to the present day grasslands. All evidence of forestation in southeast Nebraska had disappeared and the region was covered by a vast prairie (Baker et al., 2000). Periods of increased moisture became more frequent, but were still punctuated with occasional drought (Baker et al., 2000). By 2700 yr B.P., climate became moderate with little change into the present (Baker et al., 2000). In the northern Great Plains, climate was not stable, and showed an overall trend toward cool/humid conditions. Lake sediments from North Dakota show higher frequency of low lake levels indicating that there were more frequent periods of drought in the north (Valero-Garcés et al., 1997, Laird et al., 1998). Temperature records taken from stable isotopes ($\delta^{13}C$) of buried soil organic matter from this region indicate a temperature increase from 2600 yr - 1000 yr B.P. as well (Nordt et al., 2007). The $\delta^{13}C$ values from buried soil organic matter in North Dakota coincide with $\delta^{13}C$ values collected from stalagmites in central Missouri (Denniston et al., 2007) suggesting that this warming trend could have been regional.

2.3 River Patterns and Channel Geometry

The channel pattern of a river is said to be defined by the sinuosity of its fragments and how it splits around braid bars or islands (Bridge, 2003). River channel patterns are often defined using aerial photographs and/or maps of the river during a time of normal flow (Bridge, 2003). A river can be classified as either a single channel or a multi-channel system. If the river is a single channel system, its channel pattern can then be classified as either straight or meandering (Figure 2.5). If the river is a multi-channel system, its channel pattern can then be classified as either braided or anastamosing (Figure 2.5).

There are a number of publications that classify the different types of channel patterns and describe how different variables affect each one. Bridge (2003), Kleinhans (2010), Manglesdorf et al. (1990), Miall (1996), and Schumm (1985) are a few good references that break down the different types of river patterns. Miall (1996) and Bridge (2003) provide a thorough geologic review of fluvial systems. Both cover a wide range of topics including deposition, sedimentary structures, and the effects of climate change. Mangelsdorf et al. (1990) also gives a good breakdown of the differences between bedload and suspended load.

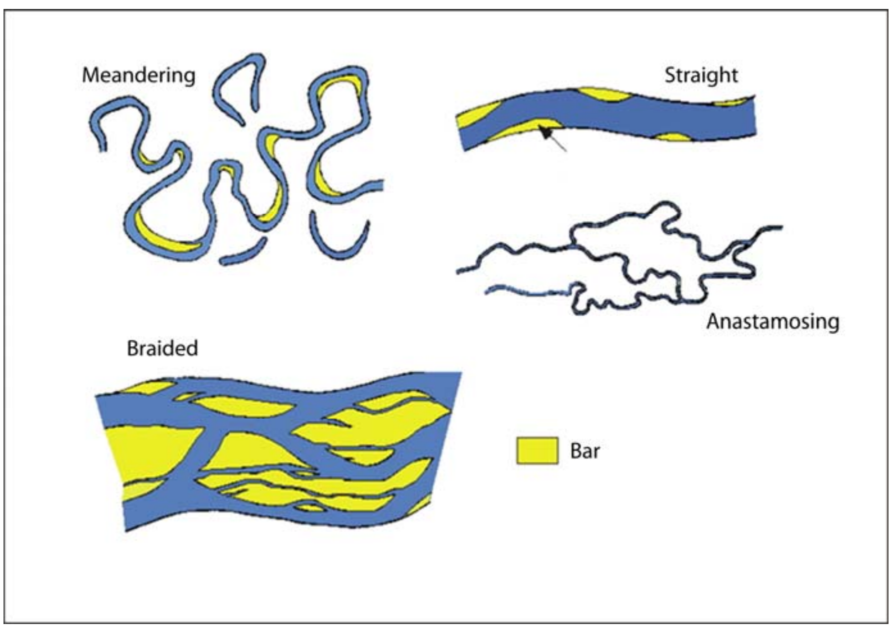


Figure 2.5 Types of channel patterns (Modified from Bridge, 2003)

2.3.1 Multi-channel Pattern: Anastamosing vs. Braided

A multi-channel river pattern is defined as the splitting of channels around bars, islands, or floodplains (Bridge, 2003). There are two multi-channel pattern classifications: anastamosing and braided. Anastamosing patterns, sometimes referred to as anabranching, are a multi-channel system of sinuous channels that are divided by areas of floodplain larger than their largest bars. A braided pattern is a multi-channel pattern in which there is a single channel that is split into a number of smaller channels by mid-channel bars and/or islands. Braided channels are known to change appearance after a heavy flood due to the re-working of unstable un-vegetated bars.

Braided rivers are generally characterized by a wide shallow channel that contains a smaller multi channel system (Figure 2.6). A braided channel will typically have mid-channel bars or islands but can also have side-attached bars. These types of rivers carry a heavy bed load of coarse grain material such as gravel and/or sand (Figure 2.6). Discharge in braided channels tends to have low velocity.

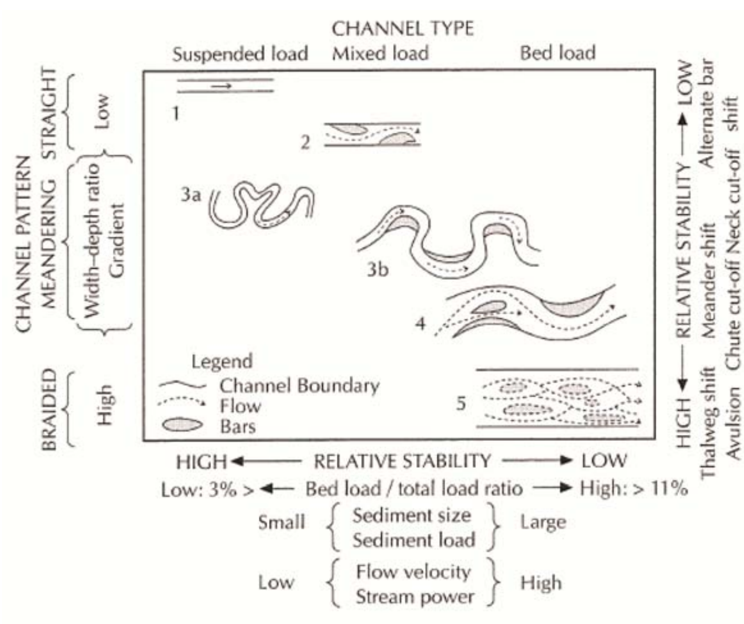


Figure 2.6 Controls on channel patterns (Bridge, 2003)

2.3.2 Single Channel Pattern: Meandering vs. Straight

There are two single channel pattern classifications: meandering and straight. Single channel pattern classification is based in sinuosity of the channel. If a channel has a sinuosity of 1.5 or greater, it is said to be meandering. Channels with sinuosity lower than 1.5 are considered straight even though they do exhibit some sinuosity and are in fact not geometrically straight. The sinuosity value of 1.5 is an arbitrary number which is generally accepted (Bridge, 2003). Three general equations that are used to determine sinuosity are: channel thalweg length/valley length (Leopold and Wolman, 1957, Rust, 1978), channel centerline length/valley length (Brice 1984, Schumm 1985), and channel length/channel belt axis length (Brice, 1964) (Figure 2.7).

Meandering rivers are generally characterized by a single channel which is deep and often times narrow. A meandering channel will typically have sand bars attached to the side, side-attached bars or point bars, and be sinuous to highly sinuous. These types of rivers carry a large suspended load of clay and/or silt to bedload ratio (Figures 2.6 and 2.8). Discharge in meandering channels tends to have high velocity. A river takes on the meandering pattern when it cuts down into the sediments rather than spreading out over the landscape.

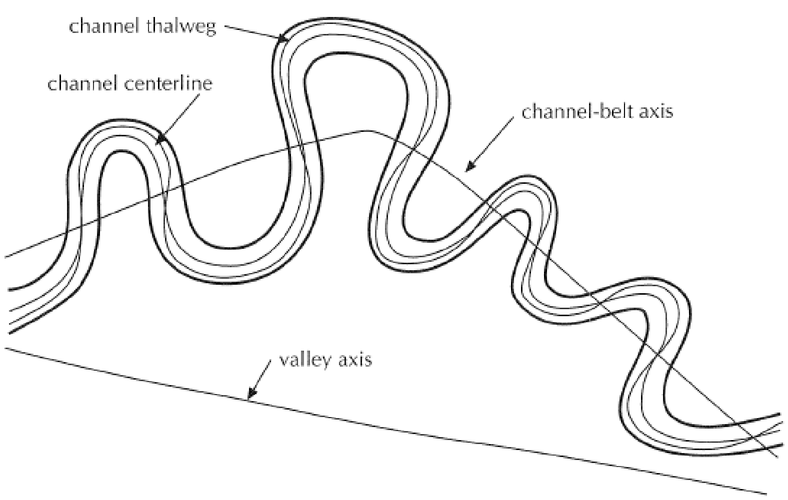


Figure 2.7 Factors used to determine channel sinuosity (Bridge, 2003)

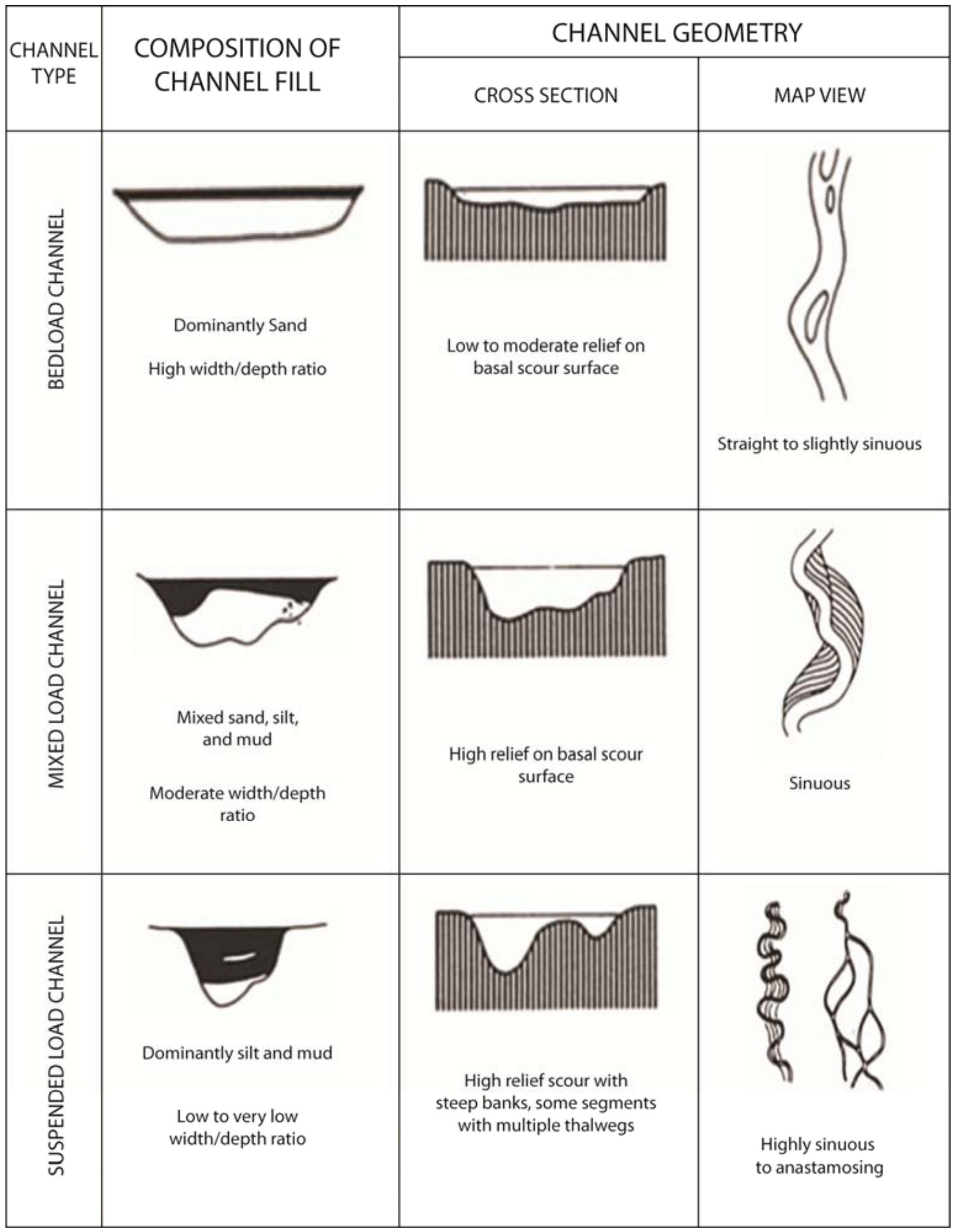


Figure 2.8 Channel geometry with cross-sections showing width to depth ratios as a function of sediment size. (Modified from Miall, 1996)

2.4 Controls on Channel Morphology

There are a number of variables that can affect the geometry of a river. Water supply, sediment supply, sediment type, vegetation, and slope are the fundamental variables (internal controls) that give a river its geometry. The major external controls on these variables are tectonic activity and changes in climate. These controls can affect the morphology of a river regionally and locally. Sensitivity to changes in both external and internal controls varies from river to river due to the complex nature of the fluvial system (Miall, 1996, Veldkamp and van Dijke, 2000, Bridge, 2003, Vandenberghe, 2003). It is important to remember that individual rivers have unique thresholds on internal controls that can affect how and to what degree the river will respond to changes (Schumm 1977, Veldkamp and van Dijke, 2000, Blum and Törnqvist, 2000). Here we discuss typical river responses to external controls.

2.4.1 Tectonic Activity

Tectonic movement changes the gradient (slope) of a river's longitudinal profile and can influence changes in base-level, which affect sedimentary accommodation space as well as regional and basin wide changes in slope (Miall, 1996). When a basin encounters lateral ground tilting, it affects the river as a whole. Tectonic activity can cause a river to gradually migrate laterally, avulse, or, if the river is already in a stable point of the basin such as a low point, it will gradually infill the depression (Peakall et al., 2000). Pulses of tectonic uplift can also be associated with changes in sediment supply to a coarser grained material (Miall, 1996).

A river's response to local valley floor deformation can produce anomalous behavior in small stretches of the river. Tectonic activity can cause tributary streams on a valley floor to change their orientation; channels will have a tendency to orient in the direction of surrounding faults (Spitz and Schumm, 1997). If the valley floor is uplifted, the river will shift and deflect around the area of uplift. Alternatively, if there is subsidence, the channel will move into the subsided area (Holbrook and Schumm, 1999). When a channel encounters a change in slope, it adjusts its longitudinal profile by altering its channel pattern (Figure 2.9). An increase in slope will cause the channel to increase its sinuosity whereas a decrease in slope will cause the channel to decrease sinuosity (Spitz and Schumm, 1997, Holbrook and Schumm, 1999). In the backtilted or backwater area, the river will experience aggradation, a decrease in the occurrence of overbank flooding, and a bedload grain size decrease. In the foretilted area, the river will experience incision, an increase in the frequency of overbank flooding, and a bedload grain size increase (Spitz and Schumm, 1997, Holbrook and Schumm, 1999).

Examples of channel pattern response to tectonic deformation are found on the Mississippi River. Spitz and Schumm (1997) describe a reach of the Mississippi River that displays an anomalous pattern linked to tectonic activity. As the river flows into the backtilted area, slope of the longitudinal profile is reduced causing the channel to aggrade. When the river reaches the downstream side of the uplift, the channel pattern becomes highly sinuous, compensating for the steepness of the slope.

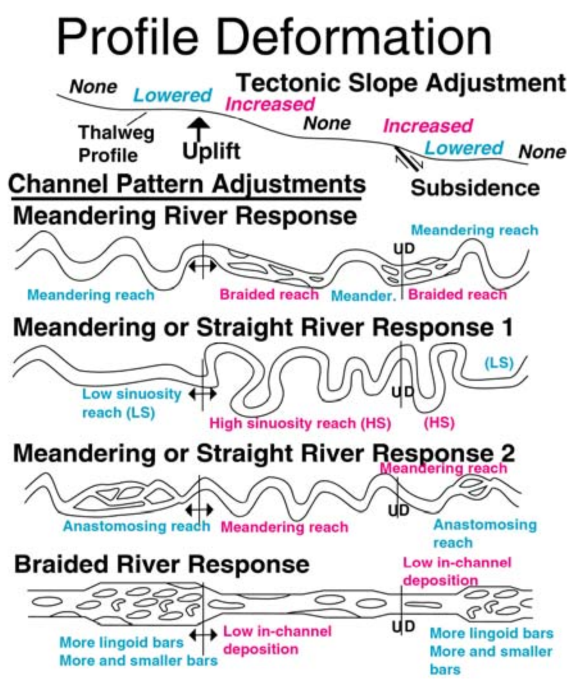


Figure 2.9 River responses to tectonic slope adjustment (Holbrook and Schumm, 1999)

2.4.2 Climate Change

Climate change affects precipitation and temperature. Precipitation and temperature control the occurrence of flooding, drought, and vegetation which in turn affects discharge and sediment supply. Discharge and sediment supply are the two major factors that control the geometry of a river. They also determine whether a river will erode (incision) the surrounding sediments or deposit (aggradation) new sediments. Climate change also changes sea level, which affects the base-level of a river, forcing the river to accommodate the change by adjusting its profile through either incision or aggradation.

Incision and aggradation of a river can be tied to changes in temperature. Incision tends to occur when a transition from either warm to cold or cold to warm occurs (Vandenberghe, 1995). For example, if there is a drop in temperature, evapotranspiration is reduced causing increased surface runoff. When there is a high ratio of discharge to sediment supply, the river will incise (Vandenberghe et al., 1994, Vandenberghe, 1995). Vegetation is not necessarily disturbed by the initial temperature drop, but can be affected over time. If the vegetation biomass is reduced, there will be an increased sediment load. Coupled with the initial increase in runoff, the river will take on a more braided-like channel pattern then begin aggrading (Vandenberghe et al., 1994, Vandenberghe, 1995). The effects of temperature on vegetation play a key role in how the geometry of the channel will change. Dense vegetation increases bank stability and soil cohesion, reducing sediment supply, typically resulting in a single-channel meandering pattern. If a shift in temperature were to dramatically reduce the amount of vegetation, bank stability and soil cohesion would also be reduced resulting in an increase in sediment supply which could cause the channel pattern to change from meandering to braided.

2.5 Dating Holocene Fluvial Deposits

There are a number of techniques that can be used to date Quaternary deposits. Most techniques fall into one of three categories: providing numerical age estimates, providing relative ages, or establishing age equivalencies (Lowe and Walker, 1997). Common techniques include radiocarbon dating, uranium series dating, potassium-argon and argon-argon dating, fission track dating, and luminescence dating. For the purposes of this project we are concerned only with the luminescence techniques. Details on the other methods listed can be found in Lowe and Walker (1997).

There are two types of luminescence dating techniques, thermoluminescence and optically stimulated luminescence. Thermoluminescence dating is the measurement of emitted light from a heated particle which is proportional to the number of electrons. The intensity of the emitted light is a product of the amount of radiation the particle received per year, thus allowing an age to be calculated. Optically stimulated luminescence (OSL) dating is the technique of measuring light-sensitive gamma radiation trapped in single grains of minerals to determine the ages of young alluvial deposits. Quartz or feldspars are the most common minerals used for OSL dating, making the technique ideal for dating fluvial sand deposits (Table 2.2).

Table 2.2 Applications of Luminescence Dating (US Geological Survey. Crustal Geophysics and Geochemistry Science Center. USGS Luminescence Dating Laboratory. Web. 8 Mar. 2012. <http://crustal.usgs.gov/laboratories/luminescence_dating/applications.html>)

Application	Context
Tectonic and paleoseismic	Marine, fluvial, lacustrine, slope deposits
Paleoclimatic and paleoenvironmental	Wide range of sediments
Geomorphic and Quaternary	Wide range of sediments
Environmental and process studies	Soils, fluvial, potential for wider range
Archaeological and paleoanthropological	Fluvial, colluvial, soils, heated/fired materials

The use of OSL dating on late Quaternary deposits is a technique that is becoming more common (Ballarini, 2006, Rodnight et al., 2005, Rittenour et al., 2005). The OSL method was successfully used to date the meander-braid transition in the lower reach of the Missouri River (Holbrook et al., 2005), which we will be comparing to the OSL dates recovered in this study. Previous studies have also been successful in using OSL dating to gain high resolution age control on fluvial deposits (Wallinga et al., 2006). Ballarini (2006) gives a good basic explanation of what OSL is and an overview of the different methods that can be used. See Aitken (1998) for a technical reference of how OSL works, laboratory techniques, and how the technique is applied to dating Quaternary sediments.

CHAPTER 3

METHODS

In 2007, students working with Dr. John Holbrook and Dr. Ron Goble, with funding from the NSF-REU and USGS-EDMAP programs, began creating a series of allostratigraphic maps and collecting OSL samples along a portion of the lower Missouri River from Yankton, SD to Decatur, NE. In the summer of 2010, 10 undergraduates and 2 graduate students added 6 quadrangles to the data set; Tekamah NW, Tekamah, and Herman, NE on the west side of the river and Blencoe, Little Sioux, and Mondamin, IA on the east side. Each quadrangle was mapped by a team of 2 students under the supervision of Dr. Holbrook. Fellow graduate student Daniel Carlin and I were responsible for mapping the Mondamin, IA quadrangle. Location of samples for OSL dating was determined by the participating students under the supervision of Dr. Holbrook. Prior to the 2010 field season, OSL data from previous years were reviewed to determine if any significant areas were overlooked. Once collected, OSL samples were then taken by the 2010 team of undergraduates to Dr. Goble at The University of Nebraska-Lincoln for processing.

3.1 Allostratigraphic Mapping

An allostratigraphic unit, or allounit, is defined as a mappable body of sedimentary rock that is defined and identified on the basis of its bounding discontinuities (NACSN, 1983). Topographic maps, aerial photographs, digital elevation models (DEM), and soil maps for each quadrangle were used as the database for the target area (Figure 3.1). These data were analyzed for topographic features and visible changes in the landscape that indicate surface expression of bounding discontinuities. Basic assumptions from our observations, in combination with established sedimentary architectural models (Miall, 1996), were used to establish possible mappable allounits in the target area. Mapped allounits included, but were not limited to, abandoned-channel fills, sand bars, splays, terraces, and backswamp.

The possible units interpreted and drawn on the topographic maps created a series of hypothetical maps that could be taken into the field (Figure 3.1). These hypothesis maps were then tested in the field with soil sampling using the Dutch hand-auger drilling method. Soil samples for each borehole were logged in 10 cm increments and described based on color, texture, and oxidation state. Colors were determined using a Munssell Soil Color Chart. Textures are based on the USDA soil-texture triangle (Figure 3.2) and the Guide to Texture by Feel (Figure 3.3).

Map units predicted from remote-sensed data were field tested by confirmation of lithofacies consistent with the predicted landform. For instance, a series of topographic ridges protruding in a dendritic pattern from the outer edge of an arced topographic trough in the remote data could be predicted to record a splay deposit on the outer edge of an abandoned-channel fill. If the landform is a splay, drilling there should produce mostly silt loam with possible sand and mud and the sequence would be less than 3m thick. If the sediment sequence matches that of a splay, then the hypothesis is supported, if not then another hypothesis is formed and tested. Ultimately, continued use of this technique produces a final map of the lithologic characteristics and allounits in the study area. The final maps were then digitized using ESRI ArcGIS software. These maps have been edited and analyzed by a group of students at The University of Texas at Arlington. The maps were sent to The University of South Dakota for publication following the format of Saucier (1994) and are in press.

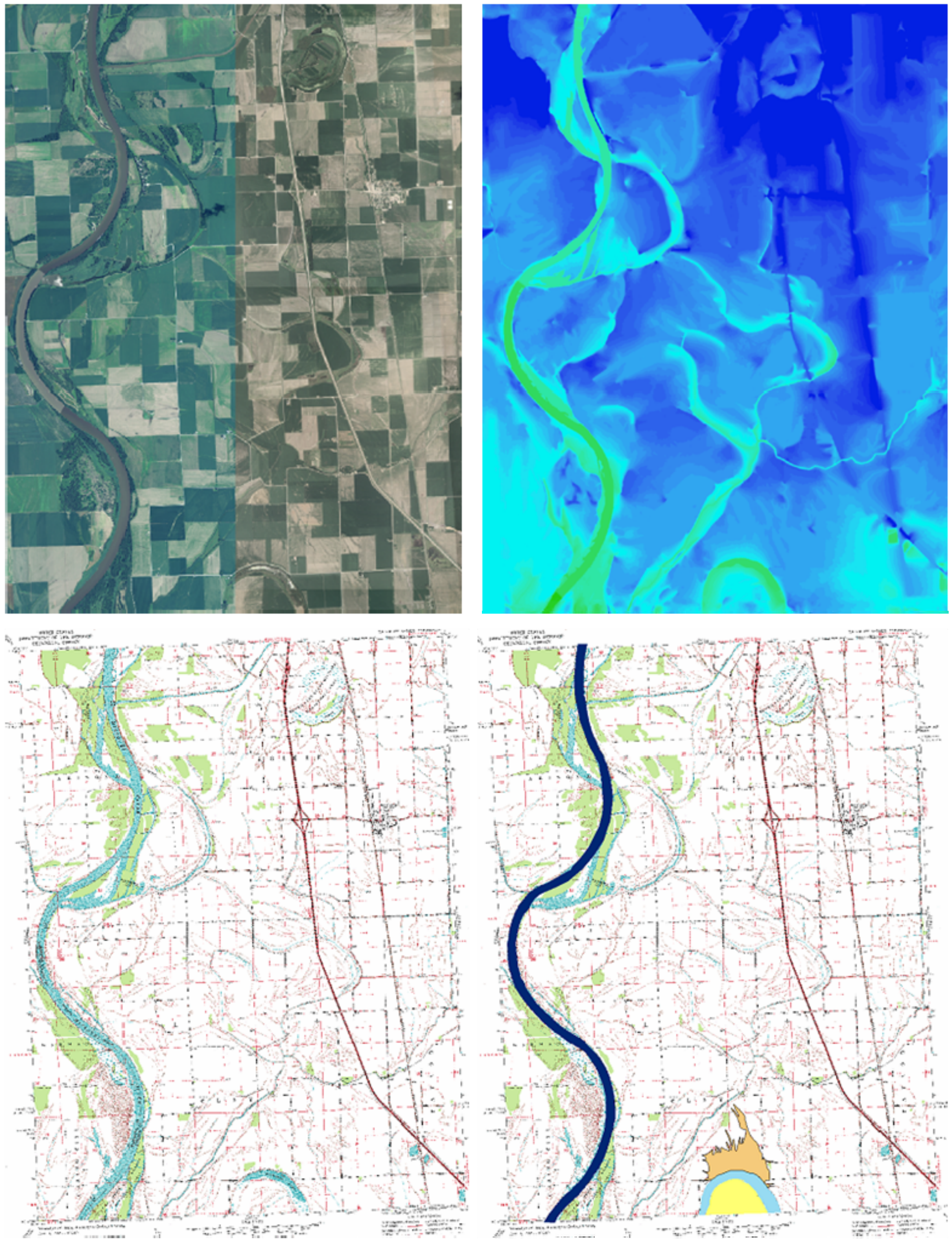


Figure 3.1 Base maps used to create allostratigraphic maps. (Top left) Aerial photograph, (Top Right) Digital elevation model, (Bottom Left) USGS 7.5 minute topographic map, (Bottom Right) Example of a hypothesis map

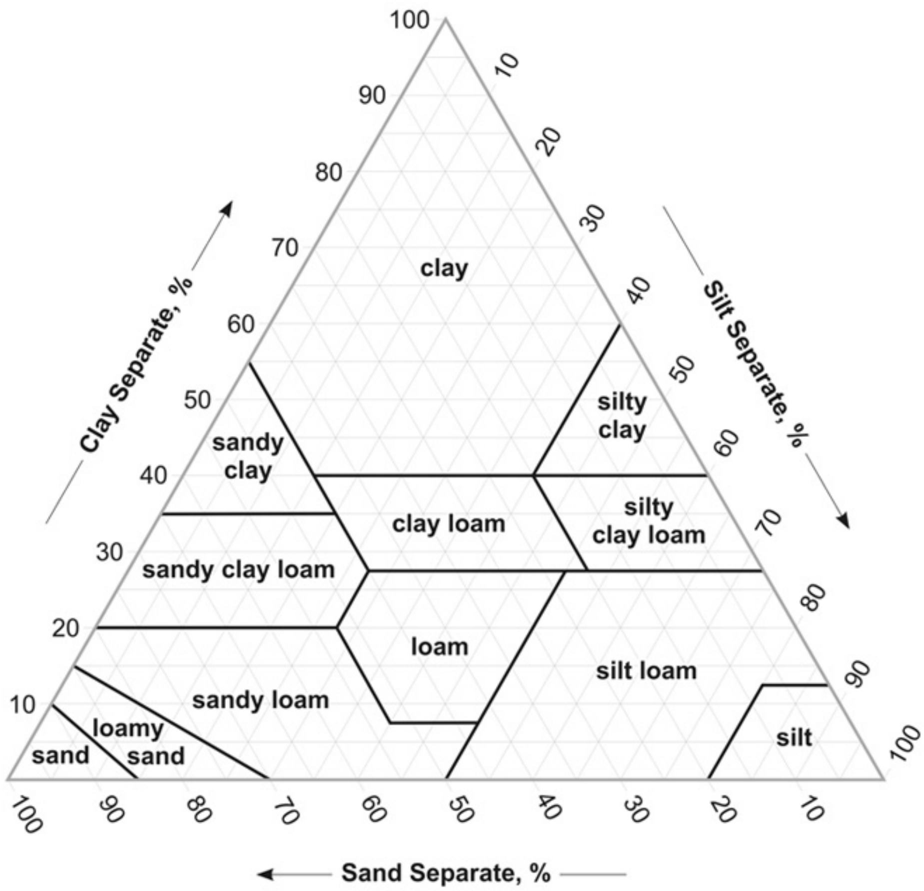


Figure 3.2 USDA Soil -Texture Triangle
(*Soil Textural Triangle*. Digital image. *United States Department of Agriculture*. Web. 28 Mar. 2012. <http://soils.usda.gov/education/resources/lessons/texture>)

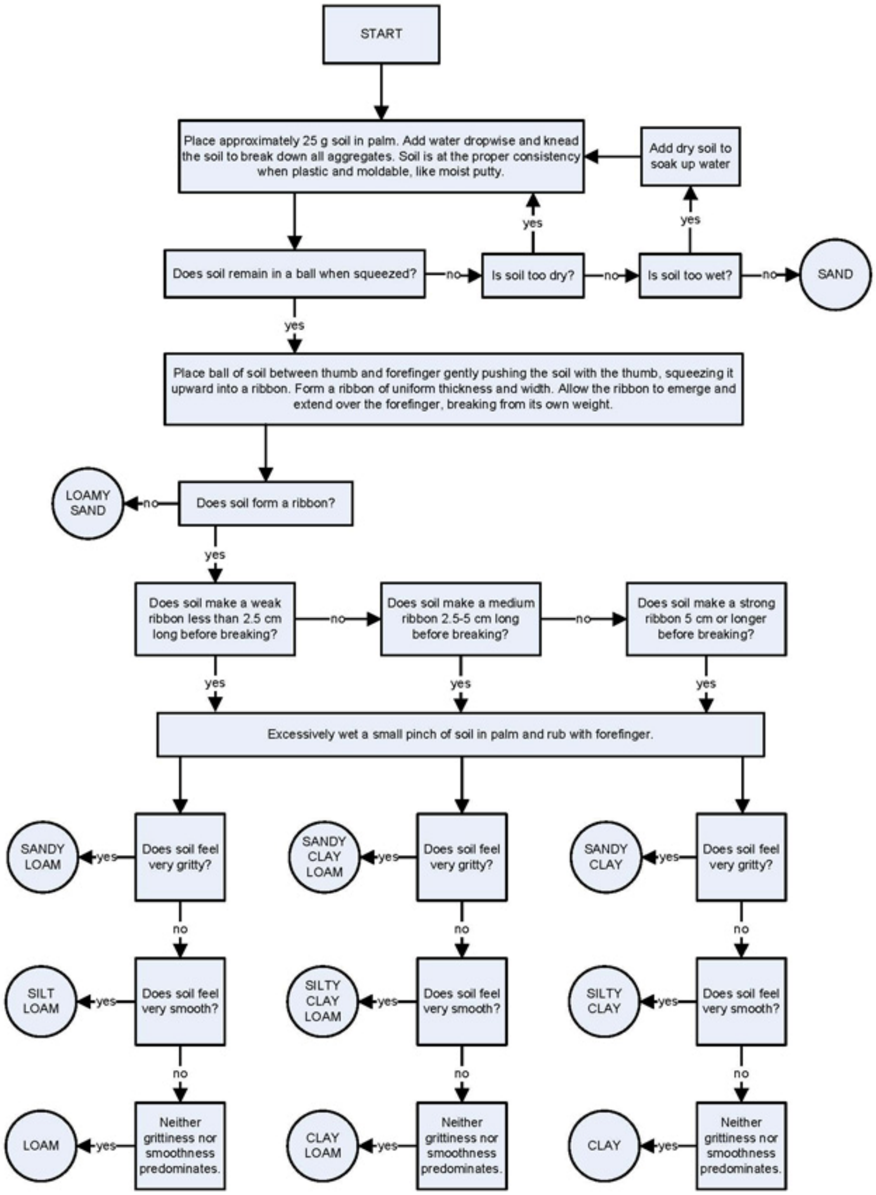


Figure 3.3 USDA Guide to Soil-Texture by Feel
(*Guide to Texture by Feel*. Digital image. *United States Department of Agriculture*. Web. 28 Mar. 2012. <http://soils.usda.gov/education/resources/lessons/texture>)

3.2 OSL Sampling

All maps were analyzed to choose optimal locations for OSL samples that would provide accurate dates of the channel transition from meandering to braided. To do this, we looked at the cross-cutting relationships of the mapped abandoned-channels to find the youngest meander loops and the oldest braided channels ascertained from relative-age sequencing. The youngest loop in this case is considered the last meander loop created by the Missouri River in its meandering phase. The oldest braid is the first braid created by the river upon entering the braided phase. Locations where primarily chosen where the date on a youngest loop next to an oldest braid could both be acquired.

After the locations were chosen, 20-40 cm samples of sand from the respective sand bars of each channel loop were collected from boreholes. Each sample was taken by a special pvc pipe tip and suction core that are connected to the drill rod (Figure 3.4). This tip is used to collect the sample and prevent it from premature exposure to light which would contaminate the sample. Once the samples were collected they are immediately capped and encased in opaque duct tape to ensure no light will reach the sample.

Figure 3.4 OSL Sample Tip

CHAPTER 4

DATA AND RESULTS

4.1 Data

Maps were created of 28 quadrangles from Yankton, South Dakota to Mondamin, Iowa of the floor of the Missouri River Valley (Appendix A). Over the course of 3 years, 900+ holes were drilled in the 28 quadrangles to complete the maps. The 900+ borehole logs can be found online at www.usd.edu. A total of 36 OSL samples were collected within those quadrangles and successfully processed (Appendix B). Only 14 of those OSL samples were collected specifically to answer the question of when the Missouri River changed pattern from meandering to braided (Table 4.1). Five OSL samples were collected at sites that represented one of the last meander loops to be created by the river before it changed to braided (Table 4.2). Nine OSL samples were collected at sites that represented the first signs of braiding (Table 4.3). These locations were chosen based on cross-cutting relationships of allostratigraphic units that were mapped in the 28 quadrangles.

Table 4.1 OSL sample locations and the river pattern allounit they were meant to date (Coordinates in UTM Zone 14N NAD83)

LOG ID	QUAD	EAST	NORTH	DATE	ALLOUNIT
MOV-AL-12	ALBATON	723827	4671534	6/22/2009	BRAID
MOV-AL-39	ALBATON	723164	4673888	7/2/2009	MEANDER
MOV-BNC-53	BLENCOE	739756	4644676	7/29/2010	MEANDER
MOV-BNC-54	BLENCOE	739203	4643338	7/29/2010	BRAID
MOV-BU-30	BURBANK	675698	4733681	7/2/2008	BRAID
MOV-BU-32	VERMILLION SE	677108	4736939	7/3/2008	MEANDER
MOV-EP-25	ELK POINT	692539	4723683	6/29/2008	BRAID
MOV-OSW-5	ONAWA SW	728911	4662077	6/19/2009	BRAID
MOV-OSW-59	ONAWA SW	735312	4661917	7/30/2010	MEANDER
MOV-PO-6	PONCA	693096	4721117	6/17/2008	BRAID
MOV-SL-50	SLOAN	729234	4667605	7/31/2010	BRAID
MOV-TKN-44	TEKEMAH NW	737725	4644785	7/29/2010	BRAID
MOV-TK-20	TEKEMAH	732866	4639478	7/19/2010	BRAID
MOV-TK-44	TEKEMAH	737932	4637110	7/28/2010	MEANDER

Table 4.2 Logs of OSL Taken to Date the Youngest Meander Loops. Clay=C, Silt Clay=SiC, Silt Clay Loam=SiCL, Silt Loam=SiL, Loam=L, Loamy Sand=LS, Sandy Loam=SL, Fine Sand=fS, Medium Sand=mS, Coarse Sand=cS, No Description=ND

	MOV-AL-39		MOV-BNC-53		MOV-BU-32		MOV-OSW-59		MOV-TK-44	
Depth(m)	Facies	OSL	Facies	OSL	Facies	OSL	Facies	OSL	Facies	OSL
0.1	SiL		C		SiL		SiL		SiC	
0.2	SiL		C		L		SiL		SiC	
0.3	SiC		C		L		SiL		SiC	
0.4	SiL		C		L		SL		C	
0.5	SiL		C		SL		LS		C	
0.6	SiL		C		LS		LS		C	
0.7	L		C		SL		LS		C	
0.8	L		SiC		SL		SL		SiC	
0.9	L		SiC		L		SL		SiC	
1	SL		SiC		SiL		SL		SiL	
1.1	SL		SiC		C		SL		SiL	
1.2	SL		SiL		SiL		L		SiL	
1.3	LS		SiL		C		SL		L	
1.4	LS		SiC		SiL		ND		SL	
1.5	LS		SiC		C		LS		fS	
1.6	mS		C		C		LS		fS	
1.7	mS		C		C		LS		fS	
1.8	cS		C		SiL		LS		fS	
1.9	cS		C		SiL		LS		fS	
2	cS		C		SiL		LS		fS	
2.1	cS		SiC		C		LS	OSL	L	
2.2	cS		SiL		SiL		LS		L	
2.3	cS		SiL		SiL		LS		SL	
2.4	cS		SiC		SiL		LS		SL	
2.5	cS		C		SiL				LS	
2.6	cS	OSL	C		SiL				LS	
2.7	cS	OSL	SiC		SiL				LS	
2.8	cS	OSL	SiC		L				LS	
2.9			C		L				fS	
3			C		LS				fS	
3.1			C		LS				fS	
3.2			C		LS				fS	
3.3			SiC		LS				fS	
3.4			SiC		mS				fS	
3.5			C		mS				fS	
3.6			C		mS				fS	
3.7			C		mS				fS	OSL
3.8			C		mS					
3.9			SiC		mS					
4			SiC		mS	OSL				
4.1			C							
4.2			C							
4.3			C							
4.4			SiL							
4.5			ND							
4.6			L							
4.7			fS	OSL						
4.8			fS							
4.9			fS							
5			fS							

Table 4.3 Logs of OSL Taken to Date the Oldest Braid Bar. Clay=C, Silt Clay=SiC, Silt Clay Loam=SiCL, Silt Loam=SiL, Loam=L, Loamy Sand=LS, Sandy Loam=SL, Fine Sand=fS, Medium Sand=mS, Coarse Sand=cS, No Description=ND

	MOV-AL-12		MOV-BNC-54		MOV-BU-30		MOV-EP-25		MOV-OSW-5		MOV-PO-6		MOV-SL-50		MOV-TKN-44		MOV-TK-20	
Depth(m)	Facies	OSL	Facies	OSL	Facies	OSL	Facies	OSL	Facies	OSL	Facies	OSL	Facies	OSL	Facies	OSL	Facies	OSL
0.1	SiC		SiC		SL		SL		C		L		LS		LS		C	
0.2	SiC		SiC		SL		SL		C		L		LS		SL		SiC	
0.3	SiC		SiC		SL		SL		C		SiL		LS		SL		C	
0.4	C		SiC		SL		SL		L		SiL		LS		SL		SiC	
0.5	C		SL		SL		SL		SL		SiC		LS		LS		SiC	
0.6	SiC		LS		LS		SL		SL		C		LS		LS		SiC	
0.7	SiC		fS	OSL	LS		SL		LS		SiC		LS		LS		SiC	
0.8	SiC		fS		SL		LS		fS		SiC		LS		LS		C	
0.9	SiL		fS		SL		LS		C		C		LS		LS		SiC	
1	L		fS		L		LS		fS		C		LS		LS		SiC	
1.1	L		LS		SL		LS		fS	OSL	C		LS		LS		SiC	
1.2	LS		LS		LS		fS		SL	OSL	C		LS		fS		SiL	
1.3	fS		fS		LS		fS		fS	OSL	C		LS		fS		L	
1.4	fS		fS		SiCL		fS		fS	OSL	C		LS		fS		LS	
1.5	fS		fS		SiL		fS		fS		C		LS		fS		fS	
1.6	fS	OSL	fS		SiL		fS		fS		SiC		LS		fS		fS	
1.7	fS	OSL	fS		SiCL		fS		fS		SiC		LS	OSL	fS		fS	OSL
1.8	fS	OSL	fS		SL		fS		fS		C		LS		fS	OSL	fS	
1.9	fS	OSL	fS		SL		fS		fS		C		LS		fS		fS	
2	fS		fS		fS		fS		fS		C		LS		fS		fS	
2.1	LS				fS		fS		fS		C				fS		fS	
2.2	L				LS		fS		fS		C						fS	
2.3	L				LS		SiL		fS		C						fS	
2.4	fS				SL		LS				C						fS	
2.5	fS				mS		LS				C						fS	
2.6	fS				mS		SiL				SiL						fS	
2.7	fS				mS		SiL				SiC							
2.8	fS				mS	OSL	SiL				SiC							
2.9	LS				mS		SiL				C							
3	LS				mS		SiL				fS							
3.1	LS				mS		SiL				fS							
3.2	fS				mS		SiL				fS							
3.3	fS						C				fS							
3.4	fS						C				fS							
3.5	fS						C				LS							
3.6							C				SiC							
3.7							SiL				LS							
3.8							SiL				fS							
3.9							fS				fS							
4							fS				fS							
4.1							fS				fS							
4.2							fS				fS							
4.3							fS				fS	OSL						
4.4							fS	OSL			fS							
4.5							fS				fS							
4.6							fS				fS							
4.7							fS											
4.8							fS											
4.9							fS											
5							fS											

4.2 Results

4.2.1 Lower Missouri River Valley Floodplain Maps

Maps were created of 28 individual quadrangles from Yankton, SD to Mondamin, IA of the floor of the Missouri River Valley (Appendix A) and were stitched together to create two seamless maps; Yankton to Jefferson (Figure 4.1) and Sioux City South to Mondamin (Figure 4.2). The seamless maps show that the river has been moving across the valley floor from east to west, reaching the western valley wall in some places (Figures 4.1 and 4.2). The maps allow us to see the braid-belt and outline the area of transition (Figures 4.3 and 4.4).

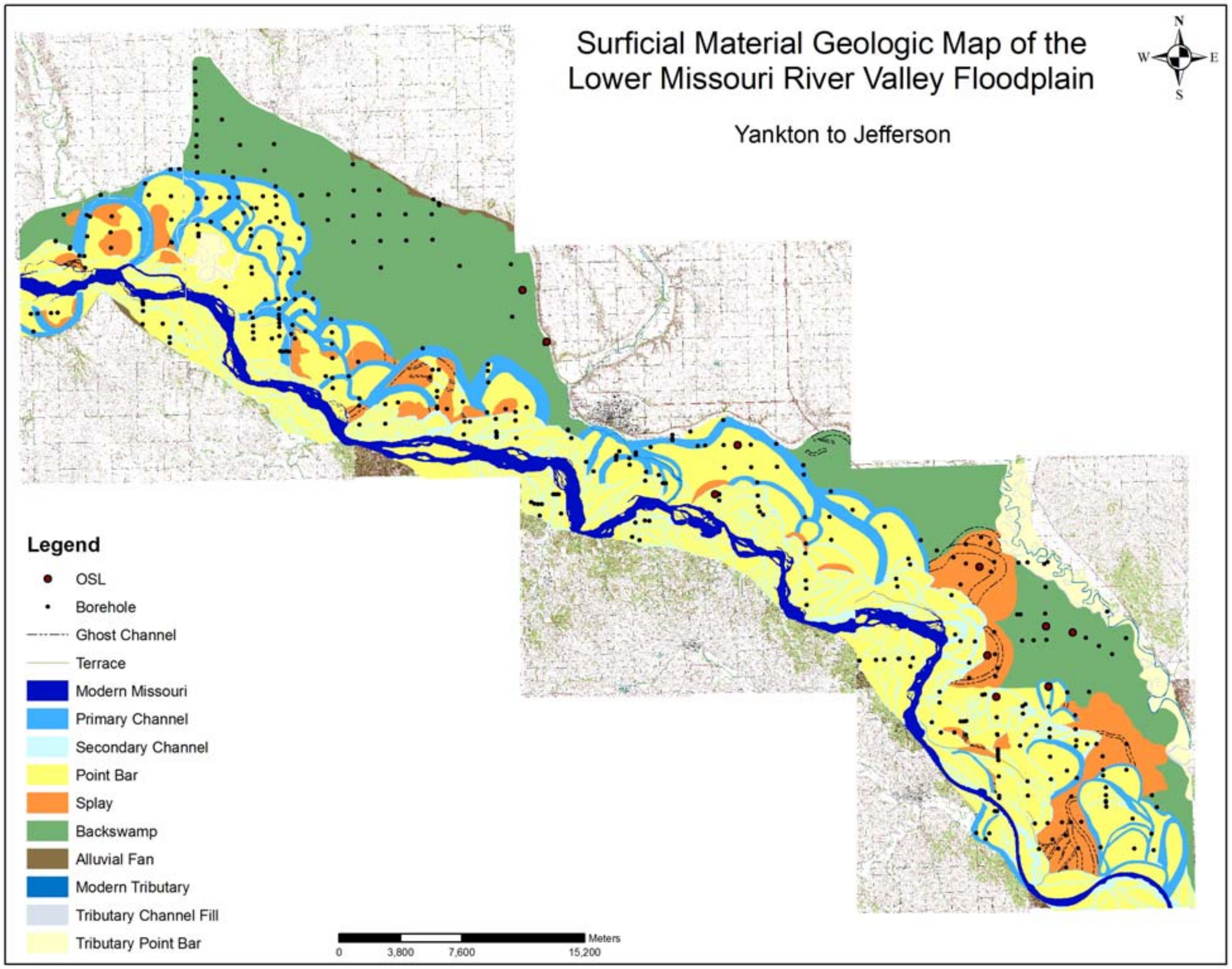


Figure 4.1 Composite floodplain map. Yankton to Jefferson

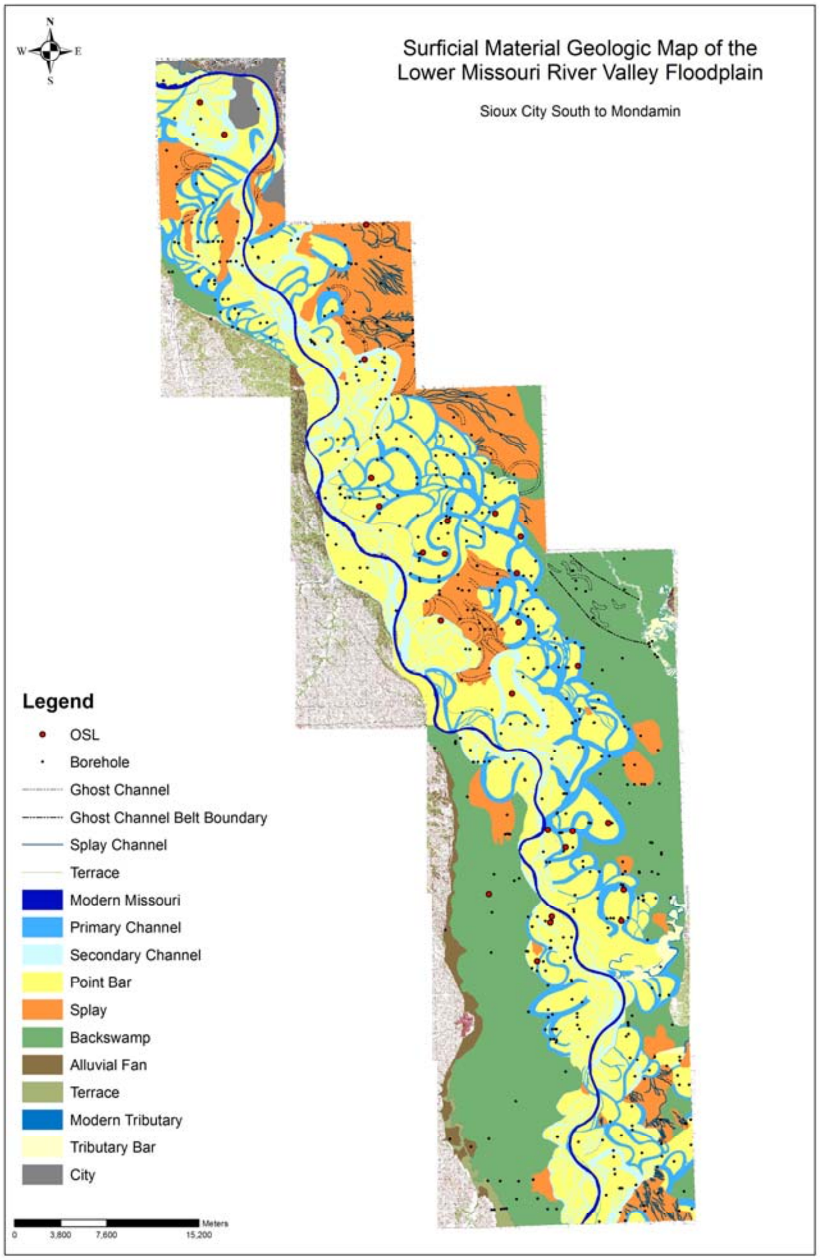


Figure 4.2 Composite floodplain map. South Sioux City to Mondamin

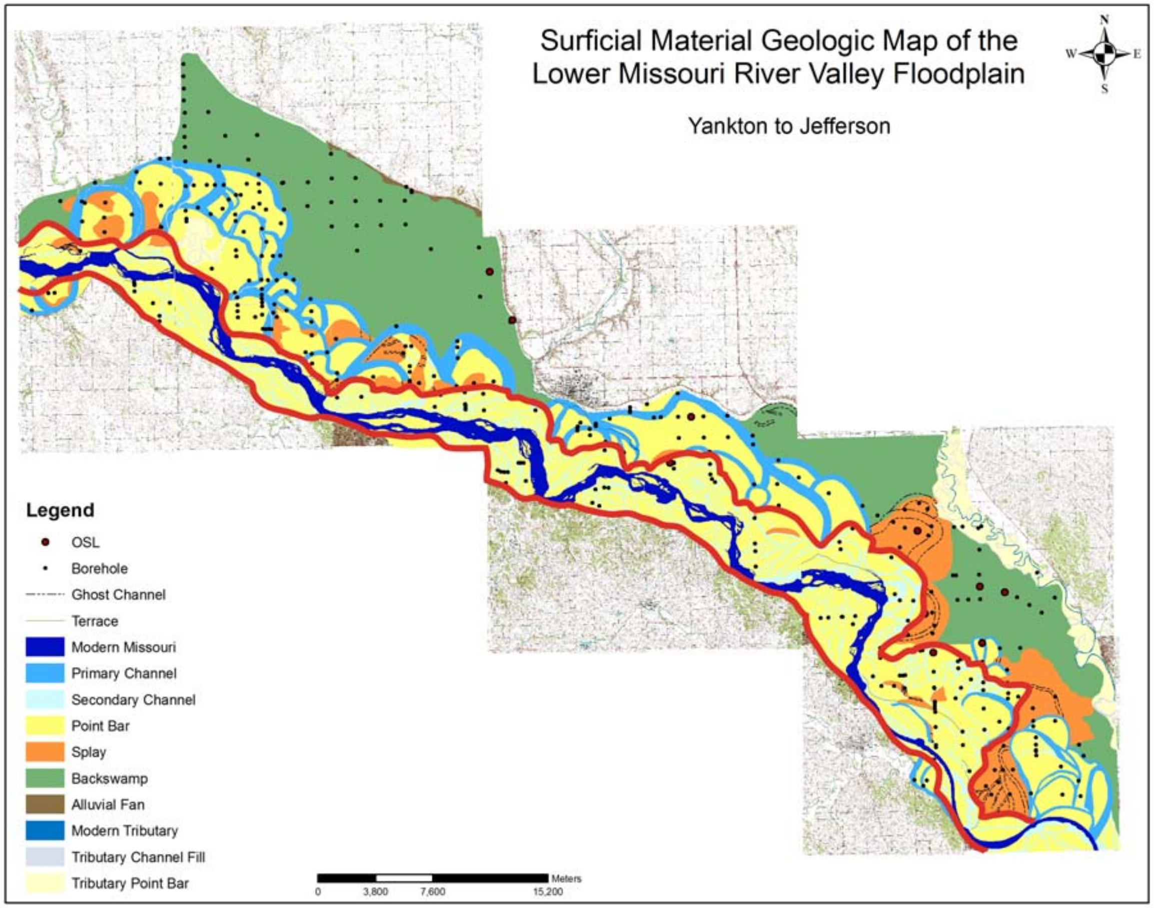


Figure 4.3 Composite floodplain map. Yankton to Jefferson. Braid belt outlined in red.

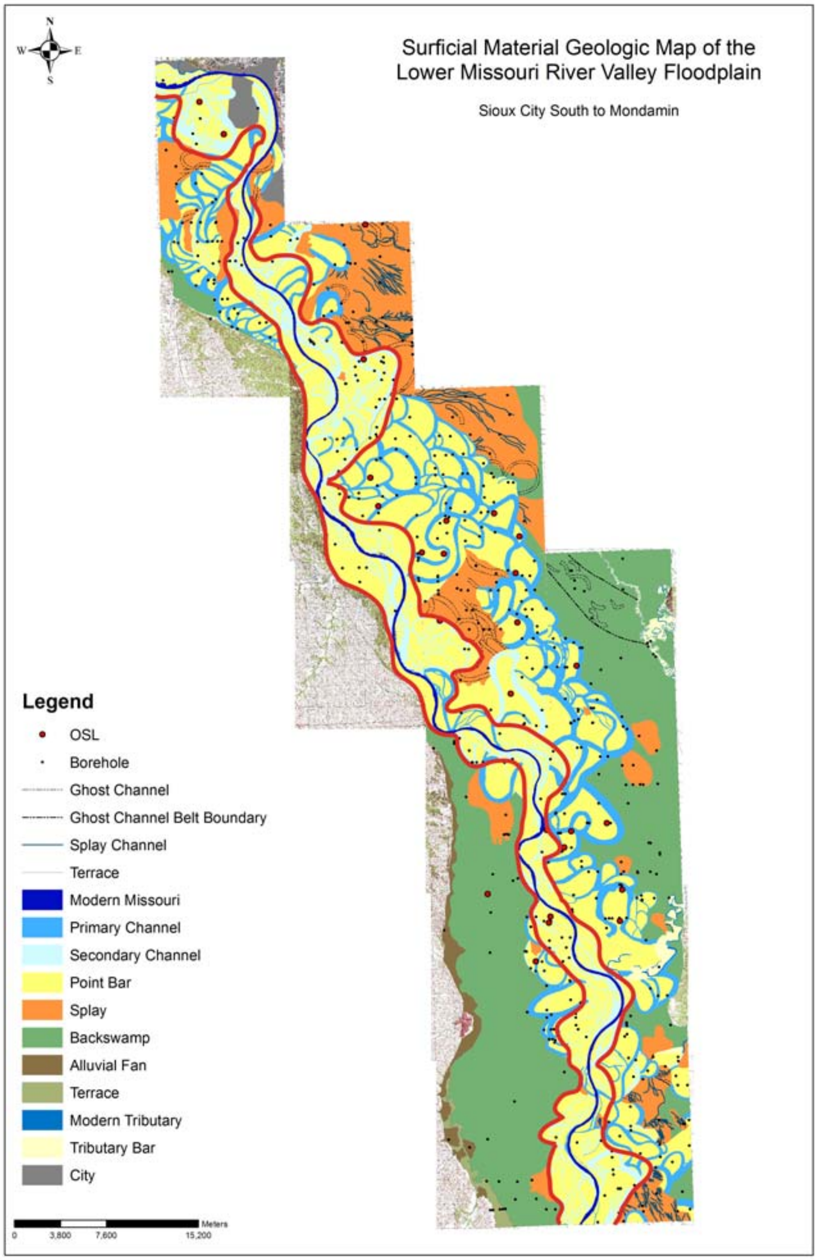


Figure 4.4 Composite floodplain map, South Sioux City to Mondamin. Braid belt outlined in red.

4.2.2 OSL Results

Results from OSL samples taken from meander loops on the eastern edge of the channel belt show the oldest loops in the belt began forming around 7.0 ± 0.2 ka B.P. The five OSL samples taken to date the youngest meander loops ranged from 3.62±0.24 ka to 1.78±0.12 ka (Table 4.4 and Figures 4.5-4.8). Results of the nine OSL samples taken to date the oldest braid bars ranged from 1.56±0.12 ka to 0.65±0.04 ka (Table 4.4 and Figures 4.5-4.8). Of the 14 OSL samples that were taken, 10 were taken as meander-braid couples in the same quad. Farthest up-stream, the two OSL samples taken in the Burbank and Vermillion SE quads date the youngest meander at 3.62±0.24 ka (MOV-BU-32), and the oldest braid at 0.74±0.06 ka (MOV-BU-30). Down-stream from Burbank is Albaton with 1.78±0.12 ka (MOV-AL-39) for the youngest meander and 1.01±0.10 ka (MOV-AL-12) for the oldest braid, Onawa SW with 2.17±0.12 ka (MOV-OSW-59) for the meander and 1.56±0.12 ka (MOV-OSW-5) for the braid, followed by Blencoe with 1.98±0.13 ka (MOV-BNC-53) for the meander and 1.19±0.05 ka (MOV-BNC-54) for the braid. Farthest down-dip is Tekemah with 1.95±0.10 ka (MOV-TK-44) for the meander and 0.93±0.07 ka (MOV-TK-20) for the braid.

Table 4.4 Results of OSL samples taken to date the meander-braid transition (Coordinates in UTM Zone 14N NAD83)

LOG ID	QUAD	EAST	NORTH	DATE	ALLOUNIT	DEPTH(m)	AGE(ka)
MOV-AL-12	ALBATON	723827	4671534	6/22/2009	BRAID	1.6-1.9	1.01±0.1
MOV-AL-39	ALBATON	723164	4673888	7/2/2009	MEANDER	2.6-2.8	1.78±0.12
MOV-BNC-53	BLENCOE	739756	4644676	7/29/2010	MEANDER	4.7	1.98±0.13
MOV-BNC-54	BLENCOE	739203	4643338	7/29/2010	BRAID	0.7	1.19±0.05
MOV-BU-30	BURBANK	675698	4733681	7/2/2008	BRAID	2.8	0.74±0.06
MOV-BU-32	VERMILLION SE	677108	4736939	7/3/2008	MEANDER	4.0	3.62±0.24
MOV-EP-25	ELK POINT	692539	4723683	6/29/2008	BRAID	4.4	1.53±0.11
MOV-OSW-5	ONAWA SW	728911	4662077	6/19/2009	BRAID	1.1-1.4	1.56±0.12
MOV-OSW-59	ONAWA SW	735312	4661917	7/30/2010	MEANDER	2.1	2.17±0.12
MOV-PO-6	PONCA	693096	4721117	6/17/2008	BRAID	4.3	0.95±0.08
MOV-SL-50	SLOAN	729234	4667605	7/31/2010	BRAID	1.7	0.83±0.05
MOV-TKN-44	TEKEMAH NW	737725	4644785	7/29/2010	BRAID	1.8	0.65±0.04
MOV-TK-20	TEKEMAH	732866	4639478	7/19/2010	BRAID	1.7	0.93±0.07
MOV-TK-44	TEKEMAH	737932	4637110	7/28/2010	MEANDER	3.7	1.95±0.10

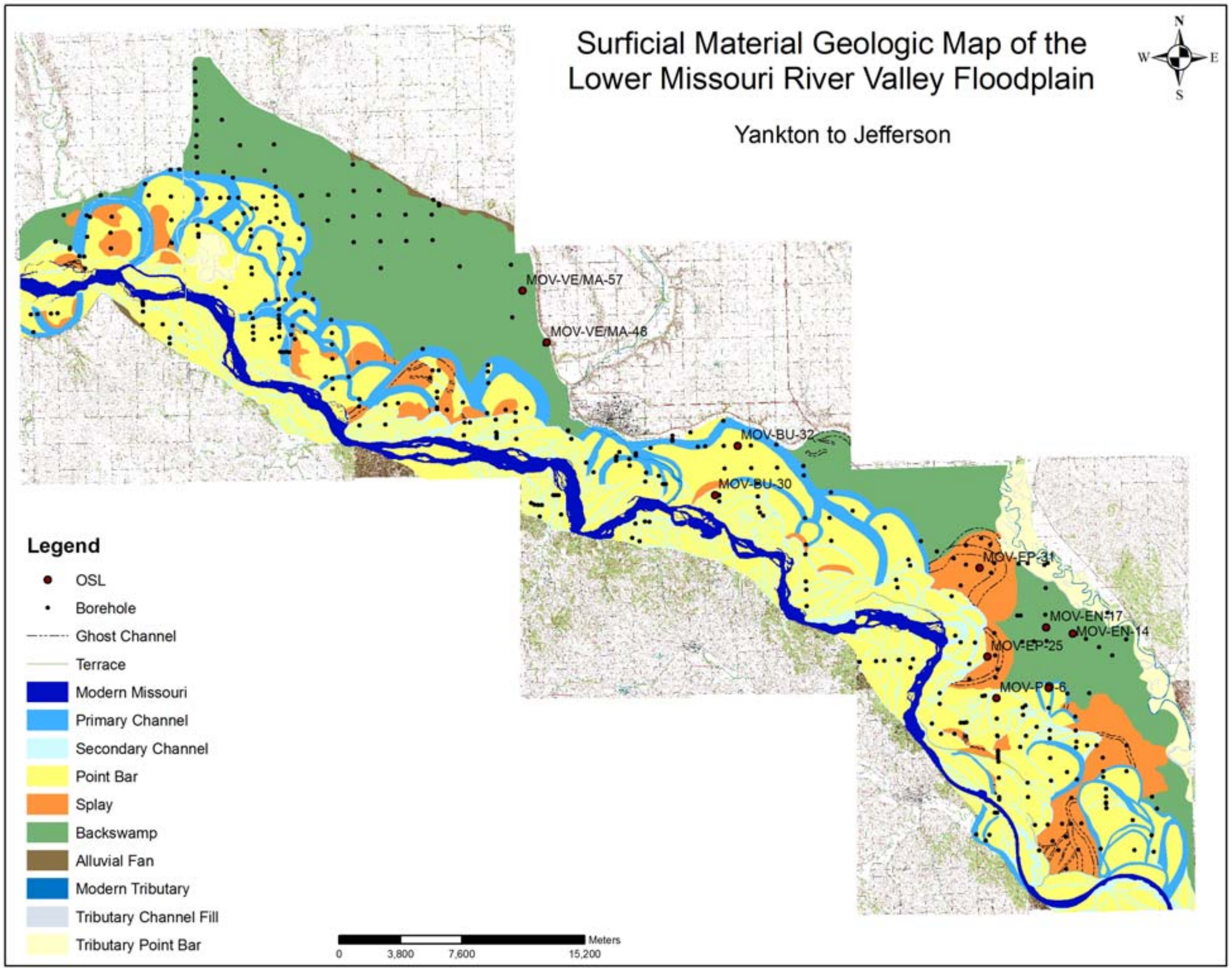


Figure 4.5 Composite floodplain map. Yankton to Jefferson. Labeled boreholes are OSL locations

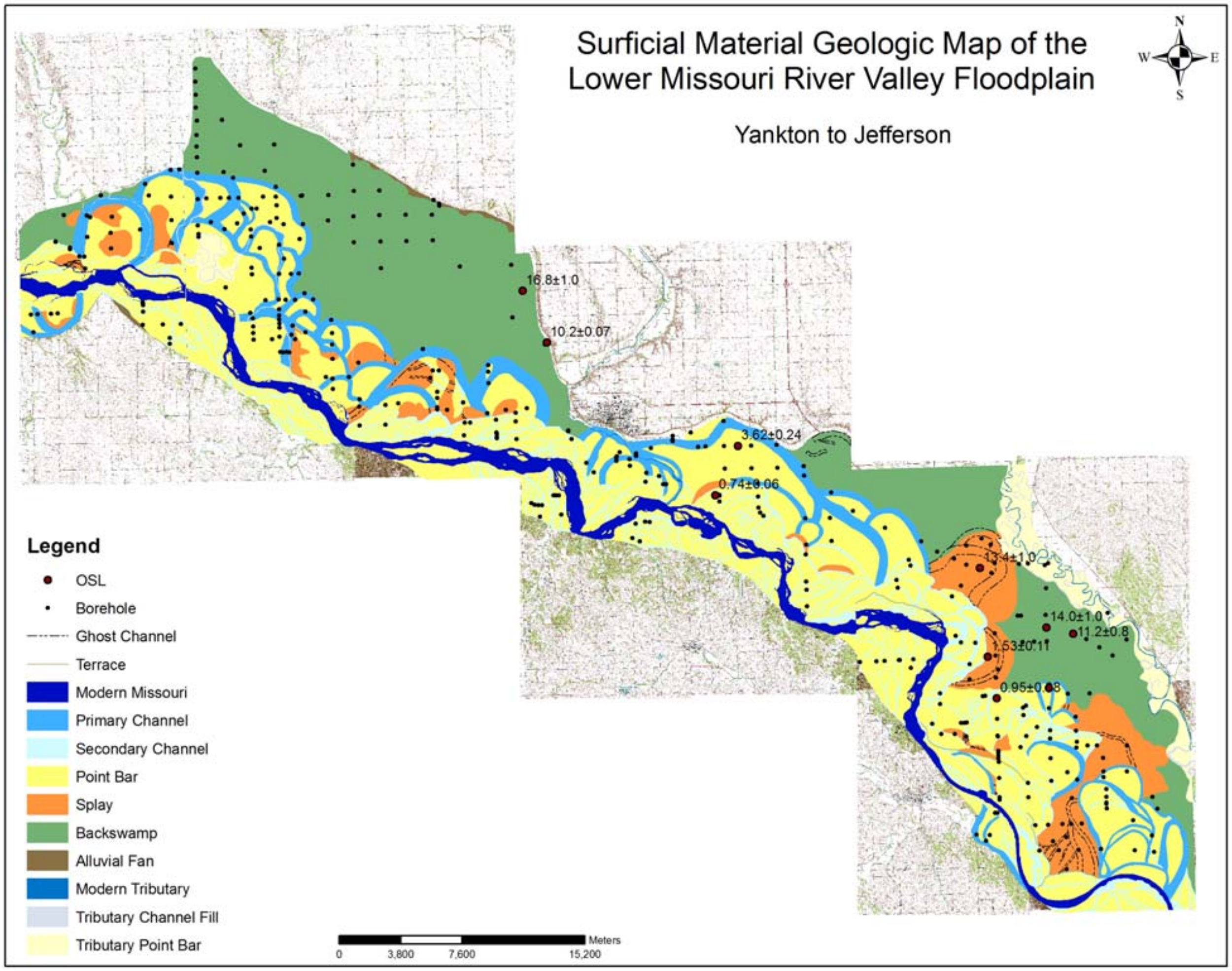


Figure 4.6 Composite floodplain map. Yankton to Jefferson. Red dots indicate OSL location. Age labels are in ka B.P

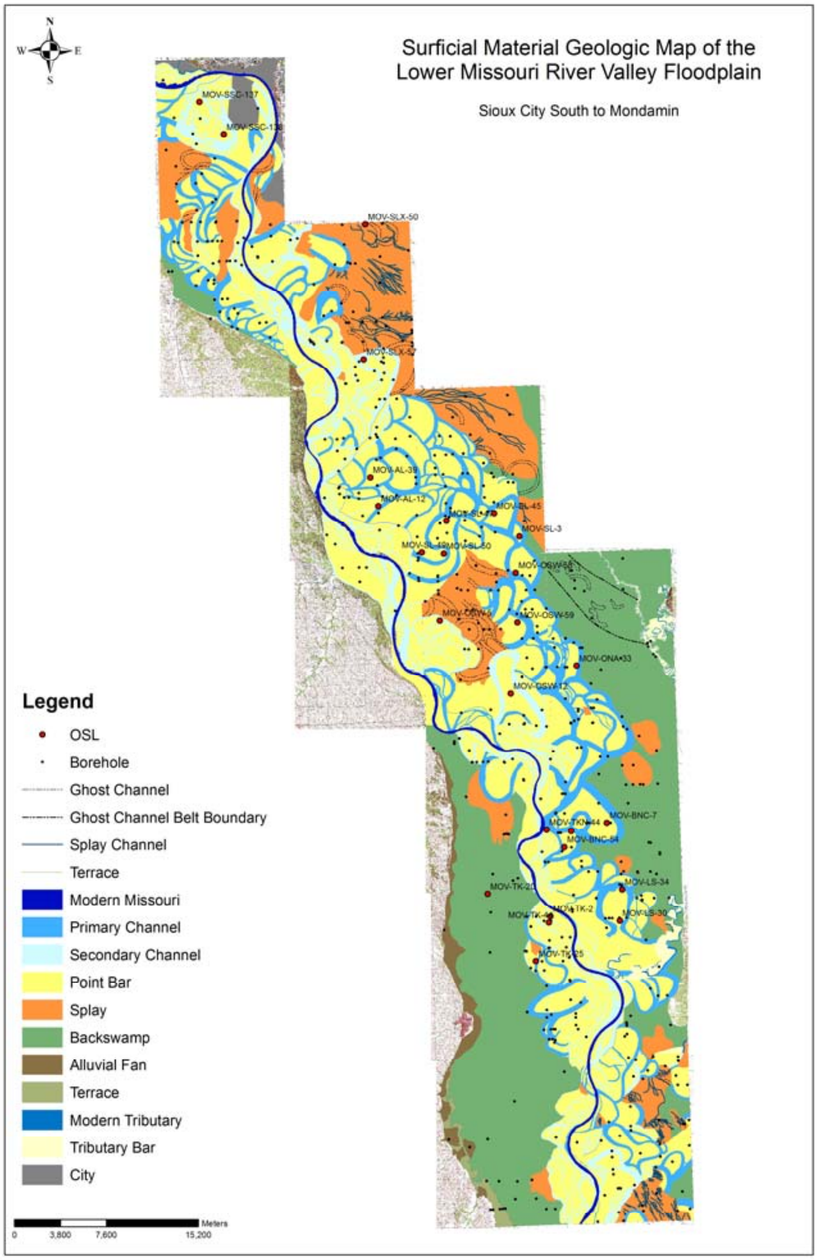


Figure 4.7 Composite floodplain map, South Sioux City to Mondamin. Labeled boreholes are OSL locations

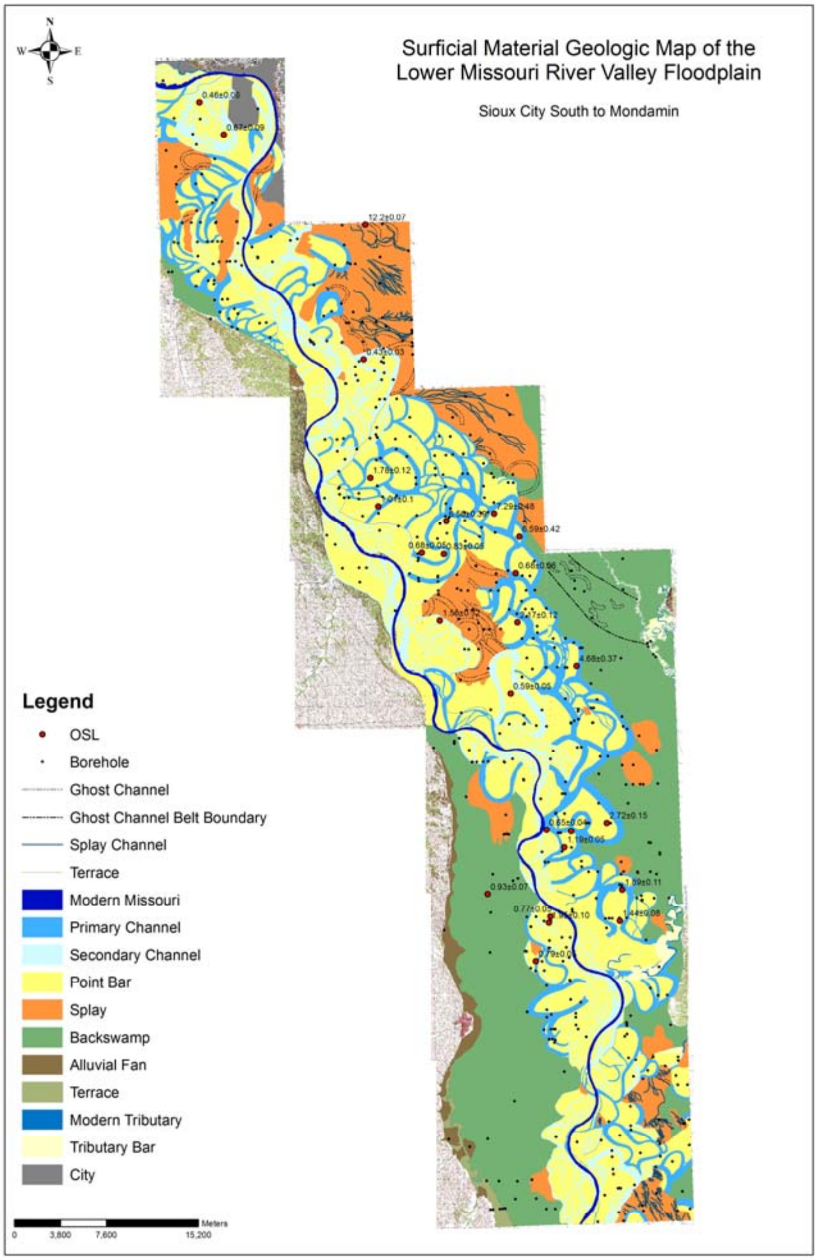


Figure 4.8 Composite floodplain map, South Sioux City to Mondamin. Red dots indicate OSL location. Age labels are in ka B.P.

CHAPTER 5

DISCUSSION

In the upper part of the lower Missouri River Valley, evidence of a meander-braid transition is written on the valley floor. Ox-bow lakes and landscape features resembling highly sinuous meandering loops mark the floodplain of the lower Missouri River Valley as scars of what was once a fully meandering Missouri River. A series of recently created maps have allowed us to visualize and better understand the nature of the pattern change and the overall behavior of the river.

The channel belt exposed at the surface began forming around 7.0 ± 0.2 ka B.P. and the river has slowly been migrating westward across the valley floor since, reaching the western valley walls in some places. The series of recently created maps in the Yankton, SD to Mondamin, IA reach of the river display a lack of transitional patterns. Features that are preserved on the floodplain are distinctively either meander loops or braided channels. Meander scars are represented by ox-bow lakes and single-channel loops whereas braided channels are represented as much wider channel assemblages with mid-channel sand bar deposits surrounded by smaller secondary channels. The distinctive geometry of the features allows us to easily outline where the change from meandering to braided pattern occurred. The lack of transitional patterns suggests that the channel pattern change from meandering to braided was not a slow progressive transition, but instead occurred somewhat abruptly in space and time. Transition rates from the 4 lower-most OSL samples exhibit an average transition time of 800 years, coinciding with the abrupt change in pattern. An OSL couple taken in the Burbank and Vermillion SE quads, nearest to the top of the up-dip study area, was anomalous with the youngest meander dating around 3.62 ka B.P. and the oldest braid dating to only 0.74 ka B.P.

Results from OSL data acquired in the Yankton, SD to Mondamin, IA reach of the river show that the oldest dated braids formed around 1.56±0.12 ka B.P. and 1.53±0.11 ka B.P. This would suggest that the river began showing signs of a fully braided system approximately 1.6±0.20 ka B.P. Since the Missouri River is such a large river, threshold variations within the length of the river are to be expected. Bedrock control, variations in vegetation, reworking of deposits, as well as the effects of input from tributaries on discharge and sediment supply can all vary at different points along the river. Reworking of the floodplain is the probable reason that dated meander loops range from 3.62±0.24 ka B.P. to 1.78±0.12 ka B.P. and dates from braid-bar deposits range from 1.56±0.12 ka B.P. to 0.65±0.04 ka B.P. It is likely that the true first braids and last meanders were reworked and erased from the depositional record. Based on the overall results of the mapping and OSL data, we propose an abrupt change in river pattern from meandering to braided around 1.6±0.20 ka B.P. (Figure 5.1).

We speculate that this pattern change occurred as a result of climate change. Climate in the study area was cool and humid from around 5000 yr B.P., becoming relatively stable around 2700 yr B.P.; however, climate in the northern Great Plains became warmer and drier around 2600 yr B.P. and continued this trend until 1000 yr B.P. It is possible that this warming trend affected tributary inputs of sediment and discharge into the river causing the pattern to compensate through pattern adjustment as temperatures increased and climate became more extreme (Valero-Garcés et al., 1997, Laird et al., 1998, Baker et al., 2000, Nordt et al., 2007). The climate shift to warmer arid conditions in the northern region likely affected the discharge and sediment balance needed by the river to maintain its single channel meandering pattern, causing it to become braided (Figures 2.6 and 2.8).

When compared to the results of the previous work done by Holbrook et al. (2005, 2006) in the lower reach of the river, down-dip from Kansas City, MO to I-70 Bridge, there is a distinct difference. Unlike the up-dip study area, features that are preserved in the down-dip area display transitional channel patterns, suggesting that the change from meandering to braided in the lower reach was slower. OSL dates collected for the meander-braid transition in the lower reach show that the transition took over 2000 years, from 3400-1200 yr B.P., to complete. This coincides with the fact that there are channel pattern features transitional from braided to meandering on the floodplain, and braiding initiates locally over a wide range in time. Holbrook et al. (2005, 2006) attribute this change in channel pattern to a regional climate shift at approximately 3500 yr B.P.

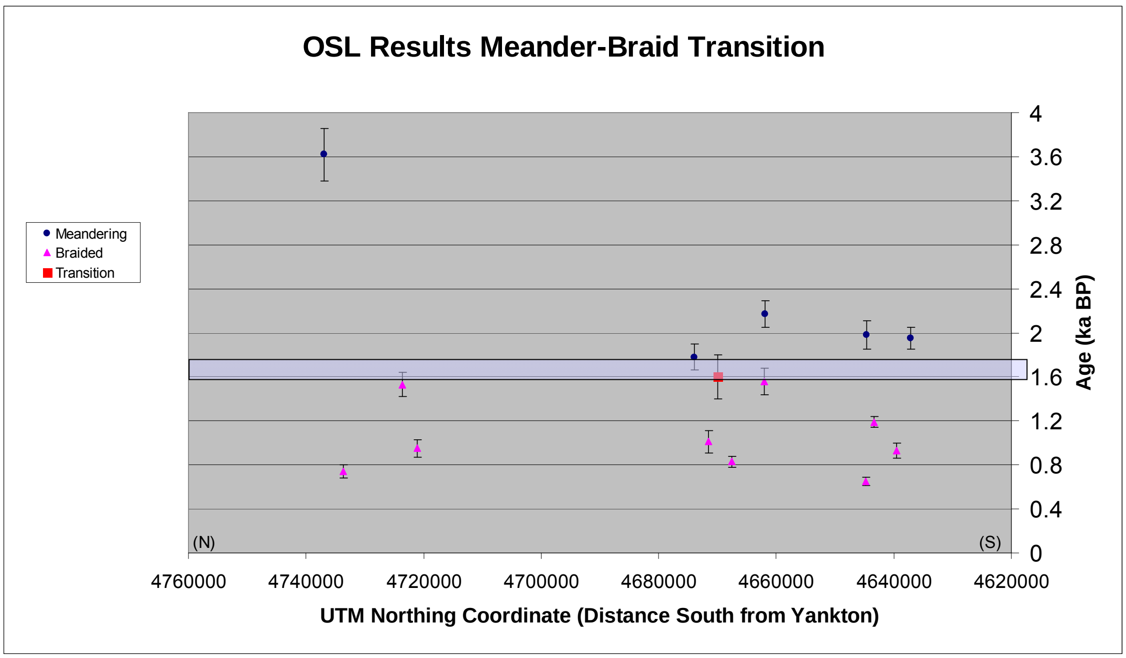


Figure 5.1 OSL Results for the Meander-Braid Transition

One hypothesis to explain this difference in the transition time and process between up-dip and down-dip reaches could be that sediment and discharge inputs from two major tributaries, below the up-dip area, were affected by regional climate change, causing the onset of a pattern change that only affected the reaches downstream of the tributary junctures. The Platte River and the Kansas River are two large tributaries of the Missouri River that carry sediment from the western US across the Great Plains region and into the Missouri River Basin. The Platte River meets the Missouri River just below Omaha, NE and the base of the up-dip study area. The Platte River Basin encompasses the North Platte River, South Platte River, Platte River, Loup River, and the Elkhorn River. The North Platte River runs through Wyoming, the South Platte River runs through Colorado and the two rivers meet in Nebraska to form the Platte River. The Platte River and its tributaries flow through the Nebraska Sand Hills, which are sand dune deposits in western Nebraska. These dunes reactivated approximately 3500 yr B.P. signaling a shift in climate to hot and arid (drought) conditions (Hanson et al., 2009, 2010, Foreman et al., 2005, Mason et al., 2004). This corresponds to the onset of the transition in the down-dip reach of the river (Holbrook et al., 2005, 2006)

The Kansas River Basin carries sediment from western Colorado, southern Nebraska, and the northern half of Kansas. These areas also experienced a shift to dry conditions around the same time (Hanson et al., 2009, 2010, Arbogast, 1996, Arbogast and Muhs, 2000, Clarke and Rendell, 2003). The lower reach of the Missouri River itself runs through Missouri, which also encountered drought conditions around 3500 yr B.P. (Denniston et al., 2007). Climate studies of the northern region, however, show temperatures in the north to be cooler and there was increased humidity with only intermittent periods of drought (Valero-Garcés et al., 1997, Laird et al., 1998, Baker et al., 2000, Nordt et al., 2007). With fewer tendencies toward drought conditions, it is likely that tributaries in the north did not experience significant enough changes in sediment or discharge input into the Missouri River for the effects to be felt until much later. It is possible that the abrupt nature of the transition up-dip is the result of a punctuated change in climate conditions that was severe enough to overcome the river's threshold and cause it to adjust its geometry to accommodate the changes (Vandenberghe et al, 1994).

Based on climate data collected throughout the region, we can speculate that the onset of drought-like conditions in the western Great Plains around 3500 yr B.P. triggered the beginning of the meander-braid transition in the lower reach from Kansas City, MO to the confluence with the Mississippi River. Alternatively, climate in the up-dip reach at that time was becoming cooler with increased humidity and with punctuated periods of drought (Baker et al., 2000). The climate shift to warmer arid conditions in the lower reach likely affected the discharge and sediment balance needed by the river to maintain its single channel meandering pattern by altering inputs toward an increase in sediment input from the two large tributaries between (Figures 2.6 and 2.8).

It is unlikely that tectonic activity influenced the change in channel pattern due to the fact that the Great Plains/Missouri River Basin region is considered to be tectonically stable, with vertical crustal movement averaging less than 1 mm/yr (Schumm, 1977, Osterkamp et al., 1987, Arborgast and Johnson, 1994). It is possible, however, that anthropogenic activity in the area could have had some influence on the change, but it would have been tied to climate change as well, and it is unlikely that it would have been the main cause. An alternative hypothesis is that climate change initiated in the upper reach, changing sediment and discharge, but the effects were felt in the lower reach first.

The area between the up-dip and down-dip sections, from Omaha, NE to Kansas City, MO, is the last remaining section of the lower Missouri River Valley to be mapped and dated. Once completed, this section will allow a complete analysis of the entire meander-braid transition of the lower reach of the Missouri River.

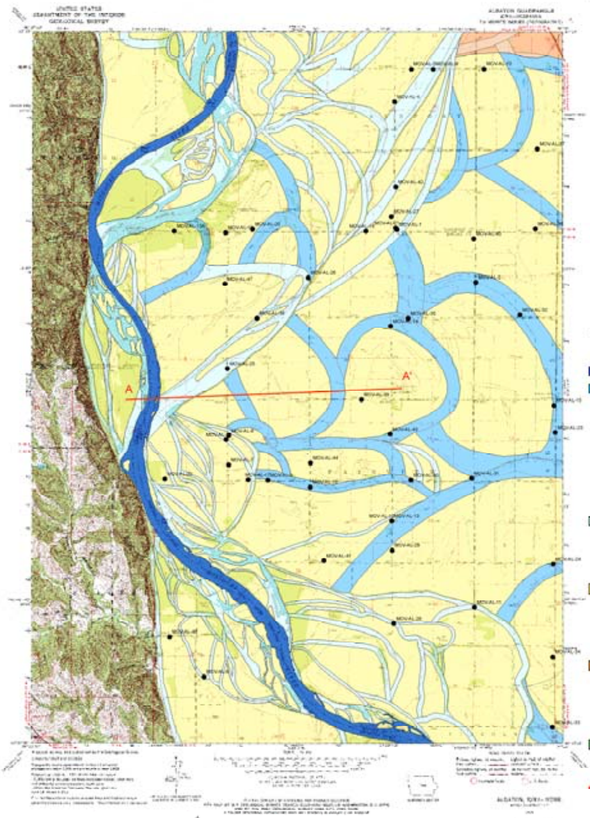
CHAPTER 6

CONCLUSIONS

Approximately 1.6±0.20 ka B.P. the Missouri River from Yankton, SD to Mondamin, IA abruptly changed its channel pattern from meandering to braided. The Missouri River changed its pattern from meandering to braided due to changes in climate. Climate shifts in the western Great Plains region affected discharge and sediment input from the northern drainage. Changes possibly began earlier down-dip due to changes from Platte River and Kansas River tributary inputs in the lower drainage area that are absent in the upper drainage. It is also possible that climate change initiated in the upper reach, changing sediment and discharge, but the effects were felt in the lower reach first.

APPENDIX A

QUADRANGLE MAPS



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SURFICIAL MATERIAL G EOLOGIC MAP OF THE ALBATON 7.5' QUADRANGLE IOWA, USA

Geology and Digital Compilation by
Kacie Baak, Lance Howell , Michele Kashouh , Daniel Carlin

GIS Technical Assistance by
Daniel Carlin

Supervisor
Dr. John M. Holbrook

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Modern Missouri River

Abandoned Channel Fill of the Missouri River

Includes channel fills that are comparable in size to full flow channels. Assumed to carry most or all of the contemporary Missouri River discharge at some point in time during history. Channel fills are floored by fine-to-medium sand, but are composed o f fine-grained facies in the upper and thickest part. Upper fined -grained fill components comprise mostly "active fill" lithology with thin to thick inter-beds of silt loam, loam, and fine sand with local lenses and layers of clay and fine sand. The fine-grained component is less commonly formed of "passive fill" lithology of clay and silty clay with minor silt loams. The basal channel fill sand is not dis tinguished well from underlying sand; the upper-fine grained components range in thickness from 4 to over 7m thick, but are more typically 4 to 6m thick.

Secondary Abandoned Channel Fill of the Missouri River

Channel fills with less than two -thirds of the cross-sectional area of the larger contemporary primary channel fills, but larger than the smaller minor chute channels included below Hpmo. Fills are approximately equal to or larger than 2m thick, and are almost entirely "active fill" lithology with rare "passive fill" lithology.

Point Bar Deposits of the Missouri River

Composed of fine-to-medium, well-sorted to loamy sand with local (<30cm) layers of fine-grained lithology. This grades upward into thin (>2cm) finer grained (silt -loam to loam) sections. These are capped by mud veneer layers (<80cm) composed of clay and silty clay. These may also be locally capped by thin (<2cm) chute channel fills composed of "active fill".

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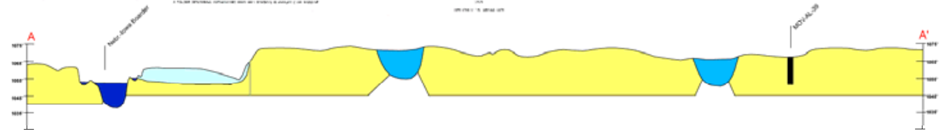
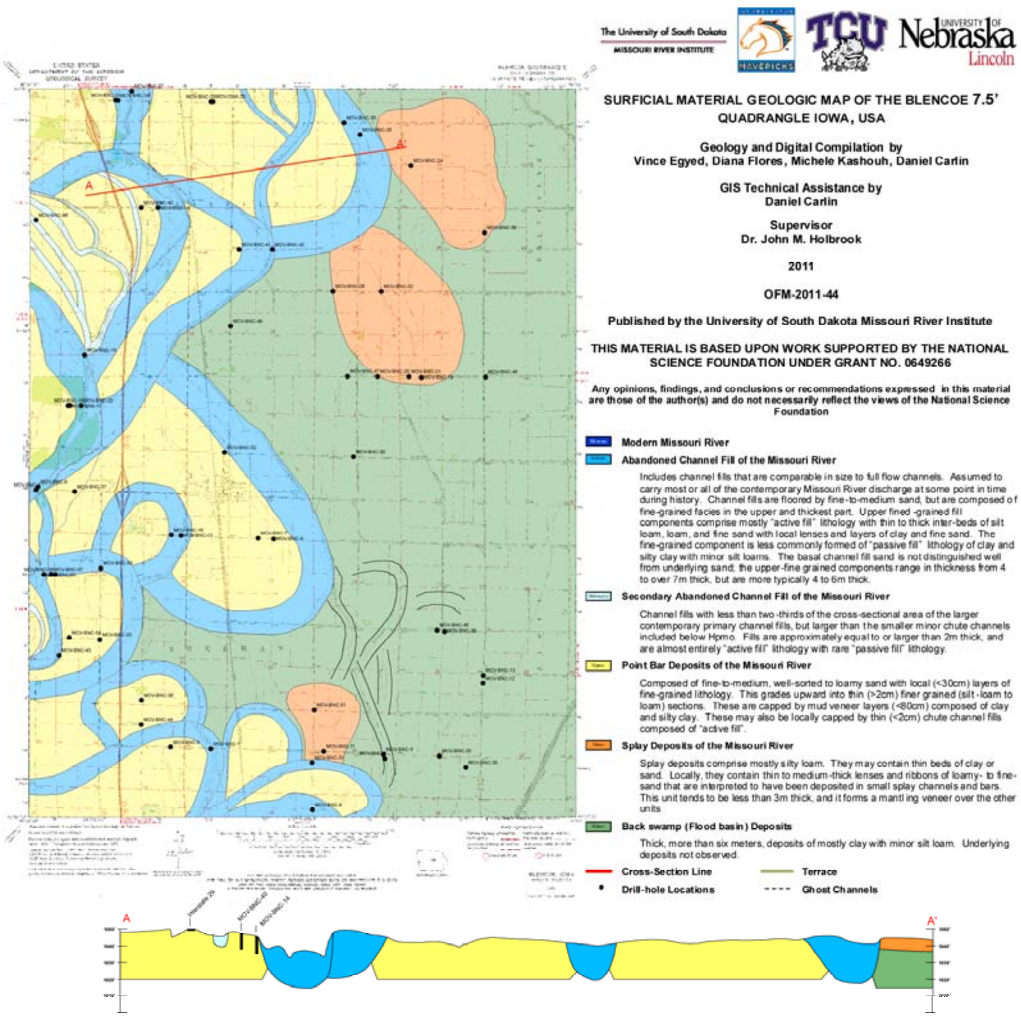
Back swamp (Flood basin) Deposits

Thick, more than six meters, deposits of mostly clay with minor silt loam. Underlying deposits not observed.

Cross-Section Line — Terrace
Drill-hole Locations ---- Ghost Channels

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Geology and Digital Compilation by
Vince Egyed, Diana Flores, Michele Kashouh, Daniel Carlin
GIS Technical Assistance by
Daniel Carlin
Supervisor
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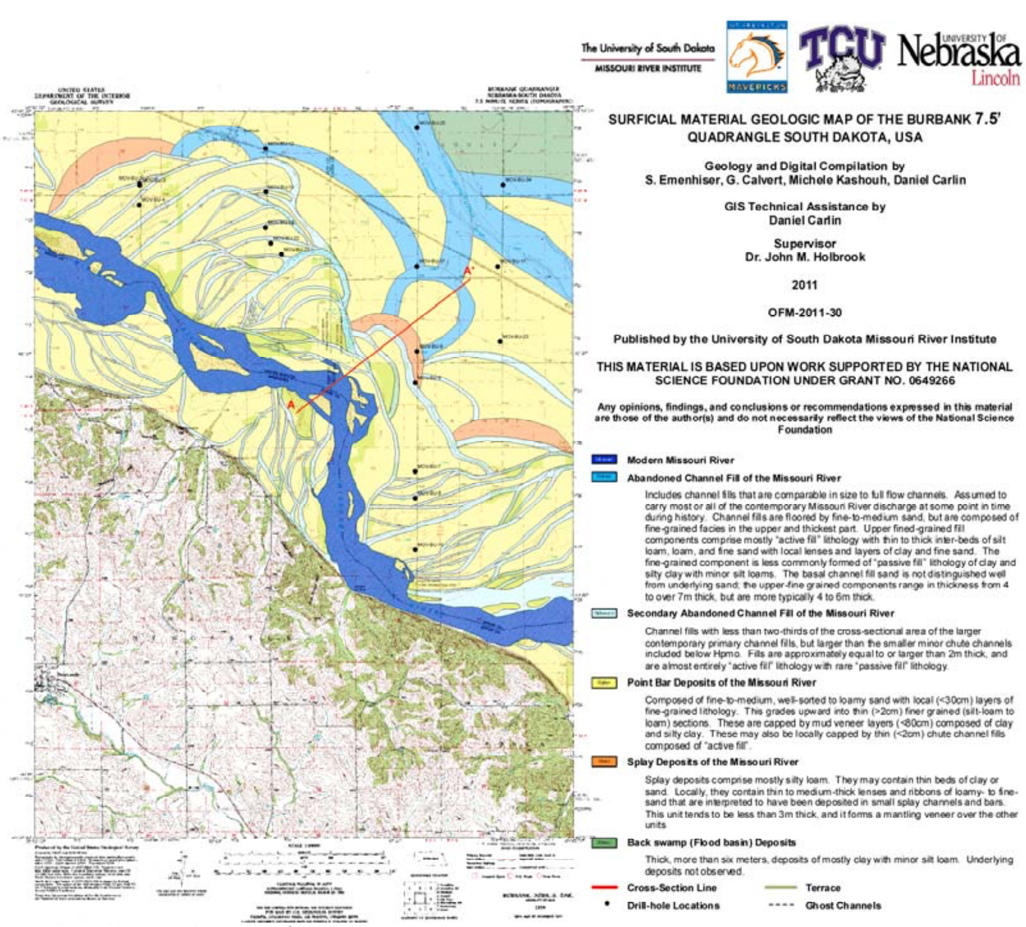
Cross-Section Line
Terrace
Drill-hole Locations
Ghost Channels
A
A'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SURFICIAL MATERIAL GEOLOGIC MAP OF THE BURBANK 7.5' QUADRANGLE SOUTH DAKOTA, USA
Geology and Digital Compilation by
S. Emenhiser, G. Calvert, Michele Kashouh, Daniel Carlin
GIS Technical Assistance by
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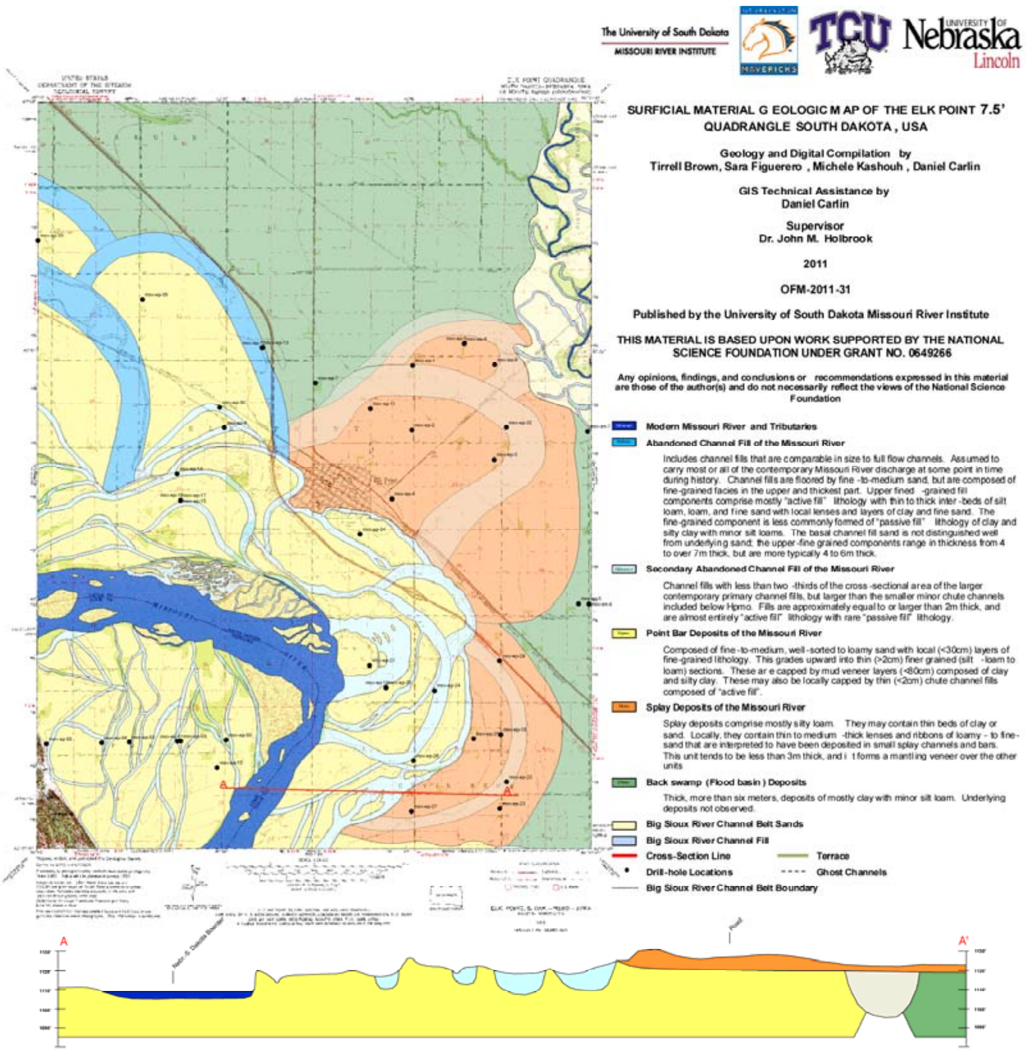
Cross-Section Line
Terrace
Drill-hole Locations
Ghost Channels
A
A'


A
A'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SURFICIAL MATERIAL G EOLOGIC M AP OF THE ELK POINT 7.5' QUADRANGLE SOUTH DAKOTA , USA
Geology and Digital Compilation by
Tirrell Brown, Sara Figuerero , Michele Kashouh , Daniel Carlin
GIS Technical Assistance by
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Big Sioux River Channel Belt Sands
Big Sioux River Channel Fill
Cross-Section Line
Terrace
Drill-hole Locations
Ghost Channels
Big Sioux River Channel Belt Boundary
A
A'

SURFICIAL MATERIAL GEOLOGIC MAP OF THE ELK POINT NE 7.5' QUADRANGLE SOUTH DAKOTA, USA

Geology and Digital Compilation by
Jill Meyers, Josh Arten, Michele Kashouh, Daniel Carlin

GIS Technical Assistance by
Daniel Carlin

Supervisor
Dr. John M. Holbrook

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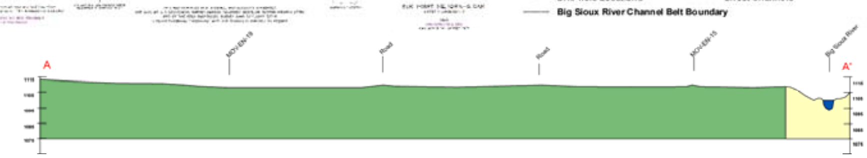

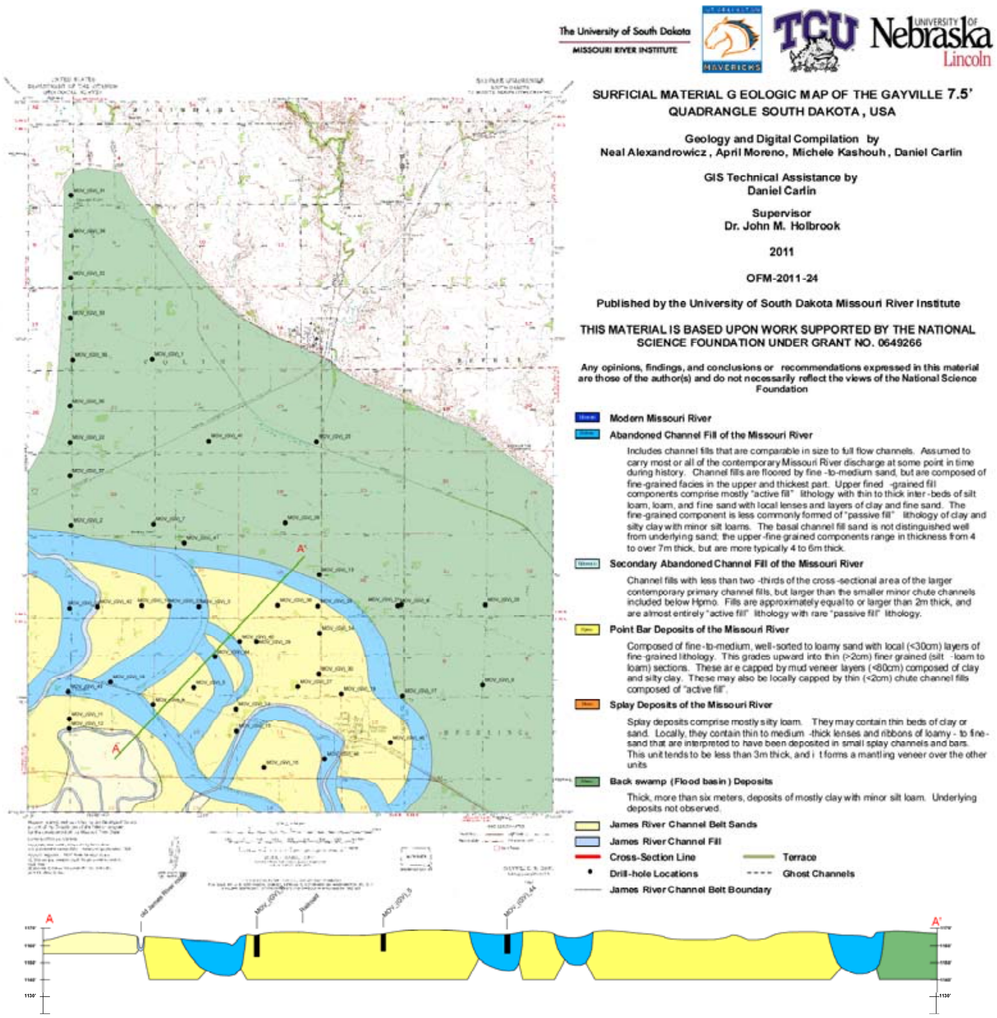
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Geology and Digital Compilation by
Neal Alexandrowicz , April Moreno, Michele Kashouh , Daniel Carlin
GIS Technical Assistance by
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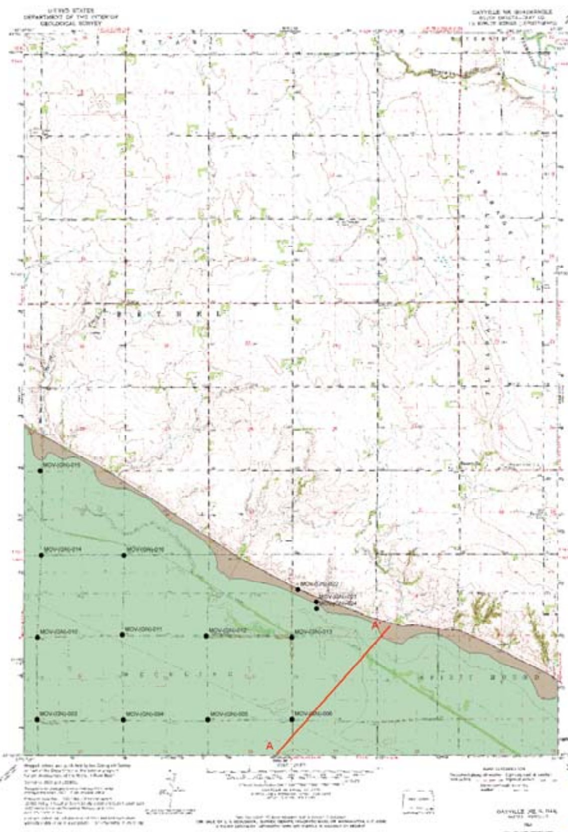
James River Channel Belt Sands
James River Channel Fill
Cross-Section Line
Terrace
Drill-hole Locations
Ghost Channels
James River Channel Belt Boundary
A
A'



SURFICIAL MATERIAL GEOLOGIC MAP OF THE GAYVILLE NE 7.5' QUADRANGLE SOUTH DAKOTA, USA

Geology and Digital Compilation by
April Moreno, Dustin Ward, Jordan Garrett, Neal Alexandrowicz, Michele Kashouh, Daniel Carlin

GIS Technical Assistance by
Daniel Carlin

Supervisor
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Back swamp (Flood basin) Deposits

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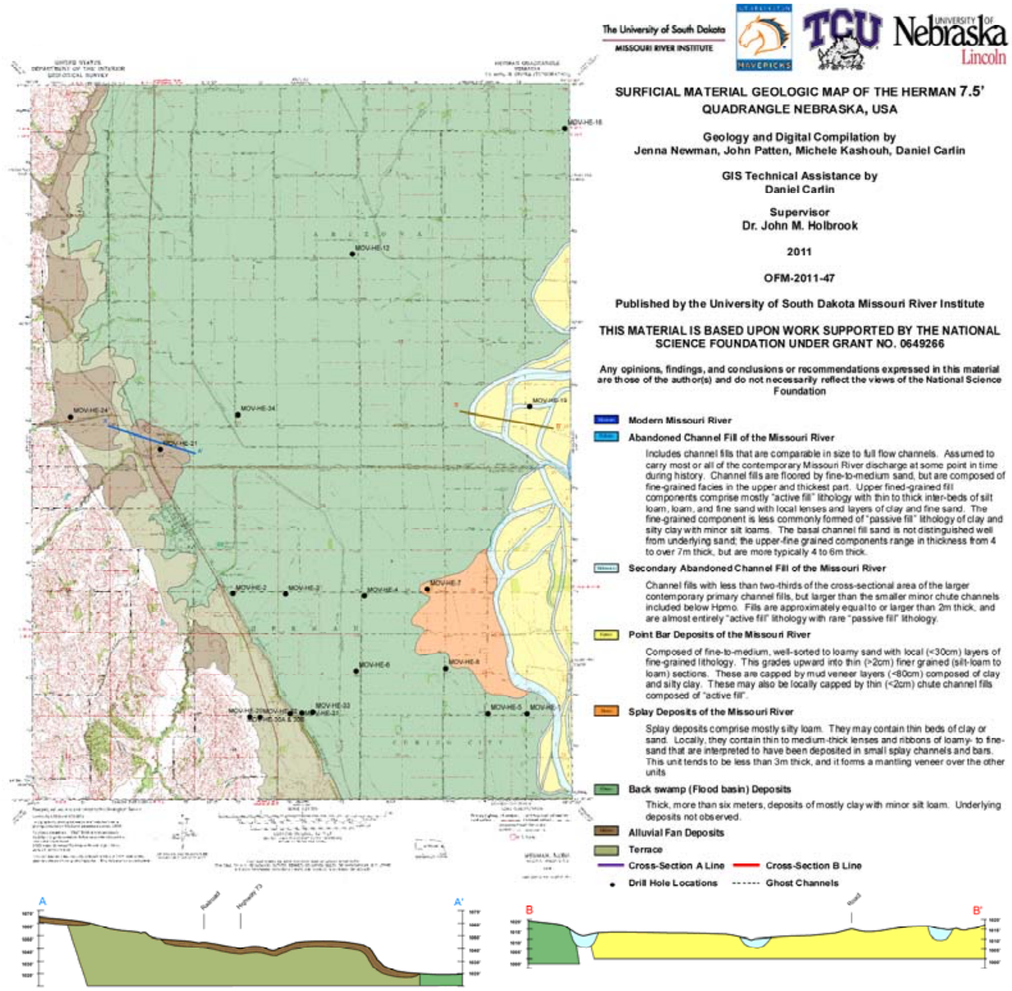
Cross-Section Line — **Terrace**

Drill-hole Locations — **Ghost Channels**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Geology and Digital Compilation by
Jenna Newman, John Patten, Michele Kashouh, Daniel Carlin
GIS Technical Assistance by
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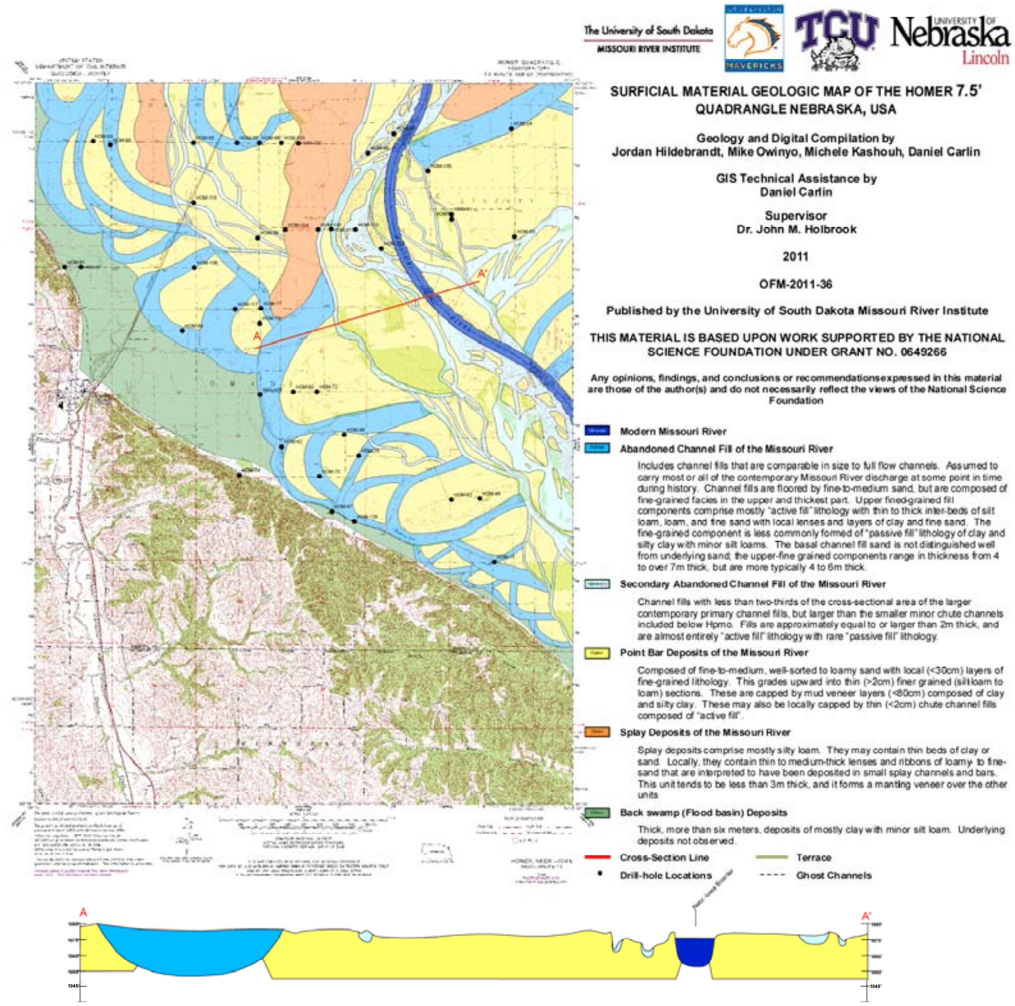
Alluvial Fan Deposits
Terrace
Cross-Section A Line
Cross-Section B Line
Drill Hole Locations
Ghost Channels
A
A'
B
B'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Geology and Digital Compilation by
Jordan Hildebrandt, Mike Owinyo, Michele Kashouh, Daniel Carlin
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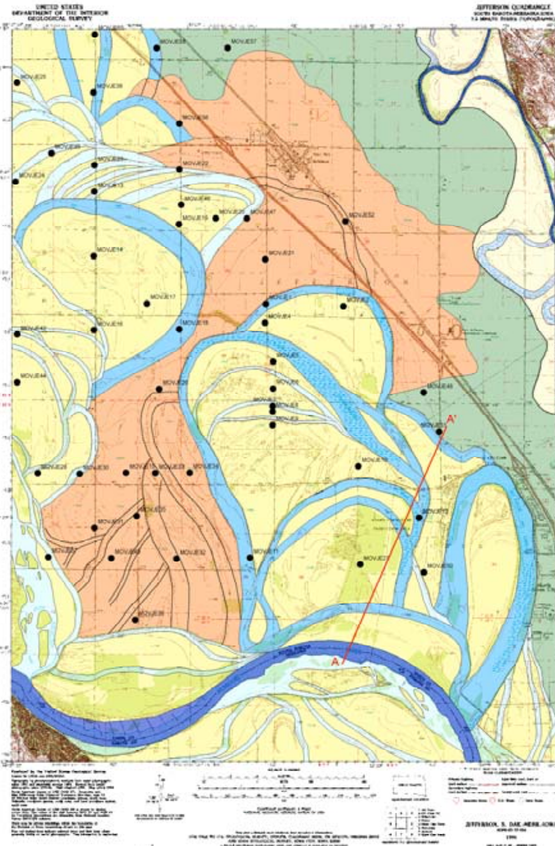
Channel fills with less than two-thirds of the cross-sectional area of the larger contemporary primary channel fills, but larger than the smaller minor chute channels included below Hpmo. Fills are approximately equal to or larger than 2m thick, and are almost entirely "active fill" lithology with rare "passive fill" lithology.
Point Bar Deposits of the Missouri River
Composed of fine-to-medium, well-sorted to loamy sand with local (<30cm) layers of fine-grained lithology. This grades upward into thin (>2cm) finer grained (silt-loam to loam) sections. These are capped by mud veneer layers (<80cm) composed of clay and silty clay. These may also be locally capped by thin (<2cm) chute channel fills composed of "active fill".
Splay Deposits of the Missouri River
Splay deposits comprise mostly silty loam. They may contain thin beds of clay or sand. Locally, they contain thin to medium-thick lenses and ribbons of loamy- to fine-sand that are interpreted to have been deposited in small splay channels and bars. This unit tends to be less than 3m thick, and it forms a mantling veneer over the other units
Back swamp (Flood basin) Deposits
Thick, more than six meters, deposits of mostly clay with minor silt loam. Underlying deposits not observed.
Cross-Section Line
Terrace
Drill-hole Locations
Ghost Channels
A
A'



SURFICIAL MATERIAL GEOLOGIC MAP OF THE JEFFERSON 7.5' QUADRANGLE SOUTH DAKOTA, USA

Geology and Digital Compilation by
Tatiana Kliem, Matt Wessale, Michele Kashouh, Daniel Carlin

GIS Technical Assistance by
Daniel Carlin

Supervisor
Dr. John M. Holbrook

2011

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Modern Missouri River and Tributaries

Abandoned Channel Fill of the Missouri River

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Channel fills with less than two -thirds of the cross-sectional area of the larger contemporary primary channel fills, but larger than the smaller minor chute channels included below Hpmo. Fills are approximately equal to or larger than 2m thick, and are almost entirely "active fill" lithology with rare "passive fill" lithology.

Point Bar Deposits of the Missouri River

Composed of fine-to-medium, well-sorted to loamy sand with local (<30cm) layers of fine-grained lithology. This grades upward into thin (>2cm) finer grained (silt -loam to loam) sections. These are capped by mud veneer layers (<80cm) composed of clay and silty clay. These may also be locally capped by thin (<2cm) chute channel fills composed of "active fill".

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Back swamp (Flood basin) Deposits

Thick, more than six meters, deposits of mostly clay with minor silt loam. Underlying deposits not observed.

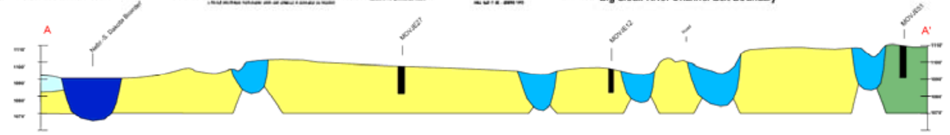
Big Sioux River Channel Belt Sands

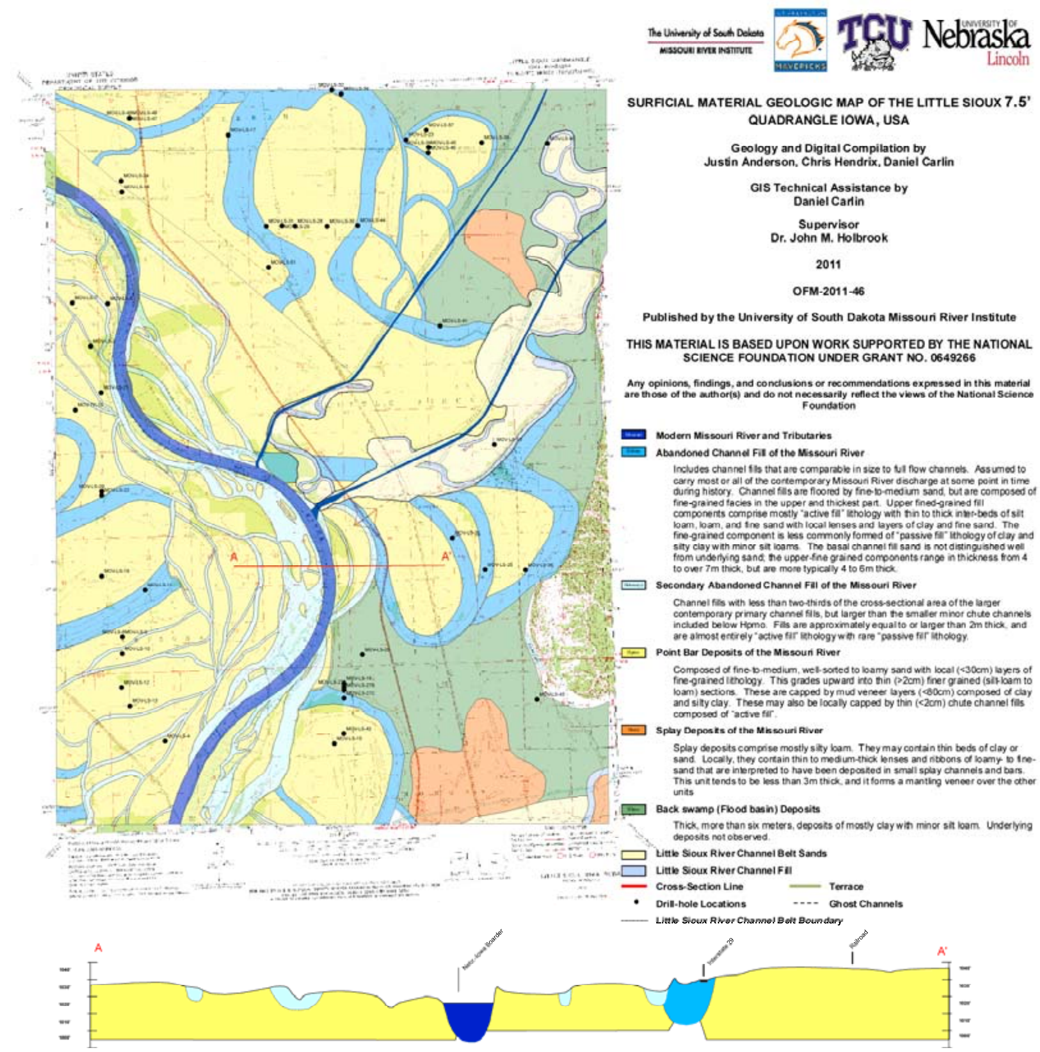
Big Sioux River Channel Fill

Cross-Section Line — **Terrace**

Drill-hole Locations — **Ghost Channels**

Big Sioux River Channel Belt Boundary




The University of South Dakota
MISSOURI RIVER INSTITUTE
Nebraska
Lincoln
SURFICIAL MATERIAL GEOLOGIC MAP OF THE LITTLE SIOUX 7.5' QUADRANGLE IOWA, USA
Geology and Digital Compilation by
Justin Anderson, Chris Hendrix, Daniel Carlin
GIS Technical Assistance by
Daniel Carlin
Supervisor
Dr. John M. Holbrook
2011
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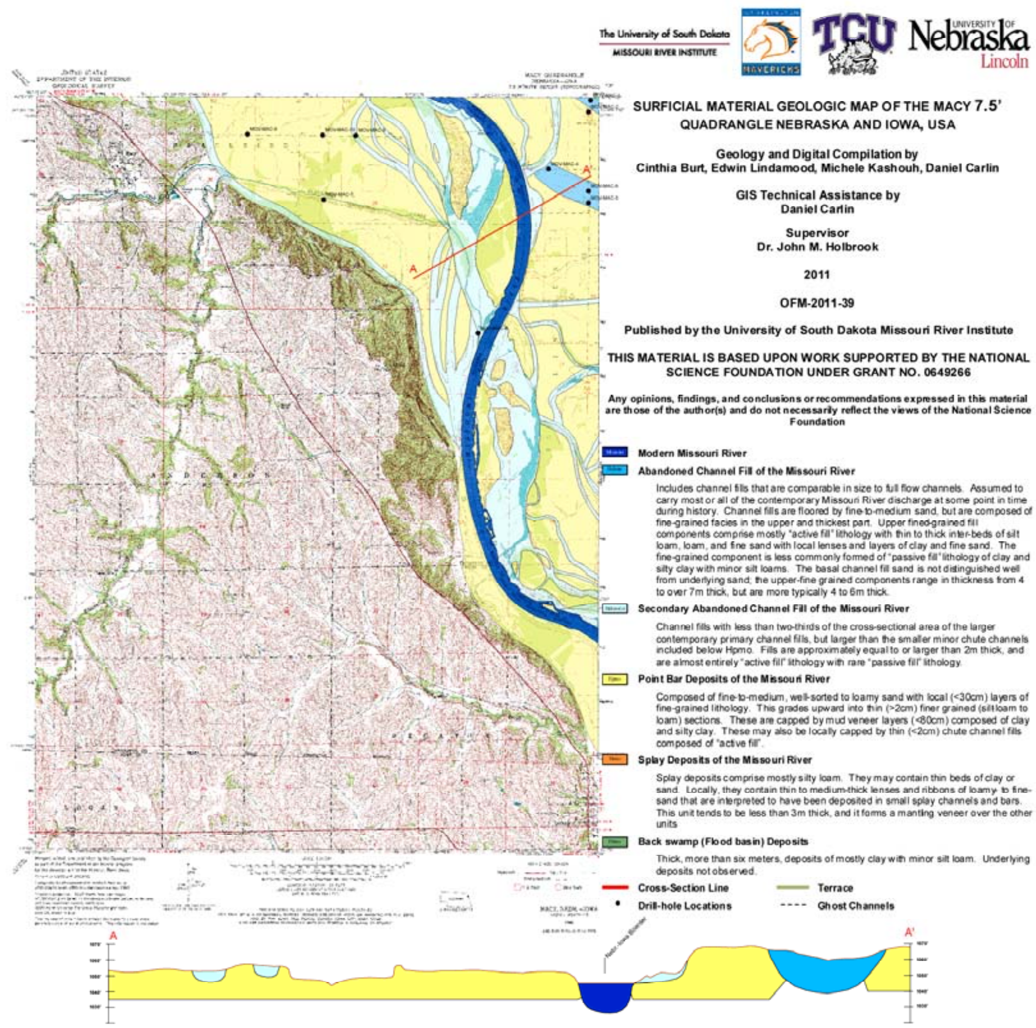
Back swamp (Flood basin) Deposits
Thick, more than six meters, deposits of mostly clay with minor silt loam. Underlying deposits not observed.
Little Sioux River Channel Belt Sands
Little Sioux River Channel Fill
Cross-Section Line
Terrace
Drill-hole Locations
Ghost Channels
Little Sioux River Channel Belt Boundary
A
A'
Interstate 29
Railroad



The University of South Dakota
MISSOURI RIVER INSTITUTE
MAVERICKS
TCU
UNIVERSITY OF Nebraska Lincoln
SURFICIAL MATERIAL GEOLOGIC MAP OF THE MACY 7.5' QUADRANGLE NEBRASKA AND IOWA, USA
Geology and Digital Compilation by
Cinthia Burt, Edwin Lindamood, Michele Kashouh, Daniel Carlin
GIS Technical Assistance by
Daniel Carlin
Supervisor
Dr. John M. Holbrook
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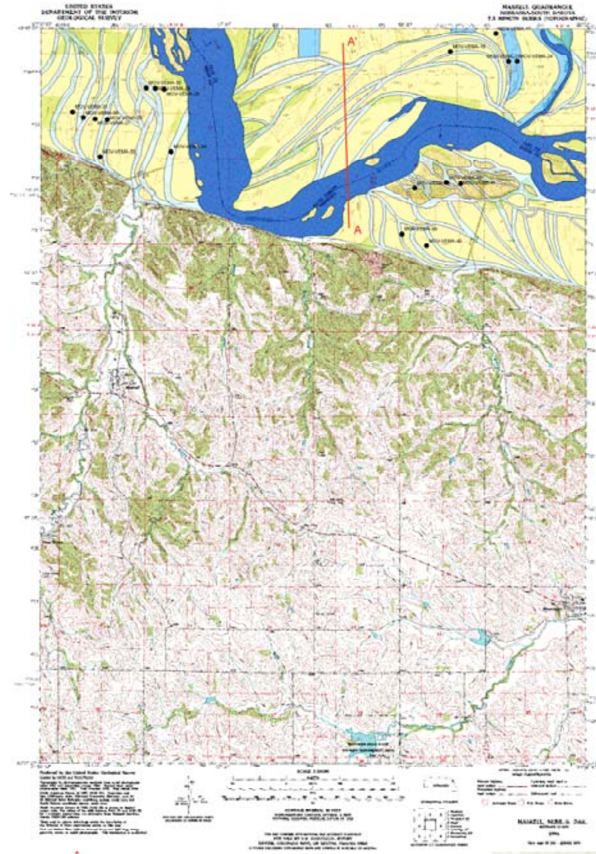
Back swamp (Flood basin) Deposits
Thick, more than six meters, deposits of mostly clay with minor silt loam. Underlying deposits not observed.
Cross-Section Line
Terrace
Drill-hole Locations
Ghost Channels
A
A'



The University of South Dakota
MISSOURI RIVER INSTITUTE

SURFICIAL MATERIAL GEOLOGIC MAP OF THE MASKELL 7.5' QUADRANGLE SOUTH DAKOTA, USA

Geology and Digital Compilation by
A. Radakovich, A. Soultiere, Michele Kashouh, Daniel Carlin

GIS Technical Assistance by
Daniel Carlin

Supervisor
Dr. John M. Holbrook

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Point Bar Deposits of the Missouri River

Composed of fine-to-medium, well-sorted to loamy sand with local (<30cm) layers of fine-grained lithology. This grades upward into thin (>2cm) finer grained (silt-loam to loam) sections. These are capped by mud veneer layers (<80cm) composed of clay and silty clay. These may also be locally capped by thin (<2cm) chute channel fills composed of "active fill".

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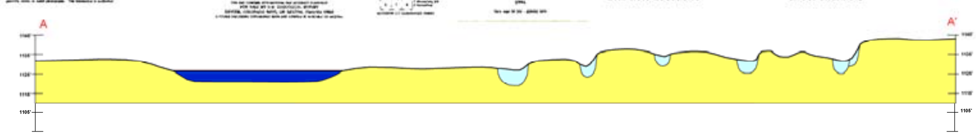
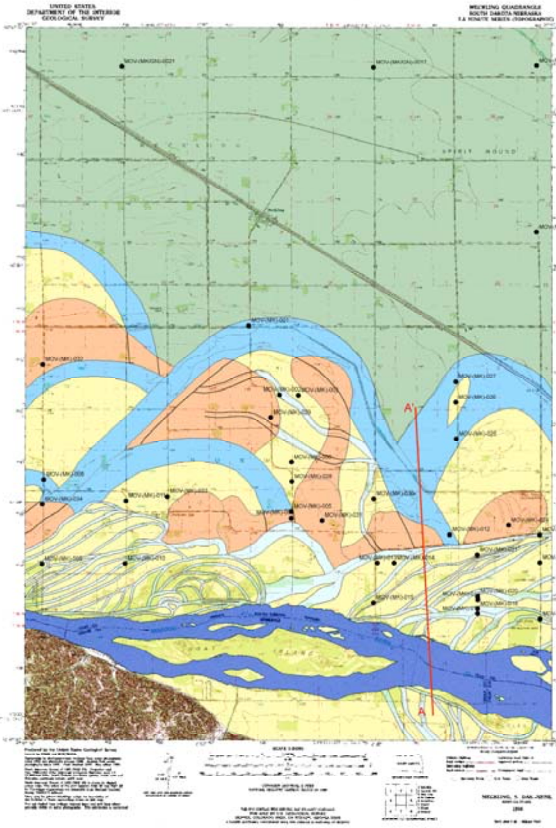
Back swamp (Flood basin) Deposits

Thick, more than six meters, deposits of mostly clay with minor silt loam. Underlying deposits not observed.

Cross-Section Line — Terrace

Drill-hole Locations — Ghost Channels





SURFICIAL MATERIAL G EOLOGIC M AP OF THE MECKLING 7.5' QUADRANGLE SOUTH DAKOTA, USA

Geology and Digital Compilation by
April Moreno, Dustin Ward , Jordan Garrett, Neal Alexandrowicz, Michele Kashouh, Daniel Carlin

GIS Technical Assistance by
Daniel Carlin

Supervisor
Dr. John M. Holbrook

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Modern Missouri River

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Channel fills with less than two -thirds of the cross-sectional area of the larger contemporary primary channel fills, but larger than t he smaller minor chute channels included below Hpmo. Fills are approximately equal to or larger than 2m thick, and are almost entirely "active fill" lithology with rare "passive fill" lithology.

Point Bar Deposits of the Missouri River

Composed of fine-to-medium, well-sorted to loamy sand with local (<30cm) layers of fine-grained lithology. This grades upward into thin (>2cm) finer grained (silt -loam to loam) sections. These are capped by mud veneer layers (<80cm) composed of clay and silty clay. These may also be locally capped by thin (<2cm) chute channel fills composed of "active fill".

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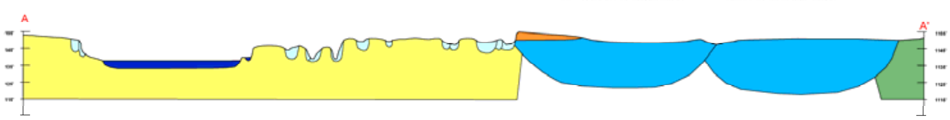
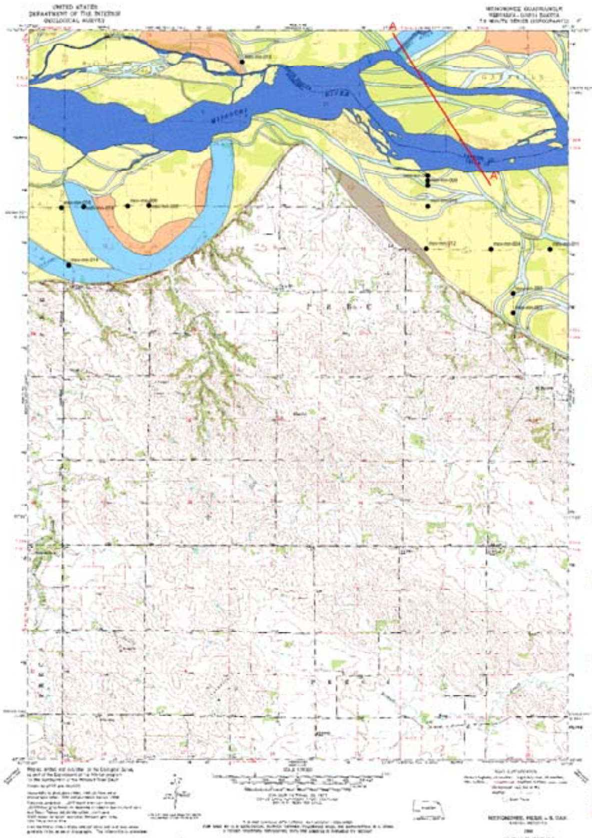
Back swamp (Flood basin) Deposits

Thick, more than six meters, deposits of mostly clay with minor silt loam. Underlying deposits not observed.

Cross-Section Line — **Terrace**

Drill-hole Locations — **Ghost Channels**





SURFICIAL MATERIAL G EOLOGIC MAP OF THE MENOMINEE 7.5' QUADRANGLE SOUTH DAKOTA , USA

Geology and Digital Compilation by
April Moreno, Eli Erikson, Michele Kashouh , Daniel Carlin

GIS Technical Assistance by
Daniel Carlin

Supervisor
Dr. John M. Holbrook

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Modern Missouri and James River

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Channel fills with less than two -thirds of the cross-sectional area of the larger contemporary primary channel fills, but larger than the smaller minor chute channels included below Hpmo. Fills are approximately equal to or larger than 2m thick, and are almost entirely "active fill" lithology with rare "passive fill" lithology.

Point Bar Deposits of the Missouri River

Composed of fine-to-medium, well-sorted to loamy sand with local (<30cm) layers of fine-grained lithology. This grades upward into thin (>2cm) finer grained (silt-loam to loam) sections. These are capped by mud veneer layers (<80cm) composed of clay and silty clay. These may also be locally capped by thin (<2cm) chute channel fills composed of "active fill".

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Back swamp (Flood basin) Deposits

Thick, more than six meters, deposits of mostly clay with minor silt loam. Underlying deposits not observed.

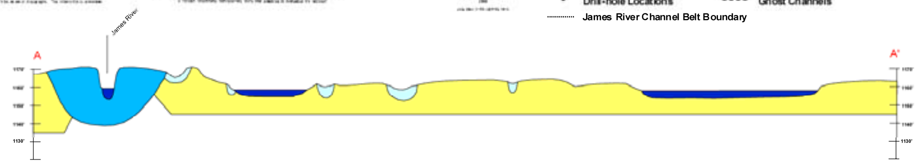
James River Channel Belt Sands

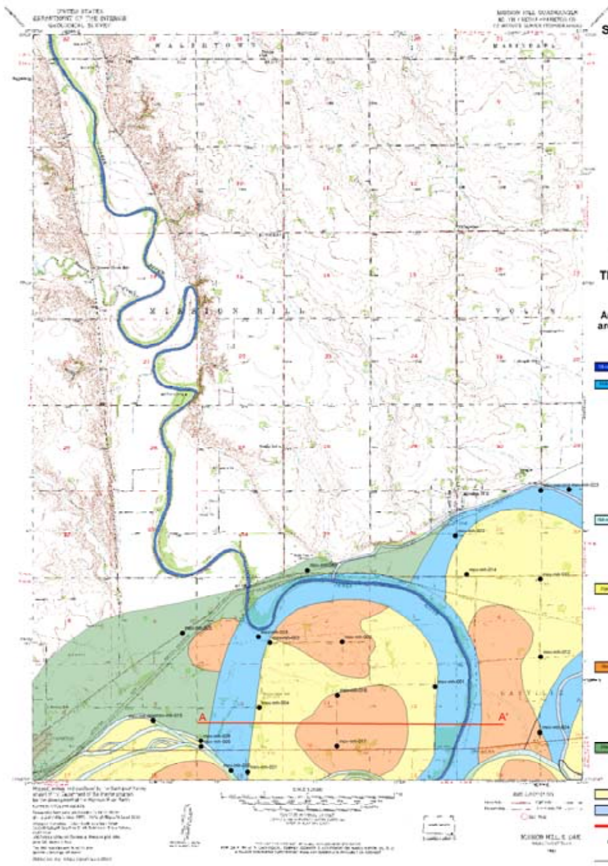
James River Channel Fill

Cross-Section Line — **Terrace**

Drill-hole Locations — **Ghost Channels**

James River Channel Belt Boundary





SURFICIAL MATERIAL GEOLOGIC MAP OF THE MISSION HILL 7.5' QUADRANGLE SOUTH DAKOTA, USA

Geology and Digital Compilation by
April Moreno, Eli Erikson, Michele Kashouh, Daniel Carlin

GIS Technical Assistance by
Daniel Carlin

Supervisor
Dr. John M. Holbrook

2011

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Point Bar Deposits of the Missouri River

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Back swamp (Flood basin) Deposits

Thick, more than six meters, deposits of mostly clay with minor silt loam. Underlying deposits not observed.

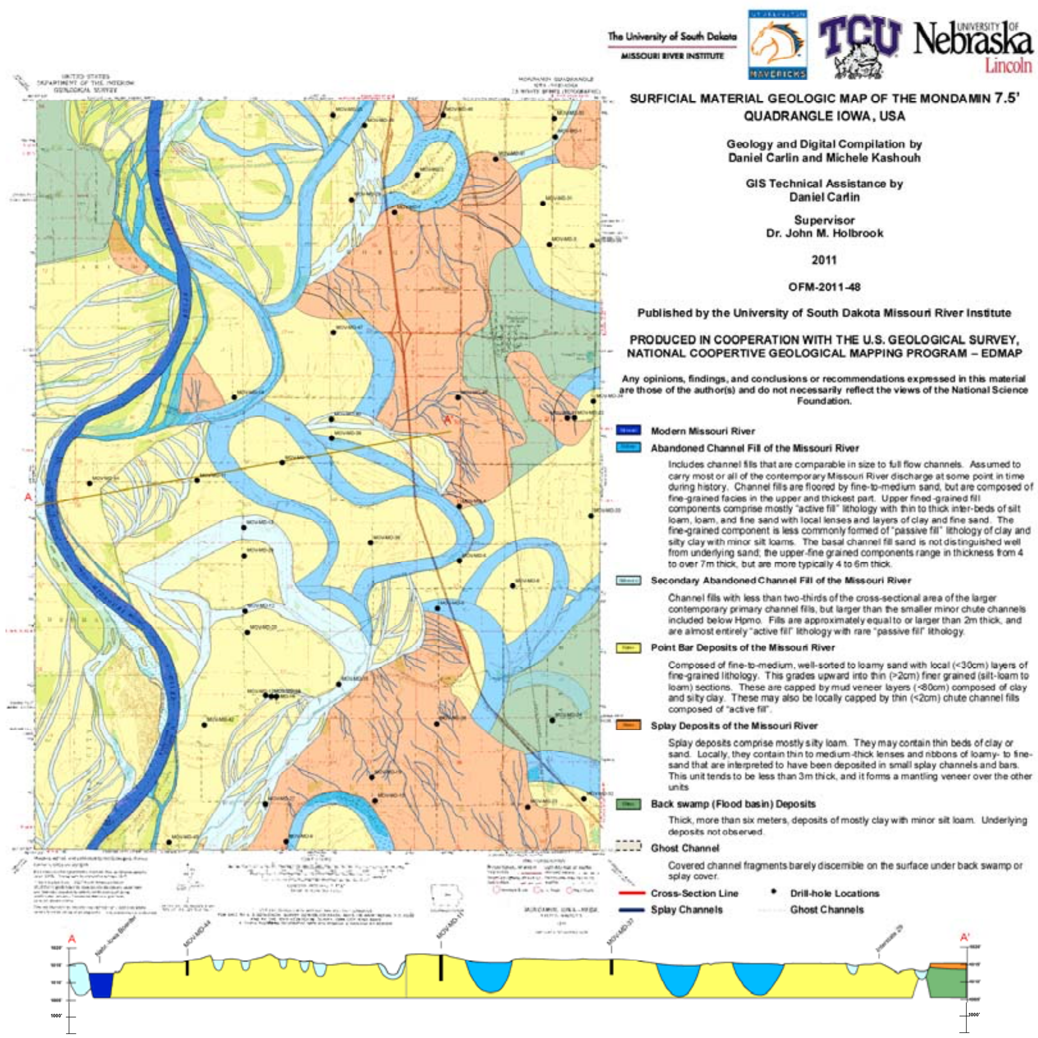
James River Channel Belt Sands

James River Channel Fill

Cross-Section Line — **Terrace**

Drill-hole Locations — **Ghost Channels**

James River Channel Belt Boundary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MISSOURI RIVER INSTITUTE
MAVERICKS
TCU
UNIVERSITY OF Nebraska Lincoln
SURFICIAL MATERIAL GEOLOGIC MAP OF THE MONDAMIN 7.5' QUADRANGLE IOWA, USA
Geology and Digital Compilation by
Daniel Carlin and Michele Kashouh
GIS Technical Assistance by
Daniel Carlin
Supervisor
Dr. John M. Holbrook
2011
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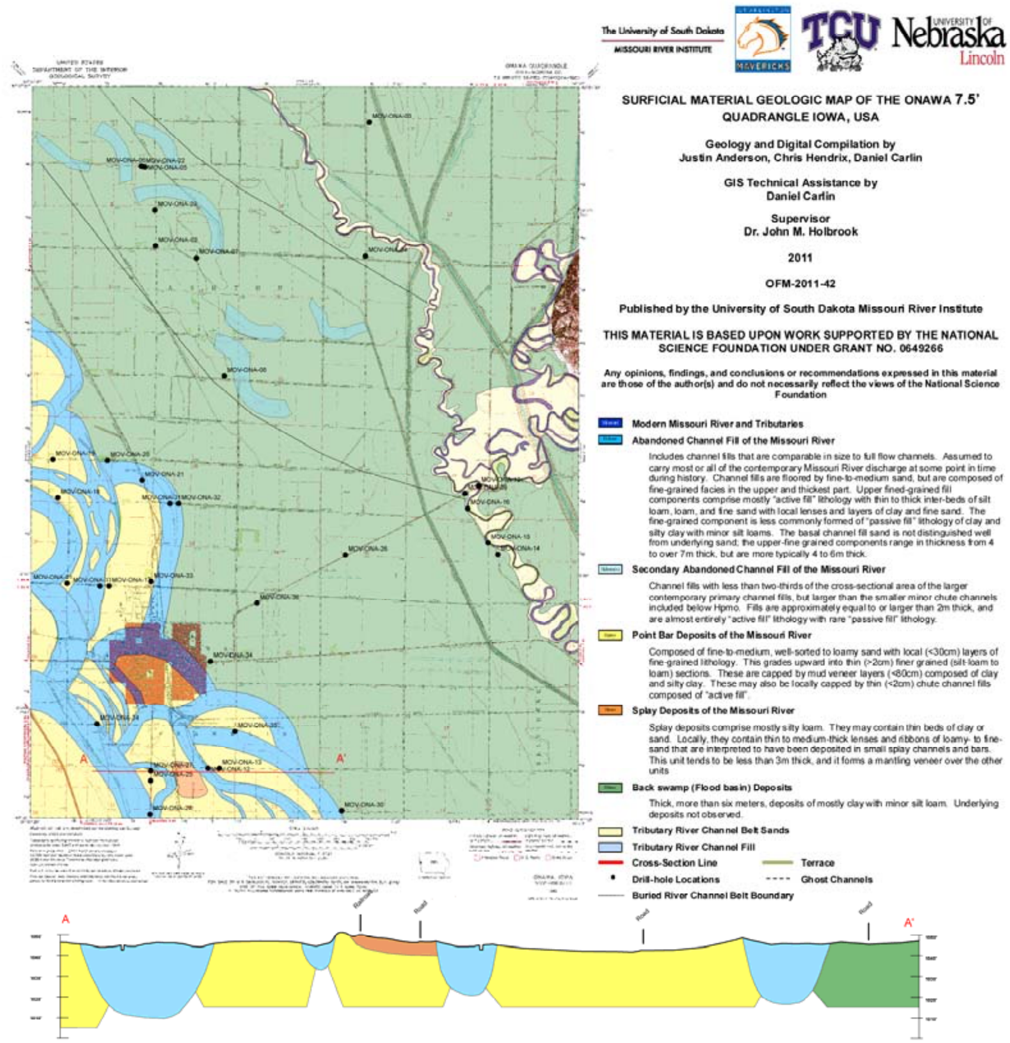
Back swamp (Flood basin) Deposits
Thick, more than six meters, deposits of mostly clay with minor silt loam. Underlying deposits not observed.
Ghost Channel
Covered channel fragments barely discernible on the surface under back swamp or splay cover.
Cross-Section Line
Drill-hole Locations
Splay Channels
Ghost Channels
A
A'
1000'


The University of South Dakota
MISSOURI RIVER INSTITUTE
MAVERICKS
TCU
UNIVERSITY OF Nebraska Lincoln
SURFICIAL MATERIAL GEOLOGIC MAP OF THE ONAWA 7.5' QUADRANGLE IOWA, USA
Geology and Digital Compilation by
Justin Anderson, Chris Hendrix, Daniel Carlin
GIS Technical Assistance by
Daniel Carlin
Supervisor
Dr. John M. Holbrook
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Modern Missouri River and Tributaries
Abandoned Channel Fill of the Missouri River
Includes channel fills that are comparable in size to full flow channels. Assumed to carry most or all of the contemporary Missouri River discharge at some point in time during history. Channel fills are floored by fine-to-medium sand, but are composed of fine-grained facies in the upper and thickest part. Upper fined-grained fill components comprise mostly "active fill" lithology with thin to thick inter-beds of silt loam, loam, and fine sand with local lenses and layers of clay and fine sand. The fine-grained component is less commonly formed of "passive fill" lithology of clay and silty clay with minor silt loams. The basal channel fill sand is not distinguished well from underlying sand; the upper-fine grained components range in thickness from 4 to over 7m thick, but are more typically 4 to 6m thick.
Secondary Abandoned Channel Fill of the Missouri River
Channel fills with less than two-thirds of the cross-sectional area of the larger contemporary primary channel fills, but larger than the smaller minor chute channels included below Hpmo. Fills are approximately equal to or larger than 2m thick, and are almost entirely "active fill" lithology with rare "passive fill" lithology.
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Composed of fine-to-medium, well-sorted to loamy sand with local (<30cm) layers of fine-grained lithology. This grades upward into thin (>2cm) finer grained (silt-loam to loam) sections. These are capped by mud veneer layers (<80cm) composed of clay and silty clay. These may also be locally capped by thin (<2cm) chute channel fills composed of "active fill".
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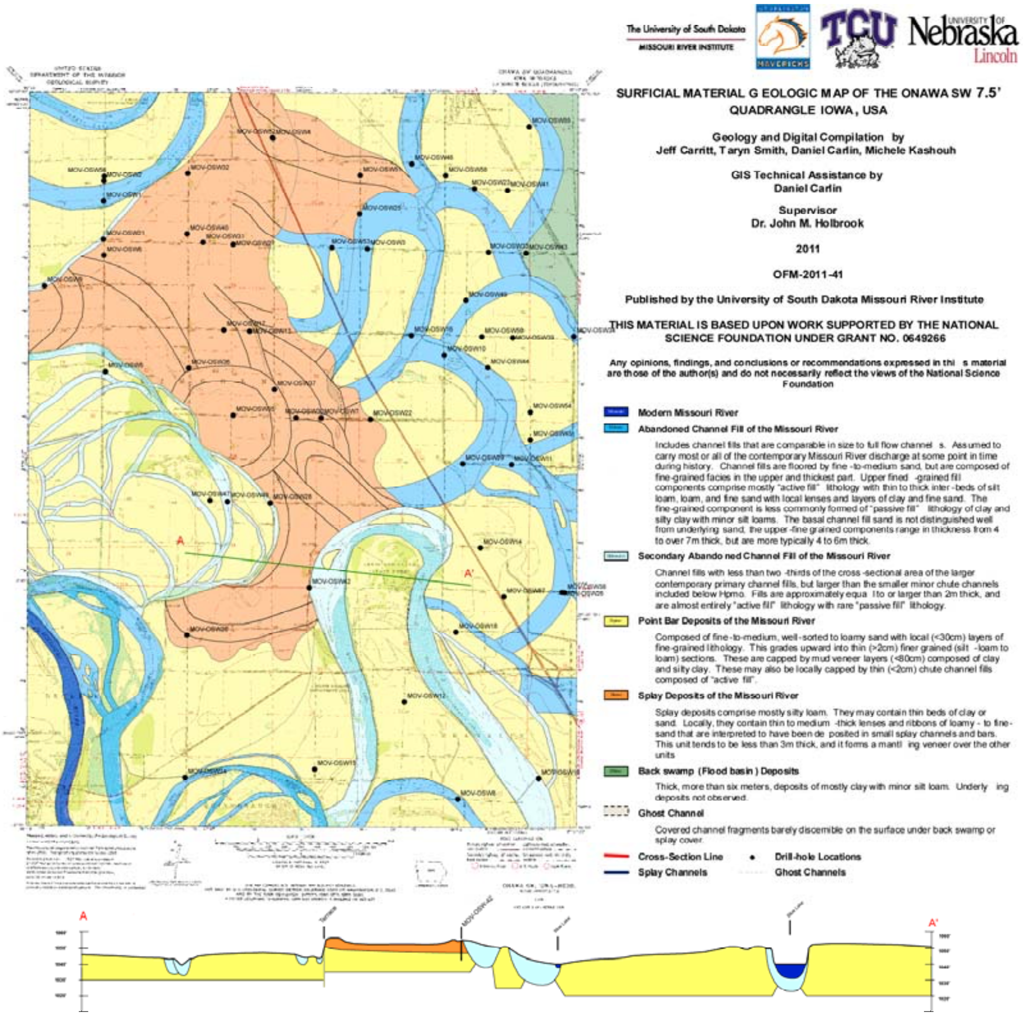
Thick, more than six meters, deposits of mostly clay with minor silt loam. Underlying deposits not observed.
Tributary River Channel Belt Sands
Tributary River Channel Fill
Cross-Section Line
Terrace
Drill-hole Locations
Ghost Channels
Buried River Channel Belt Boundary
A
A'
Road
Road
Road


The University of South Dakota
MISSOURI RIVER INSTITUTE
MAVERICKS
TCU
UNIVERSITY OF Nebraska Lincoln
SURFICIAL MATERIAL G EOLOGIC M AP OF THE ONAWA SW 7.5' QUADRANGLE IOWA , USA
Geology and Digital Compilation by
Jeff Carritt, Taryn Smith, Daniel Carlin, Michele Kashouh
GIS Technical Assistance by
Daniel Carlin
Supervisor
Dr. John M. Holbrook
2011
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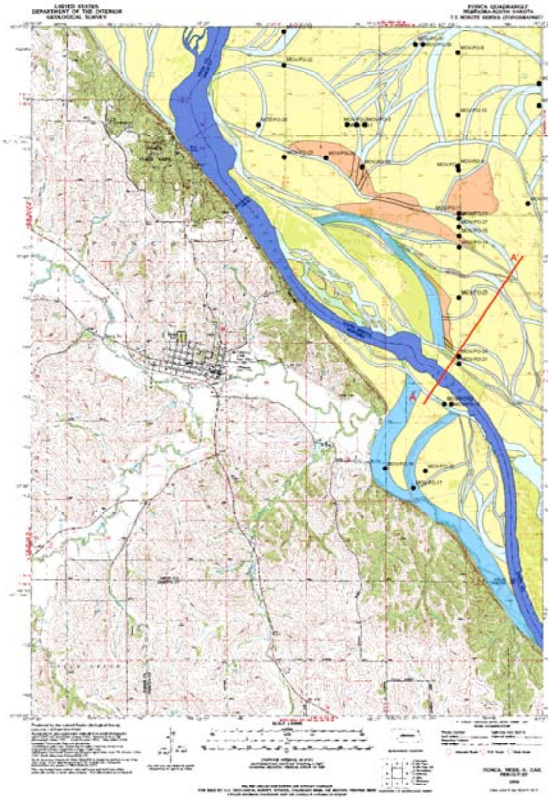
Covered channel fragments barely discernible on the surface under back swamp or splay cover.
Cross-Section Line
Drill-hole Locations
Splay Channels
Ghost Channels
A
A'



SURFICIAL MATERIAL GEOLOGIC MAP OF THE PONCA 7.5' QUADRANGLE SOUTH DAKOTA, USA

Geology and Digital Compilation by
Timothy Reed, Katherine Miller, Michele Kashouh, Daniel Carlin

GIS Technical Assistance by
Daniel Carlin

Supervisor
Dr. John M. Holbrook

2011

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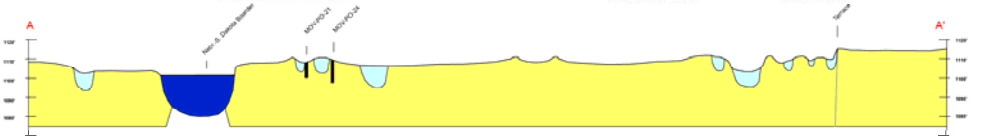
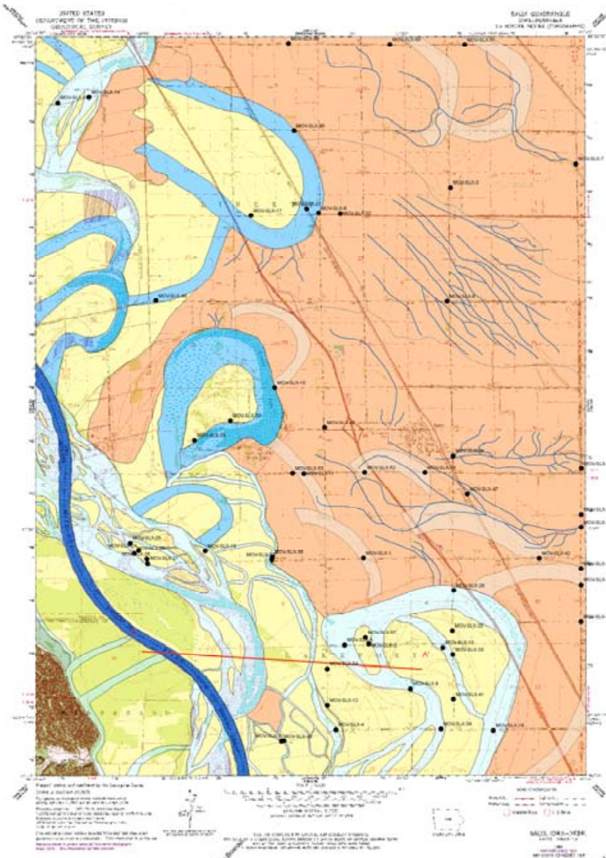
Cross-Section Line — Terrace
Drill-hole Locations — Ghost Channels





SURFICIAL MATERIAL GEOLOGIC MAP OF THE SALIX 7.5' QUADRANGLE IOWA, USA

Geology and Digital Compilation by
Angela Markson, Monica Barbery, Daniel Carlin, Michele Kashouh

GIS Technical Assistance by
Daniel Carlin

Supervisor
Dr. John M. Holbrook

2011

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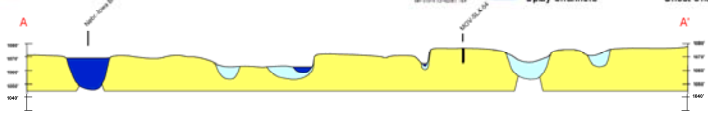
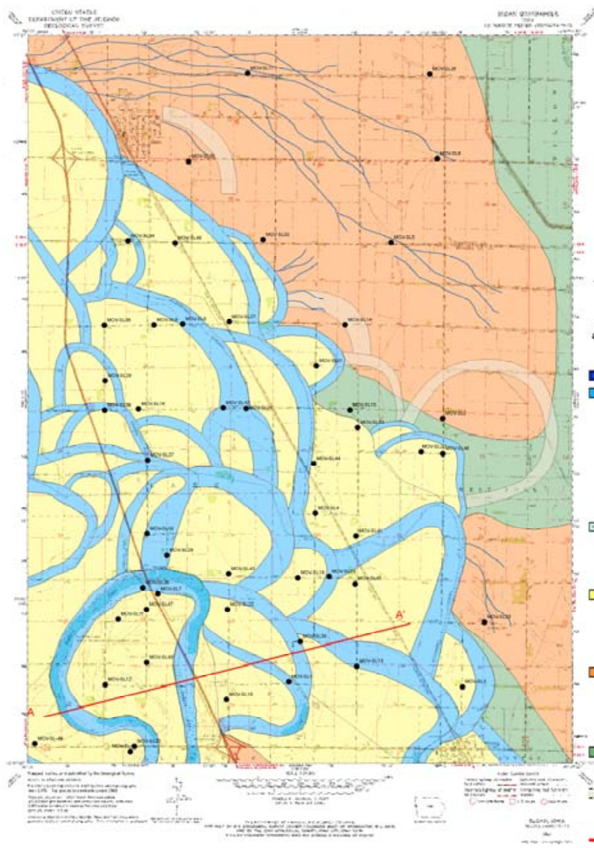
Ghost Channel

Covered channel fragments barely discernible on the surface under back swamp or splay cover.

Cross-Section Line • **Drill-hole Locations**

Splay Channels **Ghost Channels**





SURFICIAL MATERIAL GEOLOGIC MAP OF THE SLOAN 7.5' QUADRANGLE IOWA, USA

Geology and Digital Compilation by
Colin Farley, Ashley Finley, Daniel Carlin, Michele Kashouh

GIS Technical Assistance by
Daniel Carlin

Supervisor
Dr. John M. Holbrook

2011

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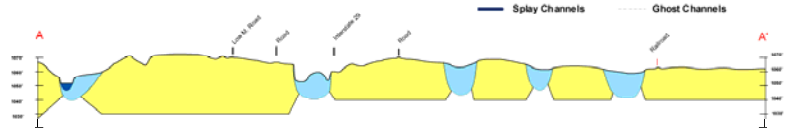
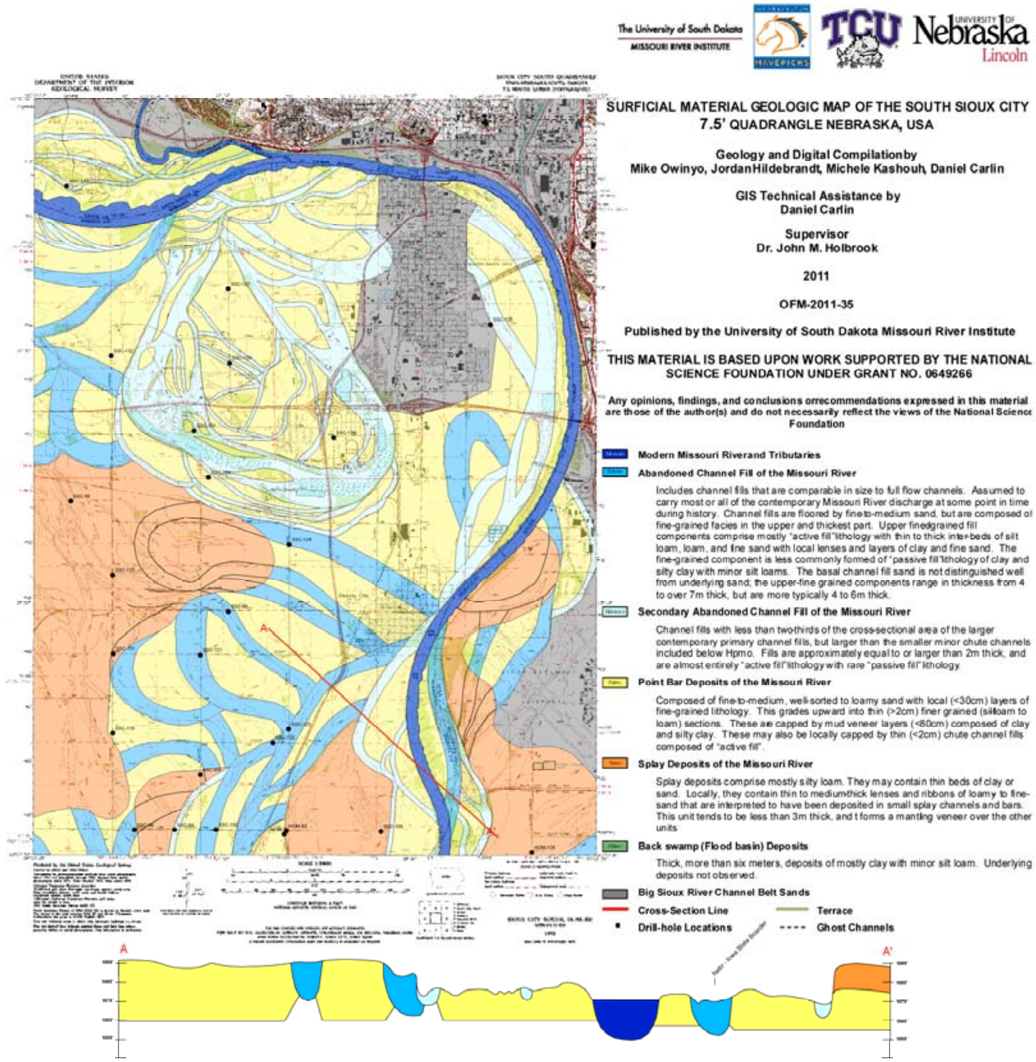
Cross-Section Line **Drill-hole Locations**

Splay Channels **Ghost Channels**

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TCU
UNIVERSITY OF Nebraska Lincoln
SURFICIAL MATERIAL GEOLOGIC MAP OF THE SOUTH SIOUX CITY
7.5' QUADRANGLE NEBRASKA, USA
Geology and Digital Compilation by
Mike Owinyo, Jordan Hildebrandt, Michele Kashouh, Daniel Carlin
GIS Technical Assistance by
Daniel Carlin
Supervisor
Dr. John M. Holbrook
2011
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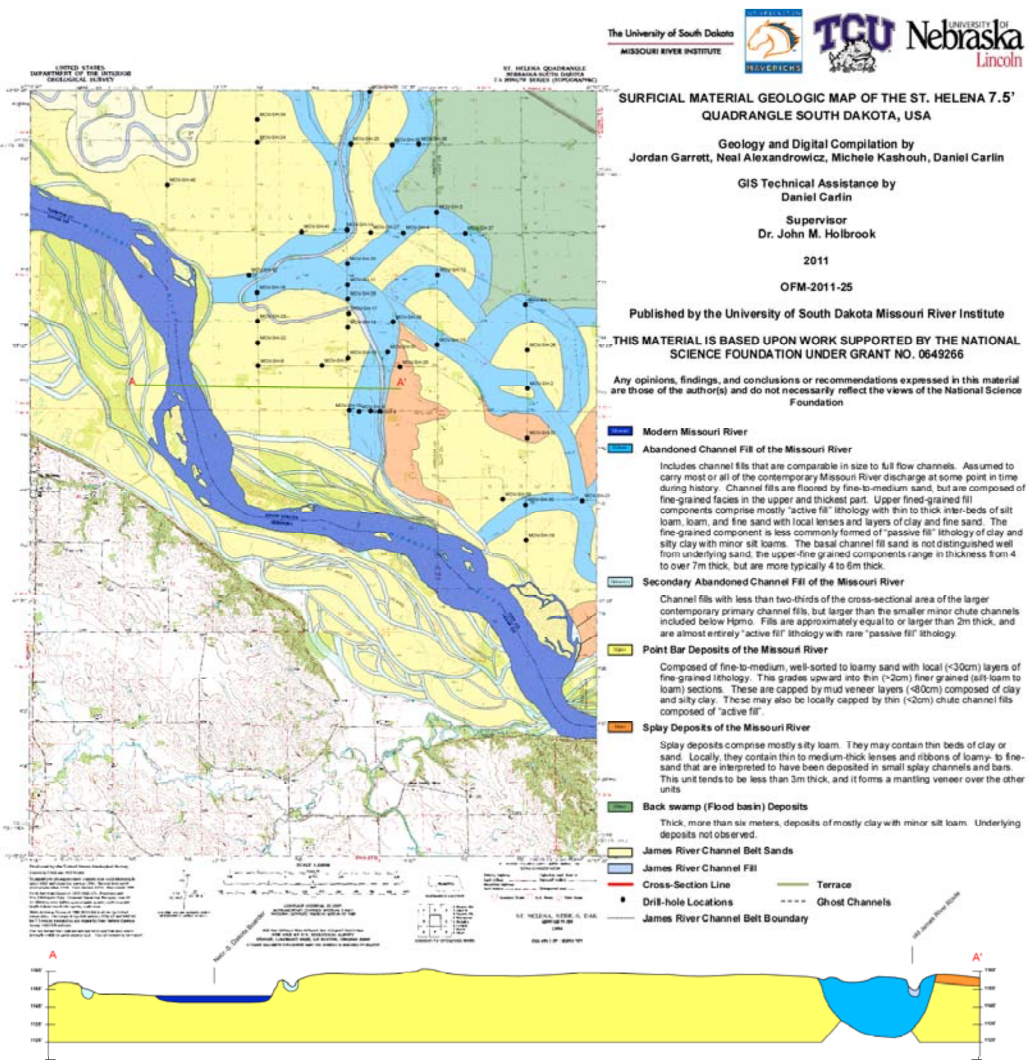
Cross-Section Line
Terrace
Drill-hole Locations
Ghost Channels
A
A'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University of Nebraska Lincoln
SURFICIAL MATERIAL GEOLOGIC MAP OF THE ST. HELENA 7.5' QUADRANGLE SOUTH DAKOTA, USA
Geology and Digital Compilation by
Jordan Garrett, Neal Alexandrowicz, Michele Kashouh, Daniel Carlin
GIS Technical Assistance by
Daniel Carlin
Supervisor
Dr. John M. Holbrook
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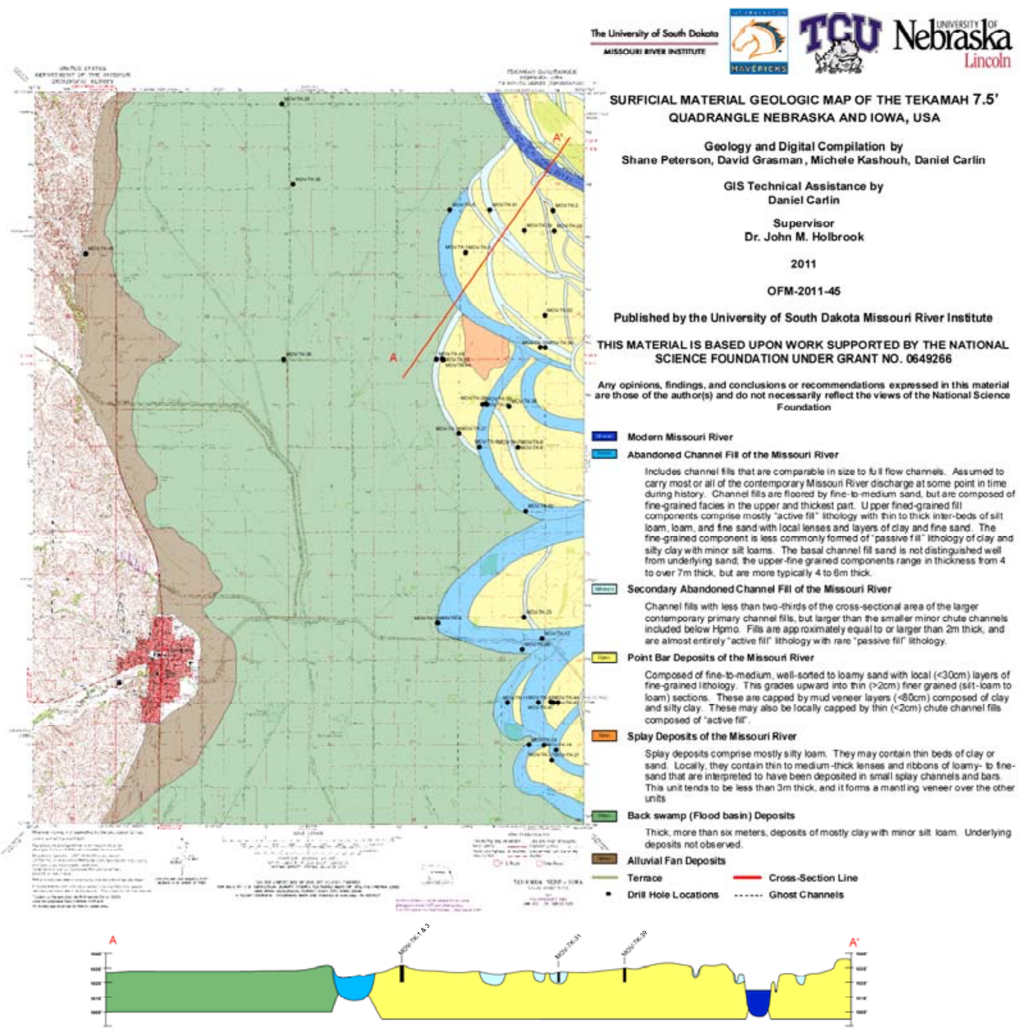
James River Channel Fill
Cross-Section Line
Terrace
Drill-hole Locations
Ghost Channels
James River Channel Belt Boundary
A
A'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Geology and Digital Compilation by
Shane Peterson, David Grasman, Michele Kashouh, Daniel Carlin
GIS Technical Assistance by
Daniel Carlin
Supervisor
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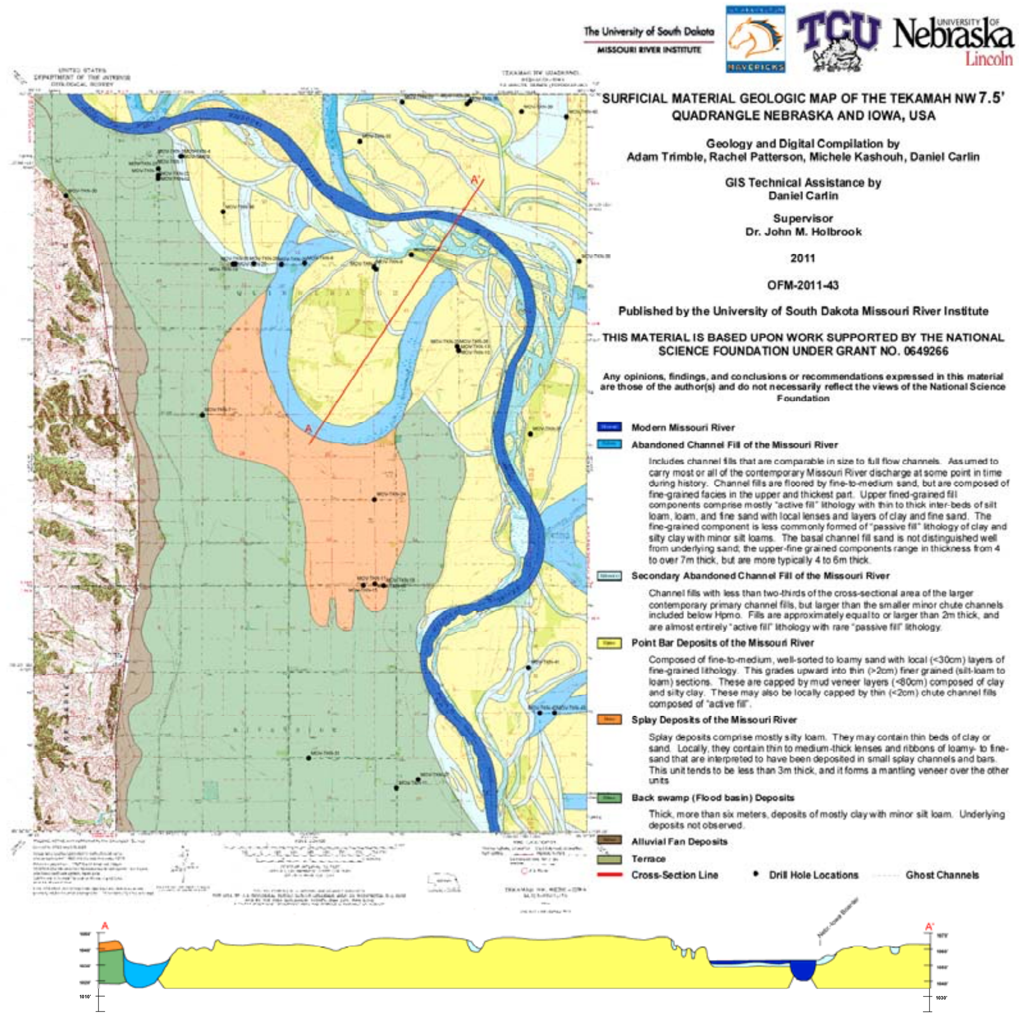
Terrace
Cross-Section Line
Drill Hole Locations
Ghost Channels
A
A'
MOV-TK-31
MOV-TK-39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Geology and Digital Compilation by
Adam Trimble, Rachel Patterson, Michele Kashouh, Daniel Carlin
GIS Technical Assistance by
Daniel Carlin
Supervisor
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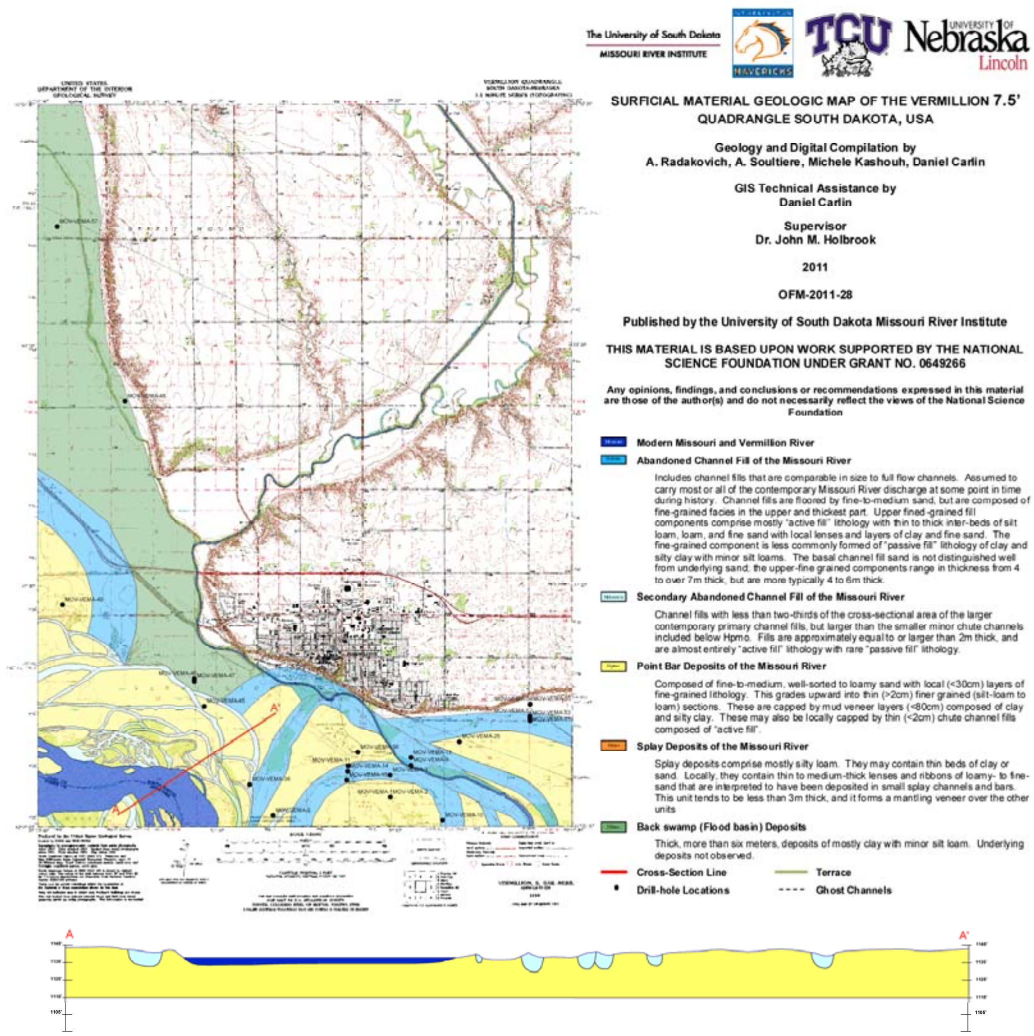
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UNIVERSITY OF Nebraska Lincoln
SURFICIAL MATERIAL GEOLOGIC MAP OF THE VERMILLION 7.5' QUADRANGLE SOUTH DAKOTA, USA
Geology and Digital Compilation by
A. Radakovich, A. Soultiere, Michele Kashouh, Daniel Carlin
GIS Technical Assistance by
Daniel Carlin
Supervisor
Dr. John M. Holbrook
2011
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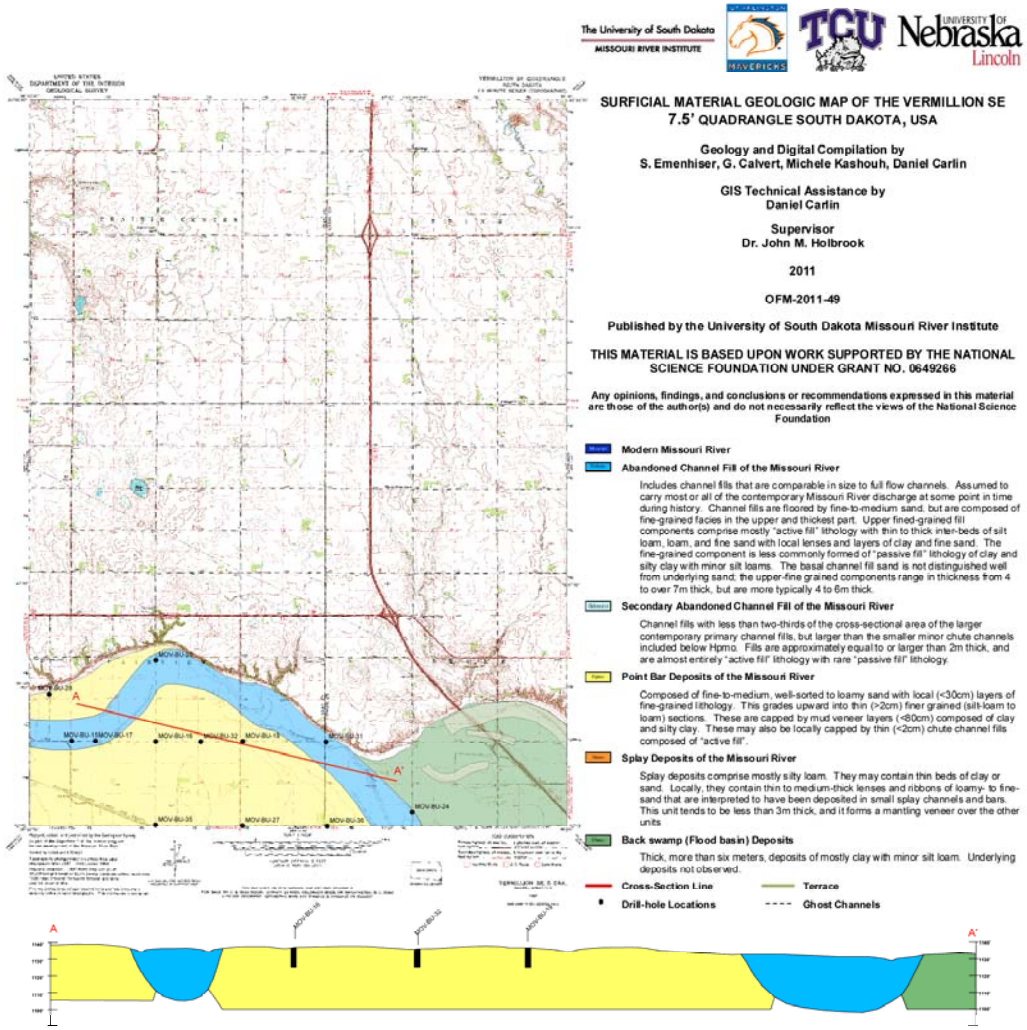
Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation
Modern Missouri and Vermillion River
Abandoned Channel Fill of the Missouri River
Includes channel fills that are comparable in size to full flow channels. Assumed to carry most or all of the contemporary Missouri River discharge at some point in time during history. Channel fills are floored by fine-to-medium sand, but are composed of fine-grained facies in the upper and thickest part. Upper fined-grained fill components comprise mostly "active fill" lithology with thin to thick inter-beds of silt loam, loam, and fine sand with local lenses and layers of clay and fine sand. The fine-grained component is less commonly formed of "passive fill" lithology of clay and silty clay with minor silt loams. The basal channel fill sand is not distinguished well from underlying sand; the upper-fine grained components range in thickness from 4 to over 7m thick, but are more typically 4 to 6m thick.
Secondary Abandoned Channel Fill of the Missouri River
Channel fills with less than two-thirds of the cross-sectional area of the larger contemporary primary channel fills, but larger than the smaller minor chute channels included below Hpmo. Fills are approximately equal to or larger than 2m thick, and are almost entirely "active fill" lithology with rare "passive fill" lithology.
Point Bar Deposits of the Missouri River
Composed of fine-to-medium, well-sorted to loamy sand with local (<30cm) layers of fine-grained lithology. This grades upward into thin (>2cm) finer grained (silt-loam to loam) sections. These are capped by mud veneer layers (<80cm) composed of clay and silty clay. These may also be locally capped by thin (<2cm) chute channel fills composed of "active fill".
Splay Deposits of the Missouri River
Splay deposits comprise mostly silty loam. They may contain thin beds of clay or sand. Locally, they contain thin to medium-thick lenses and ribbons of loamy- to fine-sand that are interpreted to have been deposited in small splay channels and bars. This unit tends to be less than 3m thick, and it forms a mantling veneer over the other units
Back swamp (Flood basin) Deposits
Thick, more than six meters, deposits of mostly clay with minor silt loam. Underlying deposits not observed.
Cross-Section Line
Terrace
Drill-hole Locations
Ghost Channels
A
A'


The University of South Dakota
MISSOURI RIVER INSTITUTE
MAVERICKS
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A'
MOV-BU-16
MOV-BU-32
MOV-BU-18
MOV-BU-35
MOV-BU-27
MOV-BU-36
MOV-BU-24

APPENDIX B

OSL LAB RESULTS

Location UNL #	Field #	Burial Depth (m)	H_2O (%)*	K_2O (%)	U (ppm)	Th (ppm)	Cosmic (Gy)	Dose Rate (Gy/ka)	D_e (Gy)	No. of Aliquots	Age (ka)
UNL2119	MOV-EP-25	4.4	5.1	2.07	2.0	6.07	0.12	2.59±0.09	3.95±0.18	27	1.53±0.11
UNL2120	MOV-VE/MA-48	8.3	26.3	2.17	1.9	5.62	0.08	2.08±0.11	21.28±0.46	33	10.2±0.7
UNL2121	MOV-PO-6	4.3	20.9	2.02	3.0	6.35	0.13	2.37±0.11	2.25±0.12	53	0.95±0.08
								MAM	1.27±0.17	53	0.54±0.08
UNL2122	MOV-BU-30	2.8	6.6	1.90	1.6	4.69	0.15	2.25±0.08	1.66±0.10	42	0.74±0.06
								MAM	1.13±0.22	65	0.50±0.10
UNL2123	MOV-EN017	7.3	27.0	2.03	2.5	7.80	0.09	2.21±0.12	30.97±0.90	26	14.0±1.0
UNL2124	MOV-BU-32	4.0	23.6	1.92	2.2	7.06	0.13	2.15±0.11	7.79±0.14	34	3.62±0.24
UNL2125	MOV-EN014	6.0	24.5	1.89	1.9	6.15	0.10	1.97±0.11	22.06±0.52	26	11.2±0.8
UNL2126	MOV-VE/MH-57	7.2	19.0	1.52	1.2	3.99	0.09	1.56±0.08	26.27±0.18	24	16.8±1.0
UNL2127	MOV-EP-31	6.4	28.0	1.90	1.9	5.98	0.10	1.91±0.12	25.66±0.83	27	13.4±1.0
UNL2128	MOV-JE-55	4.5	7.5	1.94	1.8	5.85	0.12	2.37±0.09	8.28±0.14	42	3.49±0.19

* In-situ Moisture Content
Error on De is 1 standard error
Error on age includes random and systematic errors calculated in quadrature

Dose Recovery Test on Sample UNL2120:

Preheat Temp (ºC)	De (Gy)	±	
180	22.80	0.42	
200	22.14	0.37	
220	22.25	0.19	
240	22.03	0.72	
260	22.59	0.27	
280	21.04	1.21	
Applied Dose =		21.67	Gy
Recovered Dose =		22.14 ±	0.61 Gy

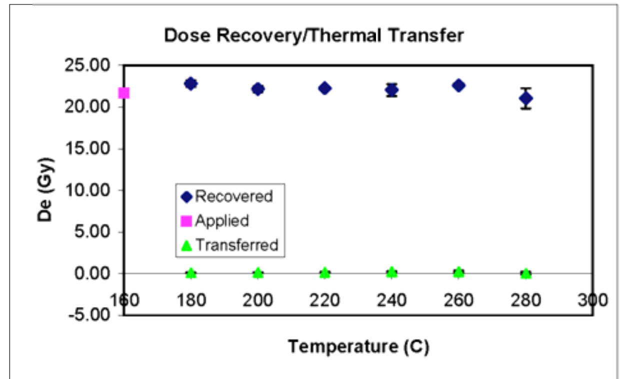
Thermal Transfer Test on Sample UNL2120:

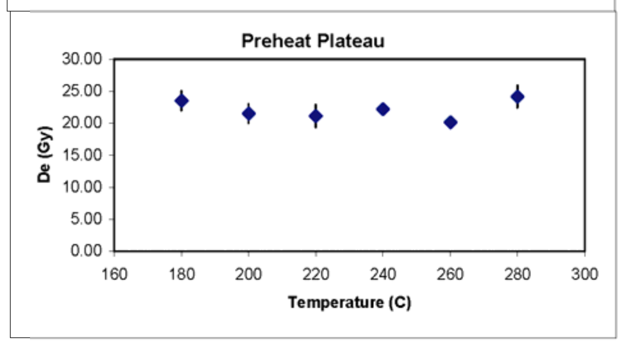
Preheat Temp (ºC)	De (Gy)	±	
180	0.10	0.02	
200	0.14	0.04	
220	0.17	0.04	
240	0.24	0.04	
260	0.23	0.11	
280	0.04	0.16	
Thermal Transfer =		0.15 ±	0.08 Gy

Preheat Plateau on Sample UNL2120:

Preheat Temp (ºC)	De (Gy)	±
180	23.52	1.51
200	21.51	1.50
220	21.10	1.78
240	22.21	0.45
260	20.13	0.06
280	24.15	1.74

Preheat of 240C used for analyses!





UNL #	Recuperation (%)	Skew	$2\sigma_c$	Kurtosis	$2\sigma_k$	Overdisp
UNL2119	7	0.00	0.94	-0.51	1.89	22
UNL2120	2	-0.05	0.85	0.34	1.71	12
UNL2121	9	1.17	0.67	1.01	1.35	35
UNL2121, MAM						
UNL2122	14	0.72	0.76	-0.62	1.51	30.48
UNL2122, MAM						
UNL2123	2	0.24	0.96	-0.80	1.92	14
UNL2124	5	0.34	0.84	0.26	1.68	9
UNL2125	4	0.04	0.96	1.51	1.92	10
UNL2126	2	-0.30	1.00	-1.12	2.00	0
UNL2127	3	-0.13	0.94	0.12	1.89	16
UNL2128	3	0.26	0.76	-0.25	1.51	10

Missouri R., Nebraska

UNL #	Field #	Burial Depth (m)	H_2O (%)*	K_2O (%)	±	U (ppm)	±	Th (ppm)	±	Cosmic (Gy)	Dose Rate (Gy/ka)	D_e (Gy)	No. of Aliquots	Age (ka)	Model
UNL2490	MOV-AL-12	1.6-1.9	17.1	2.18	0.06	3.51	0.14	8.10	0.33	0.17	2.82±0.12	2.84±0.25	34	1.01±0.10	CAM
												1.94±0.07	34	0.69±0.04	**MAM**
UNL2491	MOV-SL-45	2.25-2.45	21.9	1.90	0.05	1.66	0.09	4.26	0.24	0.16	1.93±0.09	14.05±0.47	31	7.29±0.48	CAM
UNL2492	MOV-SL-47	1.5-1.65	21.5	2.14	0.06	1.62	0.09	4.67	0.26	0.18	2.12±0.10	13.90±0.27	32	6.56±0.39	CAM
UNL2493	MOV-ONA-33	3.2-3.35	34.2	2.15	0.06	3.37	0.14	7.57	0.32	0.14	2.32±0.14	10.86±0.47	29	4.68±0.37	CAM
UNL2494	MOV-OSW-5	1.1-1.4	24.9	1.74	0.05	1.41	0.08	3.46	0.20	0.19	1.70±0.09	2.65±0.14	35	1.56±0.12	CAM
UNL2495	MOV-OSW-12	0.9-1.2	5.9	1.61	0.05	4.03	0.15	13.99	0.39	0.19	3.26±0.11	1.91±0.15	43	0.59±0.05	CAM
												1.21±0.03	43	0.37±0.02	**MAM**
UNL2496	MOU-LSY-50	4.0-4.25	25.8	1.89	0.05	2.25	0.10	6.09	0.25	0.13	2.03±0.10	24.92±0.27	44	12.2±0.7	CAM
UNL2497	MOV-OSW-58	0.7-1.0	16.5	2.13	0.06	3.69	0.14	4.69	0.26	0.20	2.66±0.11	1.80±0.15	37	0.68±0.06	CAM
												0.86±0.10	37	0.32±0.04	**MAM**
UNL2498	SSC-138	2.4-2.65	7.7	1.73	0.05	1.46	0.14	7.43	0.33	0.16	2.26±0.08	1.52±0.19	37	0.67±0.09	CAM
												0.85±0.07	37	0.38±0.04	**MAM**
UNL2499	MOV-AL-39	2.6-2.8	8.8	2.21	0.06	3.10	0.13	4.44	0.25	0.15	2.75±0.10	4.90±0.24	27	1.78±0.12	CAM
UNL2500	SSC-137	1.4-1.6	4.6	1.95	0.03	3.08	0.20	4.84	0.30	0.18	2.73±0.09	1.46±0.12	47	0.46±0.06	CAM
												0.80±0.09	47	0.29±0.04	**MAM**
UNL2501	MOV-SL-3	2.8-3.0	20.0	1.82	0.05	3.17	0.13	4.52	0.25	0.15	2.21±0.10	14.56±0.50	41	6.59±0.42	CAM

* In-situ Moisture Content
Error on De is 1 standard error
Error on age includes random and systematic errors calculated in quadrature

Dose Recovery Test on Sample UNL2500:

Preheat Temp (ºC)	De (Gy)	±	
180	1.28	0.04	
200	1.21	0.01	
220	1.28	0.04	
240	1.24	0.04	
260	1.29	0.03	
280	1.41	0.05	
Applied Dose =		1.23	Gy
Recovered Dose =		1.29 ±	0.07 Gy

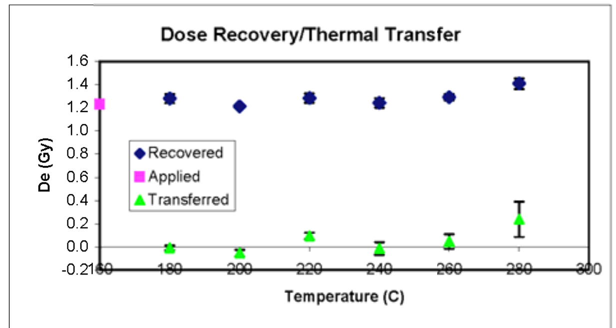
Thermal Transfer Test on Sample UNL2500:

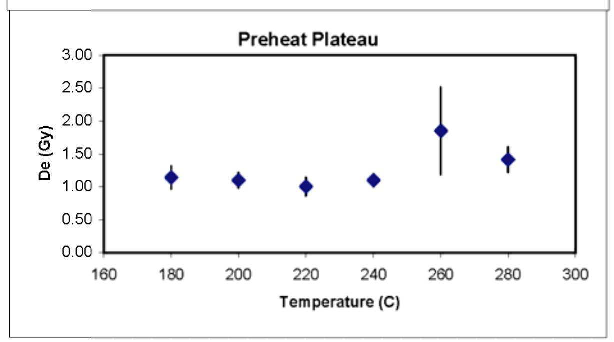
Preheat Temp (ºC)	De (Gy)	±	
180	-0.01	0.02	
200	-0.05	0.03	
220	0.09	0.03	
240	-0.01	0.05	
260	0.05	0.06	
280	0.24	0.15	
Thermal Transfer =		0.05 ±	0.11 Gy

Preheat Plateau on Sample UNL2500:

Preheat Temp (ºC)	De (Gy)	±
180	1.14	0.17
200	1.10	0.11
220	1.00	0.14
240	1.10	0.10
260	1.85	0.66
280	1.41	0.19

Preheat of 240C used for analyses!





UNL #	ecuperatic (%)	Skew/2σ_c	Kurt/2σ_k	Overdisp (	CAM/Med	CAM/PDF	CAM/Mod	CAM/Ave
UNL2490	1	**1.43**	0.78	47	1.20	1.21	1.43	0.91
UNL2491	2	0.33	-0.28	18	1.04	1.04	1.04	0.99
UNL2492	2	0.61	0.30	9	1.03	1.02	1.01	1.01
UNL2493	3	**2.04**	2.06	21	1.09	1.10	1.13	0.99
UNL2494	2	0.86	-0.08	17	1.09	1.08	1.09	0.98
UNL2495	1	**1.49**	0.53	45.32	1.08	1.16	1.50	0.90
UNL2496	2	-0.65	-0.36	5.67	0.99	0.99	1.00	1.00
UNL2497	1	**1.29**	0.38	45.73	1.10	1.21	1.25	0.91
UNL2498	3	**1.20**	0.15	65.98	1.47	1.35	1.94	0.84
UNL2499	1	0.04	-0.30	22.81	1.01	1.01	1.03	0.98
UNL2500	6	**2.65**	3.64	45.40	1.11	1.20	1.23	0.92
UNL2501	2	0.25	-0.85	21.42	1.01	1.05	1.29	0.98

UNL #	Field #	Burial Depth (m)	H_2O (%)*	K_2O (%)	±	U (ppm)	±	Th (ppm)	±	Cosmic (Gy)	Dose Rate (Gy/ka)	D_e (Gy)	No. of Aliquots	Age (ka)
UNL2818	MOV 53 BNC	4.7	22.8	1.67	0.05	1.23	0.09	3.89	0.20	0.12	1.63±0.08	3.22±0.12	51	1.98±0.13
UNL2819	MOV7 BNC	2.6	21.9	1.32	0.04	1.30	0.10	3.72	0.21	0.16	1.44±0.07	3.93±0.10	50	2.72±0.15
UNL2820	MOV-TWN-44	1.8	10.2	1.66	0.04	1.92	0.11	5.77	0.26	0.17	2.15±0.08	1.39±0.08	63	0.65±0.04
							Minimum Age Model (Galbraith et al. 1999) =					0.77±0.06	63	0.36±0.03
UNL2821	MOV-LS-34	1.5	20.3	1.59	0.04	0.83	0.08	1.95	0.17	0.18	1.47±0.07	2.78±0.10	55	1.89±0.11
							Minimum Age Model (Galbraith et al. 1999) =					1.90±0.40	55	1.29±0.28
UNL2822	MOV-BNC-54	0.7	8.2	1.77	0.05	1.60	0.10	5.23	0.27	0.20	2.21±0.08	2.62±0.04	50	1.19±0.05
UNL2823	MOV-TK-20	1.7	10.4	1.59	0.05	1.20	0.10	3.64	0.21	0.18	1.81±0.07	1.69±0.10	50	0.93±0.07
							Minimum Age Model (Galbraith et al. 1999) =					0.79±0.05	50	0.44±0.03
UNL2824	MOV-TK-25	2.1	13.0	1.52	0.04	1.07	0.08	4.21	0.22	0.17	1.71±0.07	1.35±0.07	61	0.79±0.05
							Minimum Age Model (Galbraith et al. 1999) =					0.58±0.20	61	0.34±0.12
UNL2825	MOV-LS-30	2.9	23.9	2.08	0.05	1.67	0.10	4.38	0.22	0.15	2.01±0.10	2.88±0.08	61	1.44±0.08
							Minimum Age Model (Galbraith et al. 1999) =					2.28±0.09	61	1.13±0.07
UNL2826	MOV-TK-44	3.7	20.8	1.78	0.04	1.46	0.09	4.06	0.21	0.14	1.80±0.09	3.53±0.06	62	1.95±0.10
UNL2827	MOV-SLX-57	1.1	6.4	1.59	0.04	1.16	0.09	3.90	0.21	0.19	1.91±0.07	0.82±0.04	66	0.43±0.03
							Minimum Age Model (Galbraith et al. 1999) =					0.57±0.01	66	0.30±0.01
UNL2830	MOV-SL-50	1.7	12.0	2.00	0.05	2.43	0.12	7.07	0.30	0.18	2.55±0.10	2.13±0.10	54	0.83±0.05
UNL2832	MOV-TK-2	1.5	7.1	1.55	0.04	1.78	0.10	5.77	0.26	0.18	2.12±0.08	1.63±0.10	59	0.77±0.05
							Minimum Age Model (Galbraith et al. 1999) =					1.03±0.10	59	0.49±0.05
UNL2833	MOV-OSW-59	2.1	27.9	1.76	0.05	2.36	0.13	7.57	0.29	0.17	2.05±0.11	4.45±0.09	57	2.17±0.12
							Minimum Age Model (Galbraith et al. 1999) =					3.68±0.04	57	1.80±0.10
UNL2834	MOV-SL-49	1.8	11.7	2.07	0.05	1.92	0.11	5.92	0.25	0.17	2.43±0.09	1.66±0.11	58	0.68±0.05
							Minimum Age Model (Galbraith et al. 1999) =					0.86±0.09	58	0.35±0.04

* In-situ Moisture Content

D_e calculated using the Central Age Model (Galbraith et al. 1999) unless otherwise indicated.

Error on D_e is 1 standard error

Error on age includes random and systematic errors calculated in quadrature

Dose Recovery Test on Sample UNL2820:

Preheat Temp (°C)	De (Gy)	±	
180	1.25	0.02	
200	1.22	0.02	
220	1.26	0.02	
240	1.23	0.03	
260	1.33	0.04	
280	1.42	0.04	
Applied Dose =		1.21	Gy
Recovered Dose =		1.28 ±	0.08 Gy

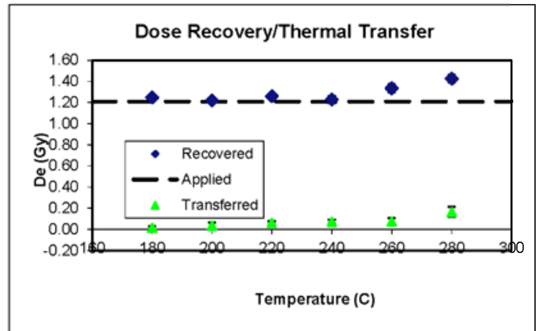
Thermal Transfer Test on Sample UNL2820:

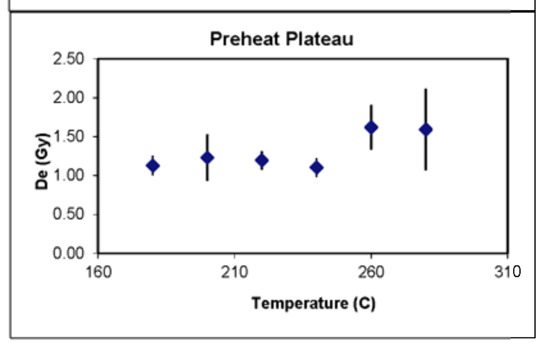
Preheat Temp (°C)	De (Gy)	±	
180	0.01	0.02	
200	0.04	0.03	
220	0.06	0.02	
240	0.07	0.02	
260	0.08	0.03	
280	0.17	0.05	
Thermal Transfer =		0.07 ±	0.05 Gy

Preheat Plateau on Sample UNL2820:

Preheat Temp (°C)	De (Gy)	±
180	1.13	0.13
200	1.23	0.30
220	1.19	0.12
240	1.10	0.12
260	1.62	0.29
280	1.59	0.52

Preheat of 200C used for analyses!





UNL #	Dose Recovery (Rec/Appl)	(±)	Recuperation (%)	Skew/2σ_c	Kurt/2σ_k	Overdisp (%)	CAM/Med	CAM/PDF Fit	CAM/Mode	CAM/Ave
UNL2818	0.98	0.03	3	0.3	-0.7	24	1.04	1.05	1.19	0.99
UNL2819	0.98	0.02	2	0.7	-0.4	16	1.02	1.04	1.06	0.99
UNL2820	1.01	0.02	7	**1.2**	0.0	40	1.05	1.12	1.12	0.93
UNL2821	nd		2	**1.0**	0.6	22	1.04	1.05	1.00	1.00
UNL2822	1.01	0.02	3	-0.3	-0.7	7	1.00	1.01	0.99	1.01
UNL2823	1.00	0.04	3	**1.5**	0.8	40	1.01	1.08	1.20	0.93
UNL2824	1.07	0.05	4	**1.2**	0.0	37	1.06	1.10	1.25	0.96
UNL2825	0.99	0.02	3	**2.1**	1.4	21	1.04	1.07	1.14	0.98
UNL2826	1.01	0.02	4	0.7	-0.3	12	1.03	1.03	1.08	1.00
UNL2827	0.94	0.06	6	**2.6**	2.4	35	1.12	1.16	1.27	0.97
UNL2830	1.04	0.05	7	0.7	-0.4	31	1.05	1.10	1.23	0.97
UNL2832	0.98	0.06	7	**1.7**	0.7	41	1.14	1.16	1.20	0.95
UNL2833	1.03	0.01	6	**1.9**	-0.6	14	1.04	1.07	1.14	0.99
UNL2834	0.92	0.04	7	**1.8**	1.3	44	1.09	1.17	1.35	0.93

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BIOGRAPHICAL INFORMATION

Michele Kashouh began her academic career as a Geologist in 2005 as an undergraduate at The University of Texas at Dallas, where she earned a Bachelor of Science degree in Geosciences in December of 2008. During her time at UTD, she participated in a senior research project which combined sedimentology, stratigraphy, paleontology, and cybermapping. Wishing to continue her studies in sedimentology, she enrolled in the Master of Science in Geology program at The University of Texas at Arlington to work with professor and fluvial sedimentologist, John Holbrook. In the immediate future, Michele plans to enter the workforce and begin building her career as a professional Geologist. She intends to one day return to academia to pursue a PhD.