Rethinking the Classic Oxbow Filling Model: Some Hope for Improved Reservoir Connectivity*

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Abstract

The idea of the oxbow lake originating from meander neck cutoff and subsequently filling with clay is a well-established mainstay of fluvial sedimentary models. Though not necessarily intended, this model has led to a widely held assumption that preserved oxbow channel fills are typified by impermeable mud from base to top, which can strongly partition sandy point-bars and otherwise compartmentalize channel-belt reservoirs. These models originate from modern analogs that largely birthed in the Lower Mississippi Valley.

We have reexamined this model over a 100 km reach of the Mississippi Holocene meander belt using surficial mapping and borehole data. Over 500 boreholes penetrate the approximately 20 oxbow fills in this reach. These data are then compared to a late 1800's survey of channel depth which is here used as a standard of typical pre-modification channel morphology. Averaging of data reveals that the bankfull thalweg depth of the Mississippi River from the 1800's survey is 78 ft. Borehole data yield an average channel-belt thickness of 85 ft. Channel fills average in ascending order 29 ft. of sand, 34 ft. of heterolithic sand and mud, and 22 ft. of mud-dominant strata. This argues for the following sand-rich fill process. Approximately 10% of the channel depth is preserved as bed-load sand prior to cut off. Sand then fills approximately one quarter of the open channel to a level approximately at the inflection of the curve defining area vs. depth (app. 55 ft.). This is because the deeper part of the channel defines minimal channel volume and is easily filled during the decades long period of channel cutoff lasting up until the end is fully plugged. Above this, channel area expands greatly and filling moves to a heterolithic splay-fill mode that persists until the fill/channel slope is too low to support bedload transport into the channel through tie channels penetrating the end plugs. Filling then moves to the more classic muddy oxbow filling. This occurs at approximately the low-water stage of river flow (app. 30 ft. below bankfull).

Though mud is presumed to fill the entire open channel during neck cutoff, the actual mud fill is only about the upper channel third. The substantial sand content typical of the lower part of the channel fill means that petroleum has a high probability of passing beneath muddy parts of the fill through the more permeable basal sands in channel-belt reservoirs.

References

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Rethinking the Classic Oxbow Filling Model:

Some Hope for Improved Reservoir Connectivity

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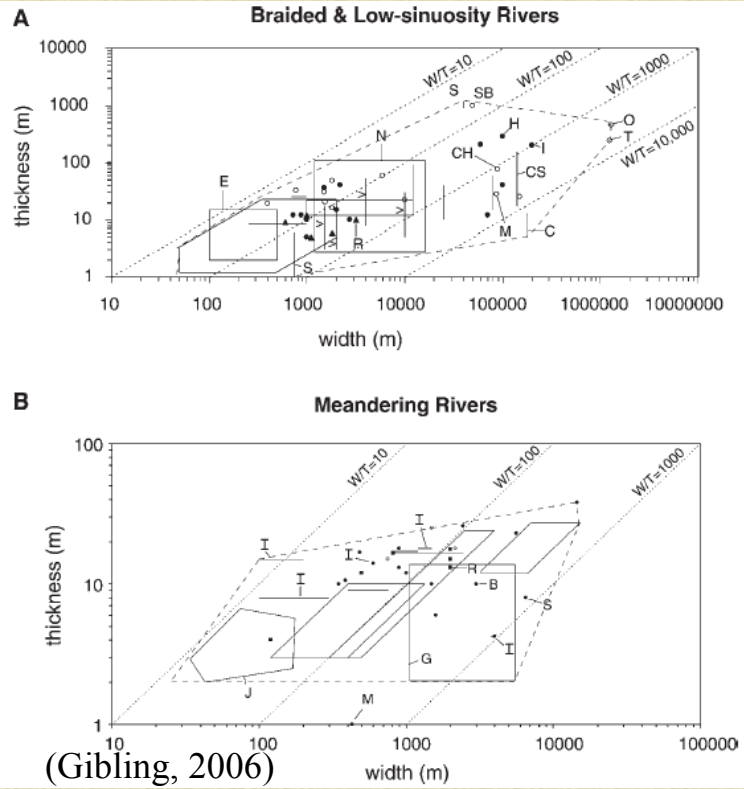
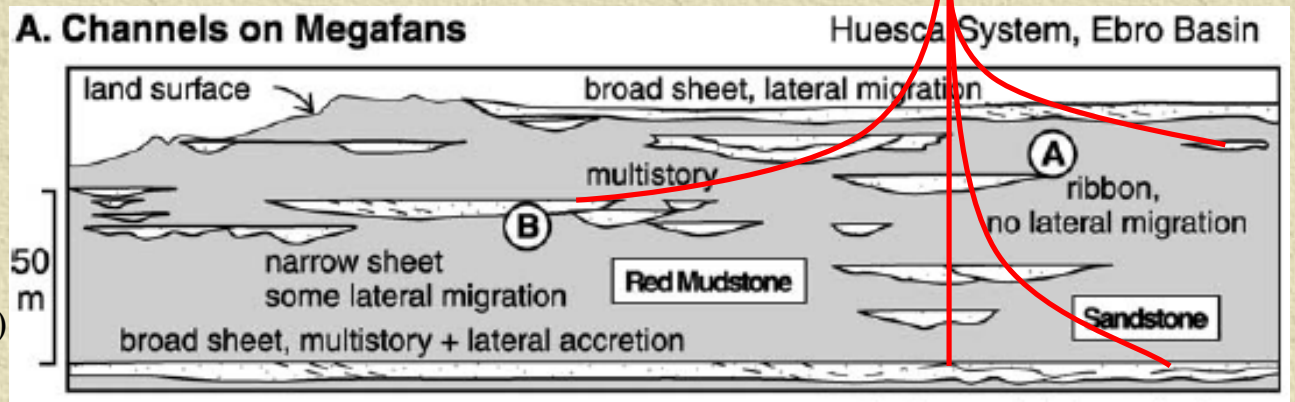
Supported by the Petroleum Research Fund and USGS EDMAP Program

Channel Belts as Target Units

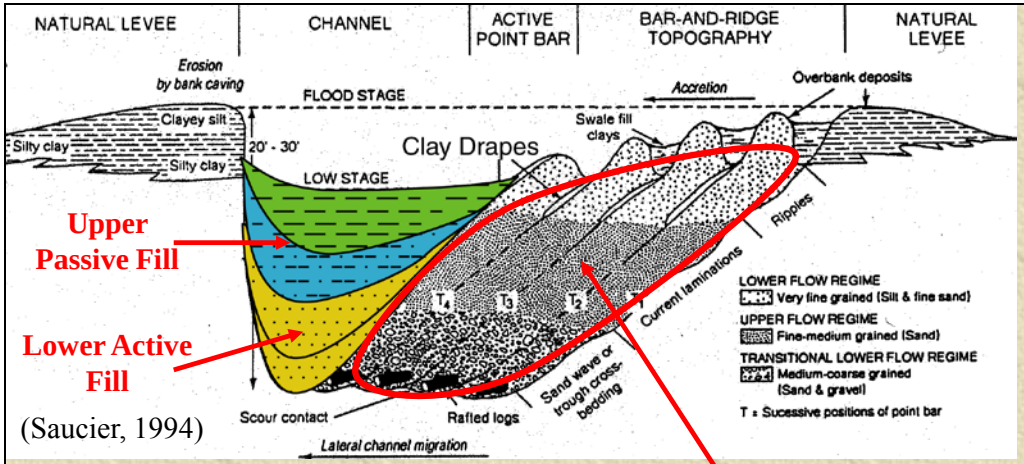


(Gibling, 2006)

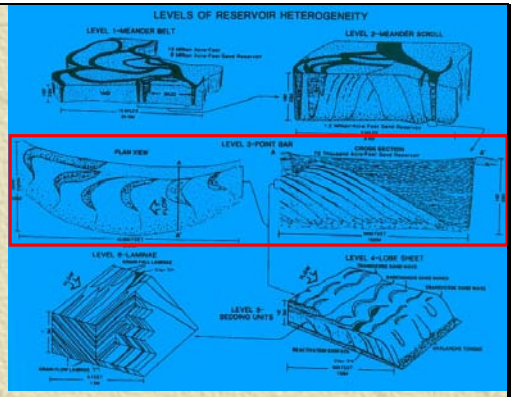


(Gibling, 2006)

Notes by Presenter: Channel belts are the main producible sand bodies within otherwise shalely fluvial sequences. Whether amalgamated or isolated, they are thus the main reservoir targets in fluvial sections. Because of this, much consideration has been put into understanding controls on their dimensions and distribution.

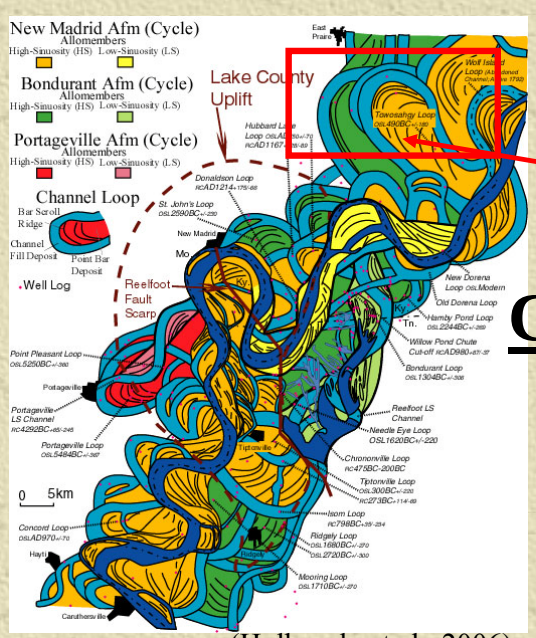


(Saucier, 1994)

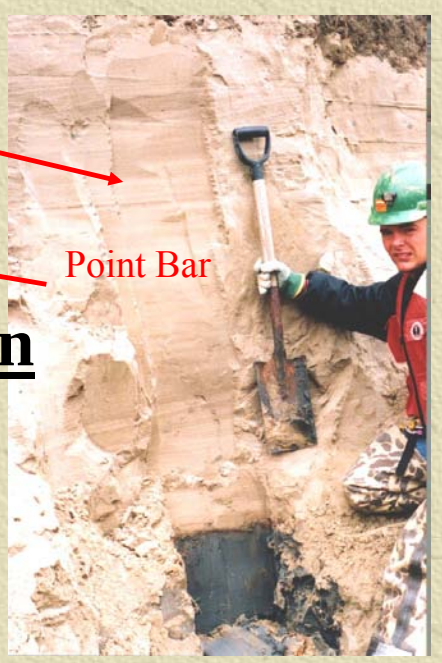


Level 3 Heterogeneity

Point-bar Reservoir Sand



(Holbrook, et al., 2006)



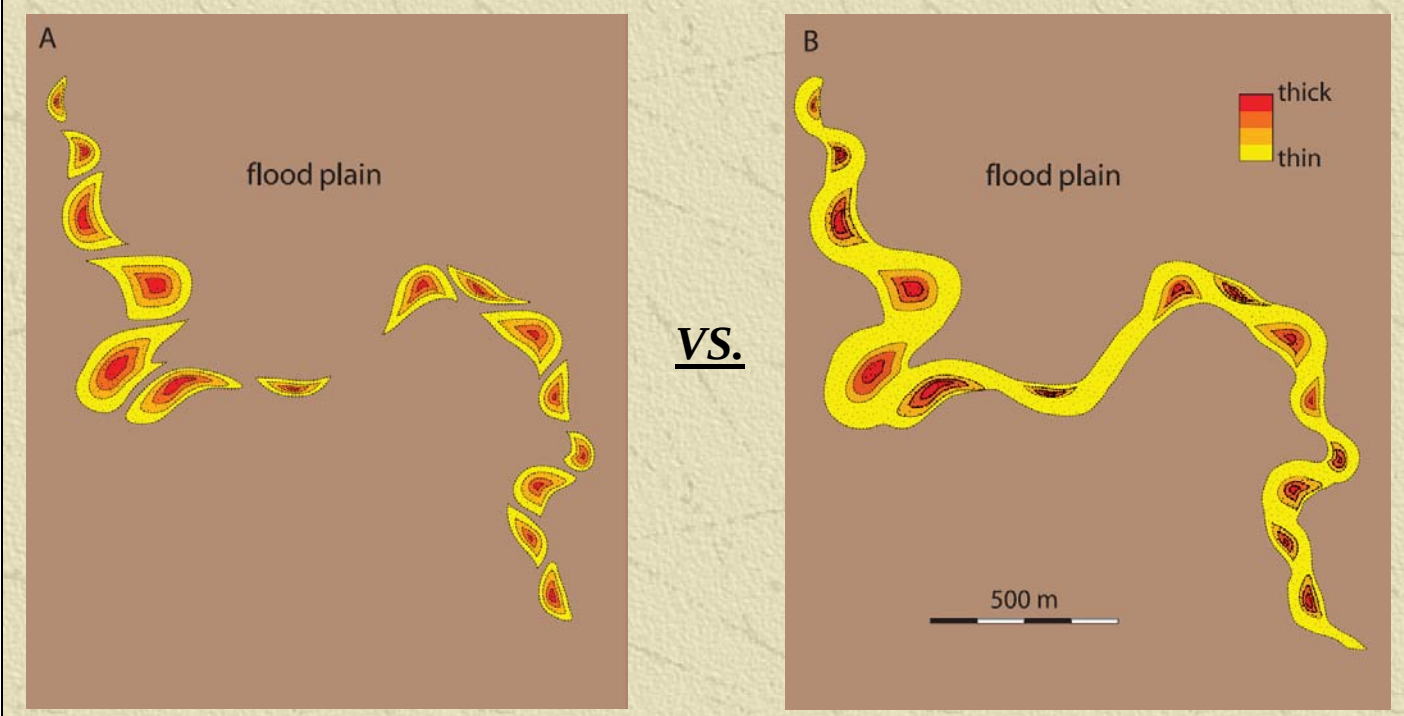
Connectivity Within Channel Belts

Bars as Reservoir Units

Notes by Presenter: Bar deposits like these point bars are the main reservoir target. Point-bar units form the sandy reservoir lithofacies. These are wrapped by finer channel-fill allounits, and are typically constructed of medium-to-fine-grained medium-sorted cross-bedded-to-planar-laminated sand with local thin-to-medium-bed-thickness mud drapes. Point bars fine upward from coarse to fine sand and are capped by levee/splay and mud veneer strata. Point bars record lateral migration of the channel and accretion deposition of sandy bar strata in the channel's wake.

Connectivity vs. Compartmentalization

Within Belts

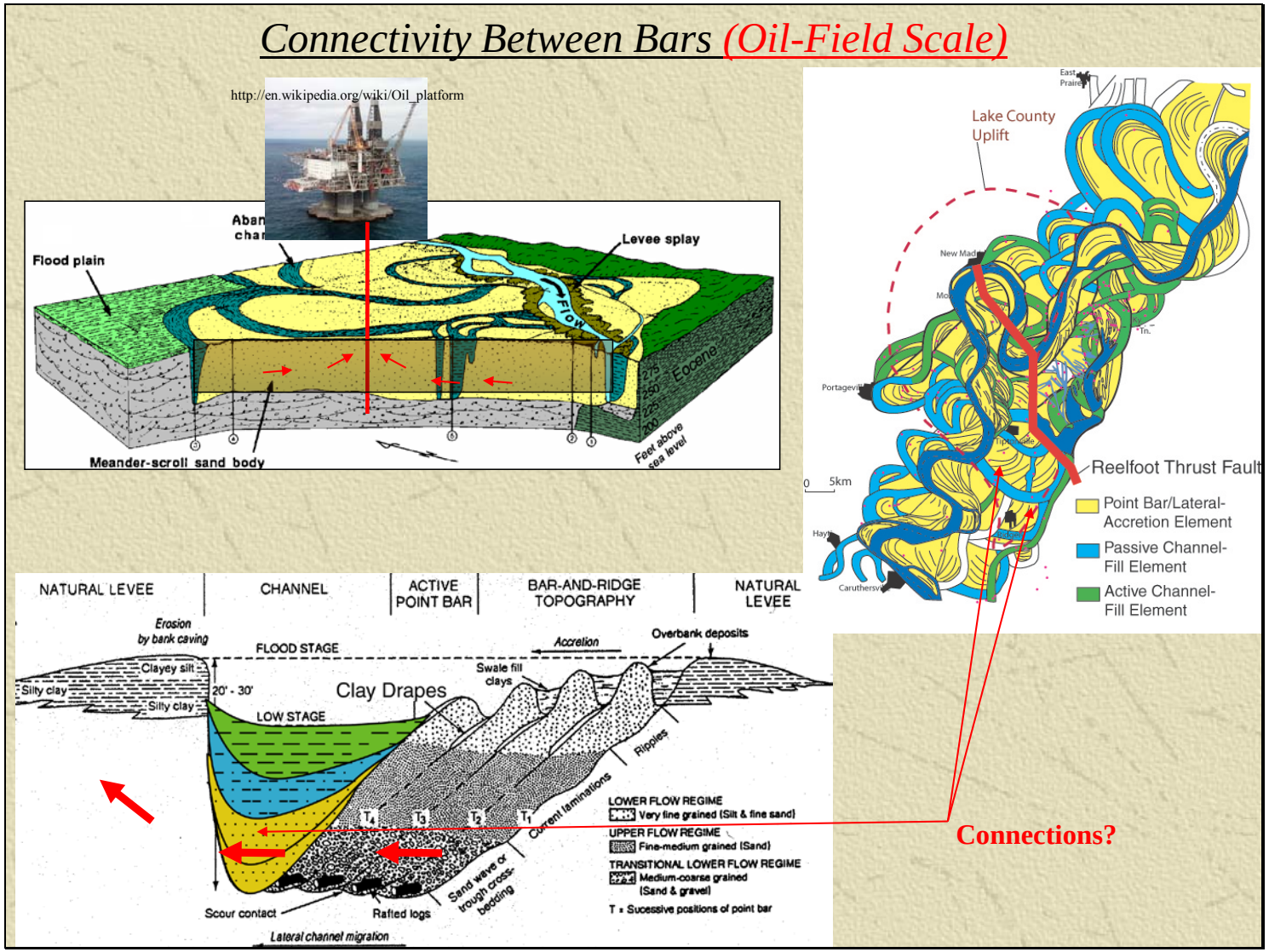


(Donsellar 2008)

Notes by Presenter: Connectivity determines the degree to which two otherwise distinct adjacent reservoirs are connected such that they operate as one. If connectivity between two connected reservoirs is zero, they are said to be compartmentalized. It is important to note that this can occur laterally between reservoir components within the same belt or vertically between belts. We will discuss both cases.

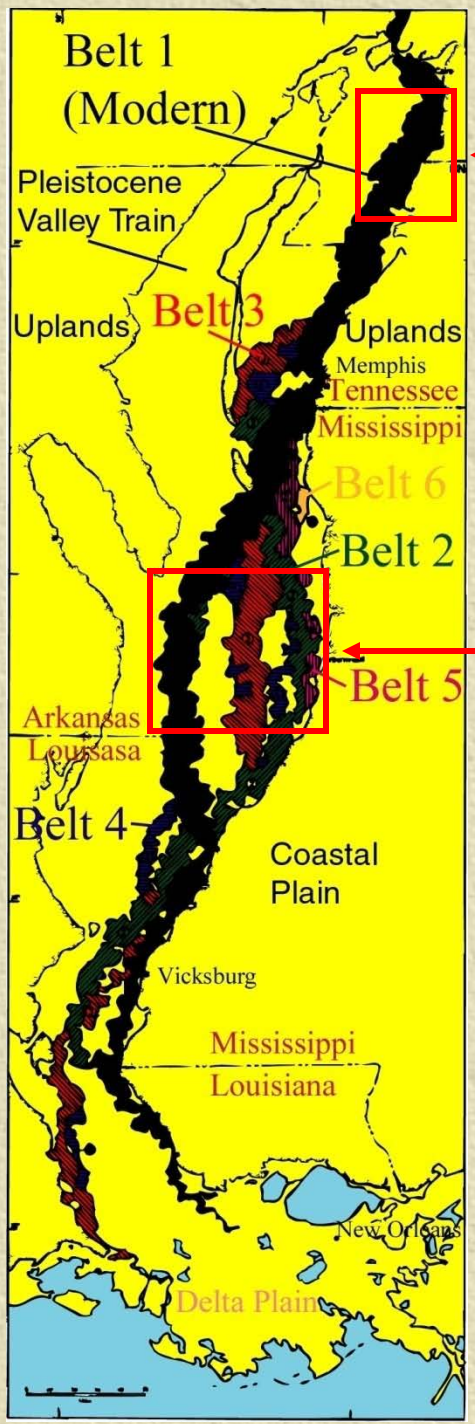
The factors that control reservoir connectivity are a reflection of the architecture of the target fluvial volume. They can be considered at any scale, but for the sake of time, we will consider two scales: 1) Bar reservoir -to- bar reservoir within a belt and 2) Connectivity between belts.
Illustrated here is the issue of connection vs. separation of bars by a channel plug within a channel belt, and the potential of connectivity vs. compartmentalization of point-bar reservoirs.

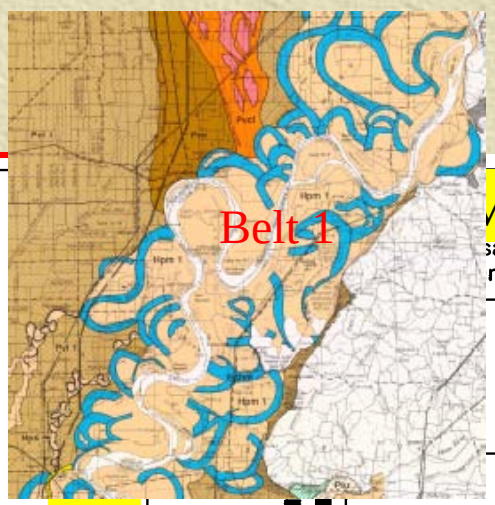
Connectivity Between Bars (Oil-Field Scale)

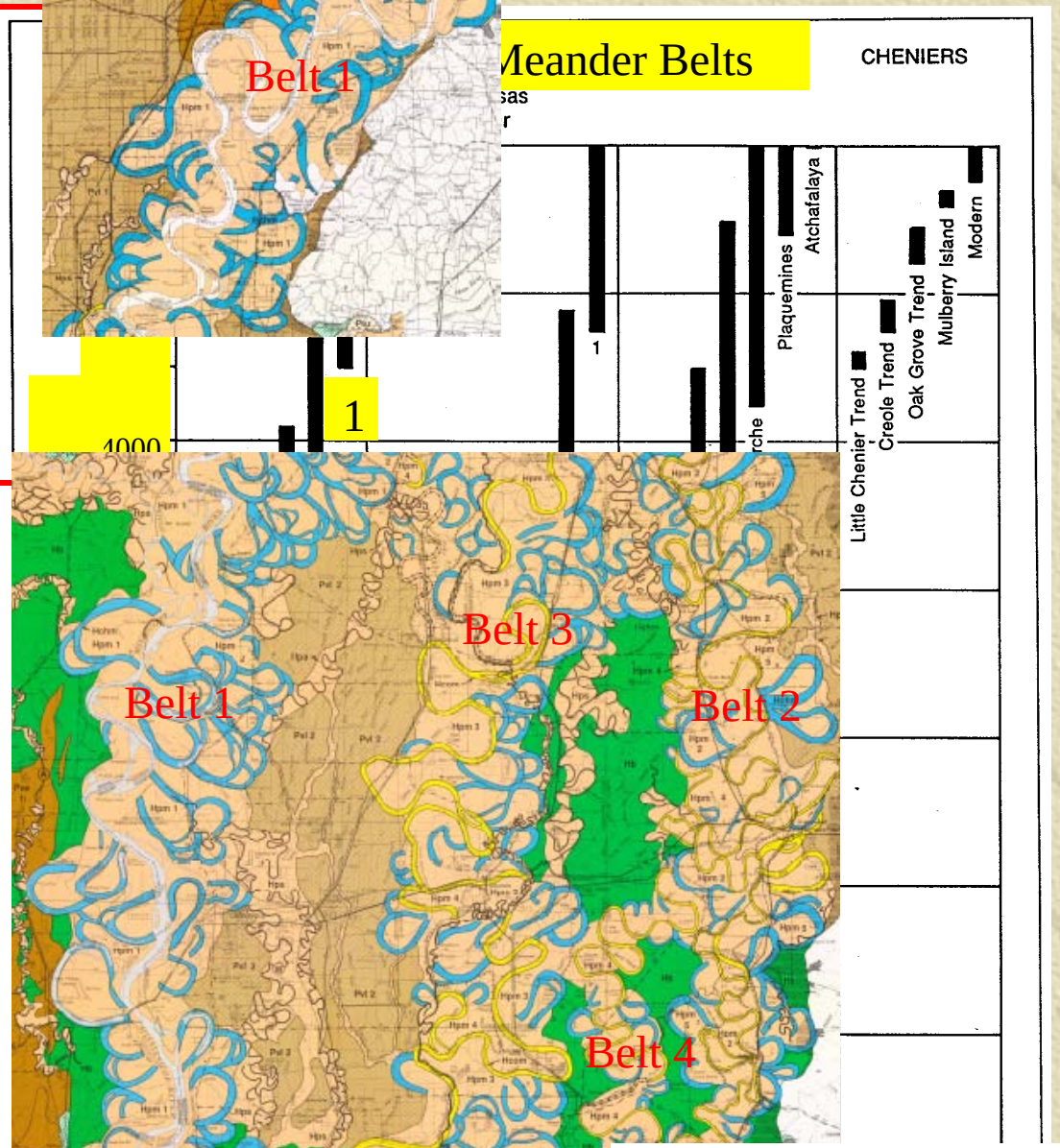


Notes by Presenter: Even though flow can likely get under the channel to connect the bars, the upper channel is a barrier and prone to trap fluids. In addition, special consideration should be given to heterogeneity when draining a channel-belt reservoir. Drill penetration of a belt will only generally penetrate a single point bar, which will be compartmentalized by an engulfing channel fill. Production will drain the petroleum within the penetrated point bar readily, but production of petroleum from adjacent point bars requires connections. Passive channel fills will be highly effective barriers to flow and active fills will be moderately effective barriers. This means that connection between point bars will need to be made through the base of channel fills. Even if basal connection is effective, some substantial proportion of the petroleum can be trapped against channel fills in the tops of non-penetrated point bars. A production plan needs to compensate according to recover these fluids.

Lateral Belt Connectivity

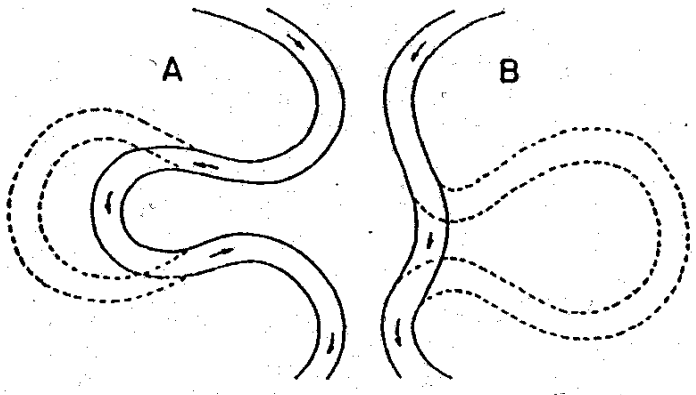




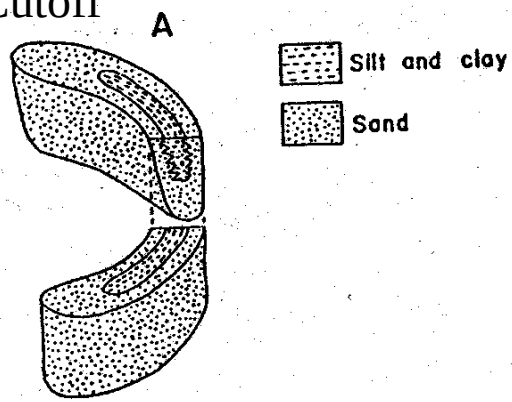


(All Figures, Saucier 1994)

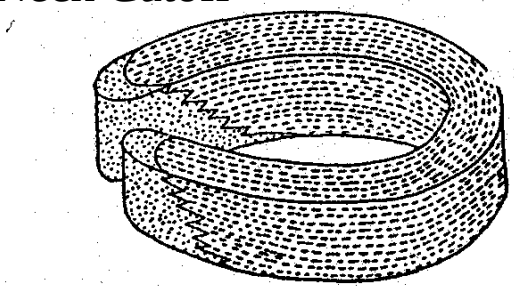
Chute vs. Neck Cutoff and Channel Lakes and Fills



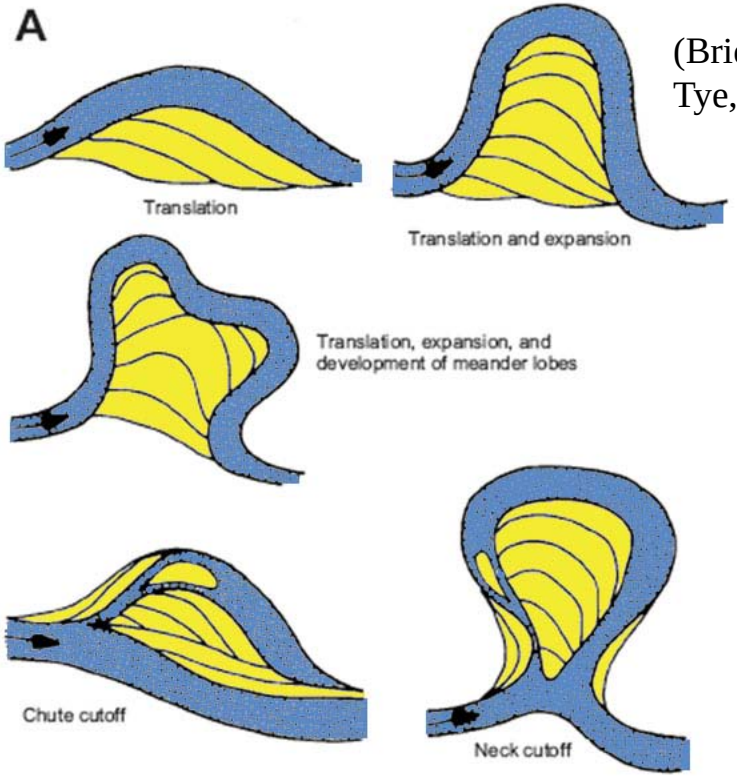
Chute Cutoff



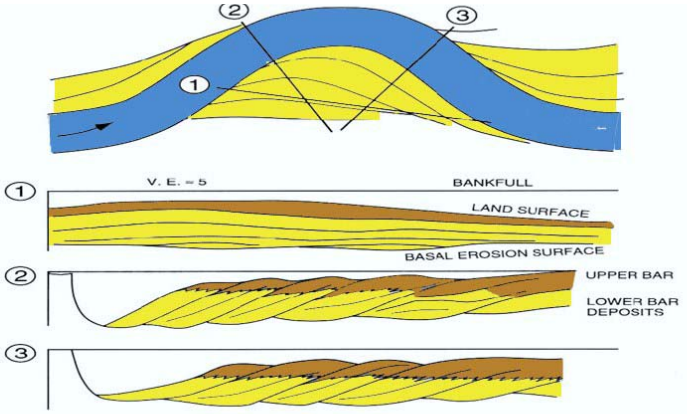
Neck Cutoff



(Fisk, 1945)



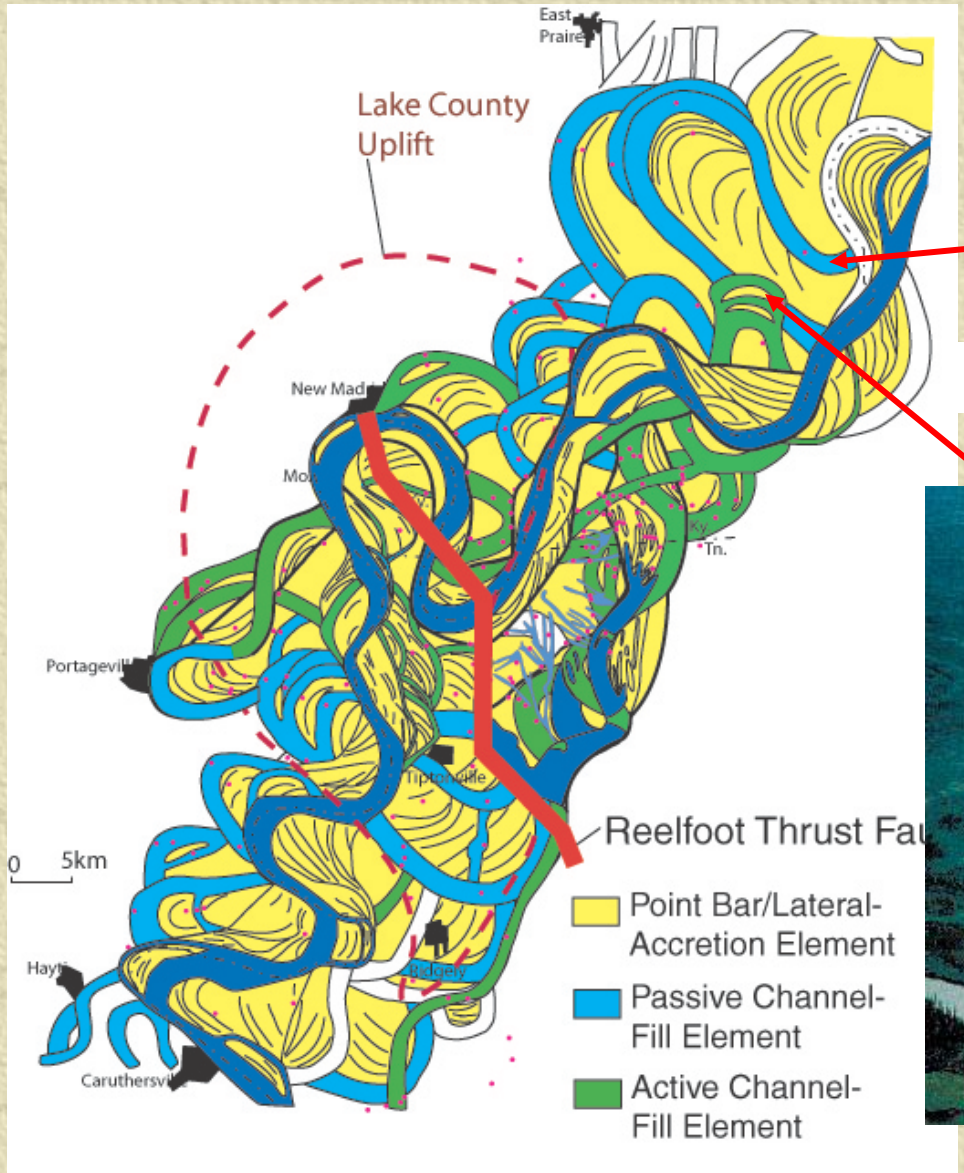
(Bridge and Tye,2000)

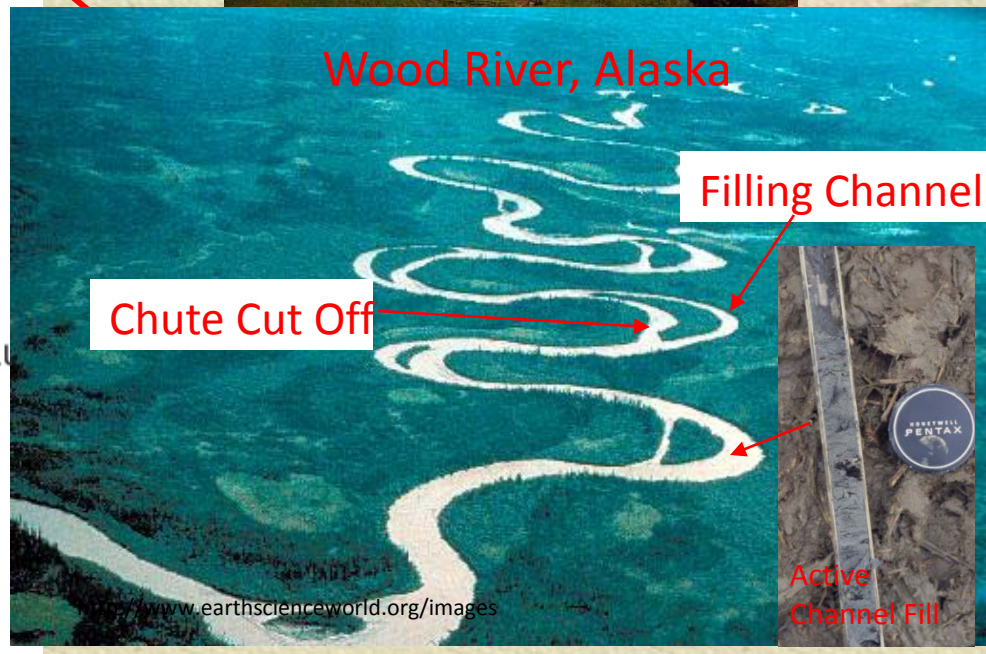


Side-Attached Bars

Chute vs. Neck Cutoff and Channel Lakes and Fills

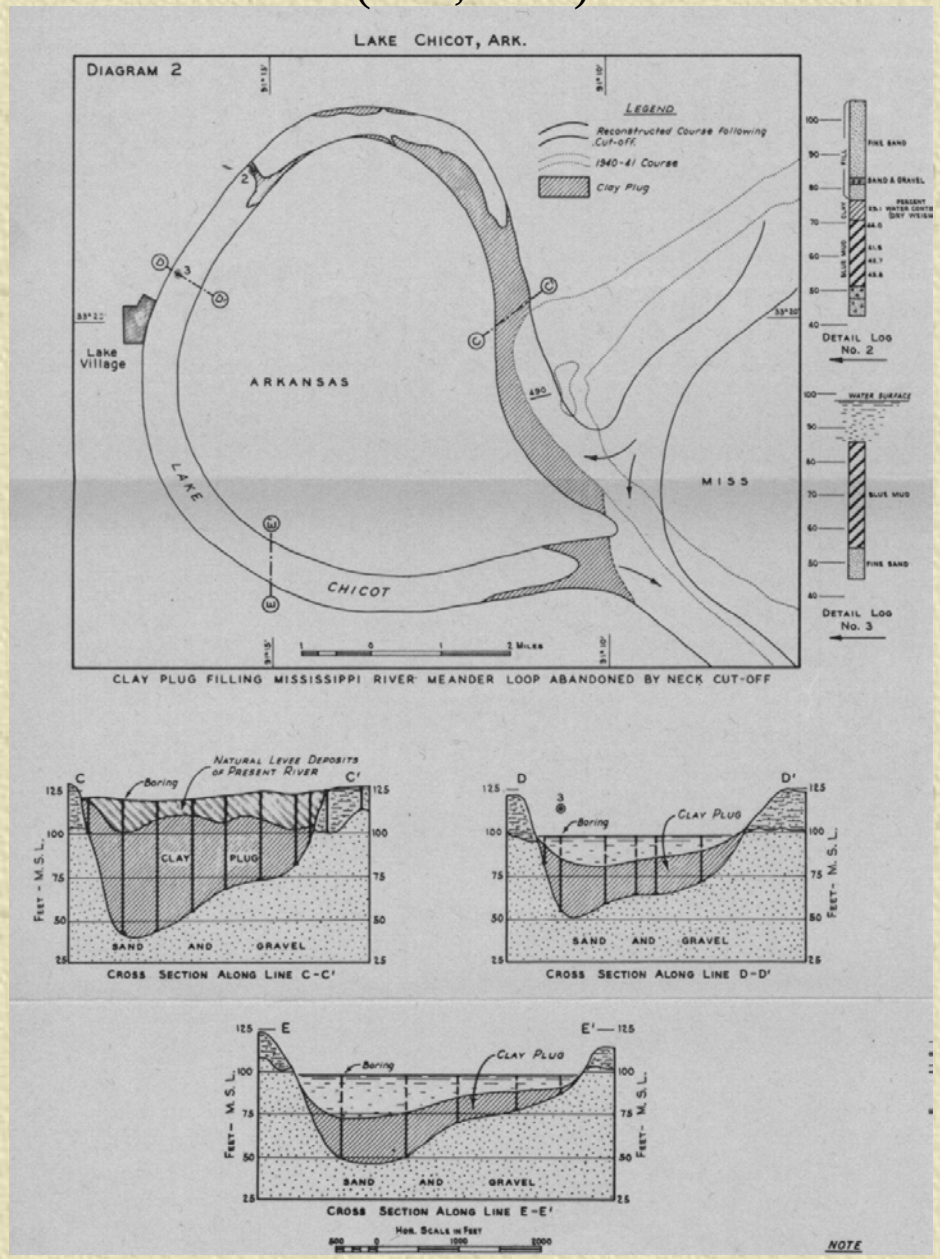
Meandering Channel Cut-Off Styles



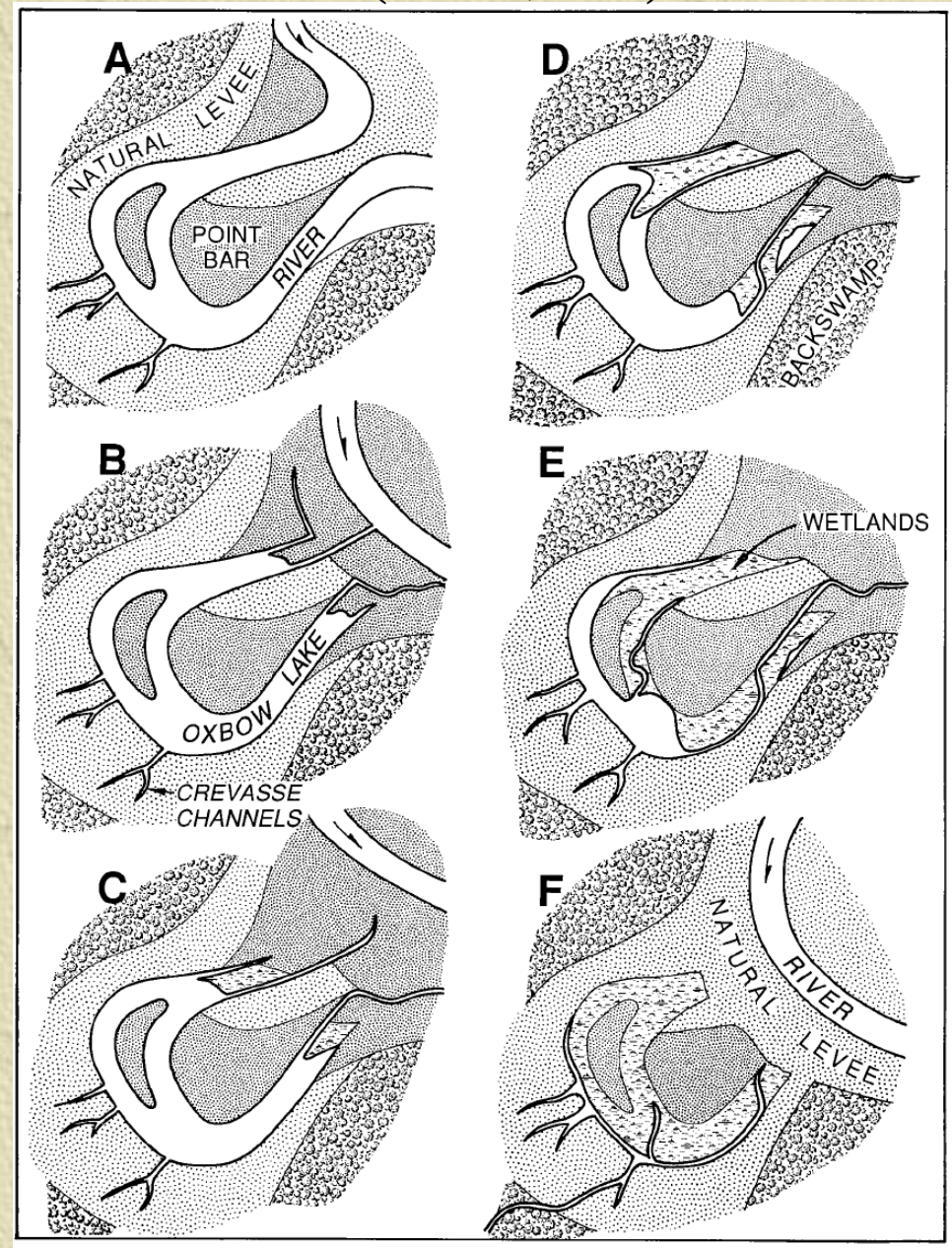


Oxbow Lake Fill Models

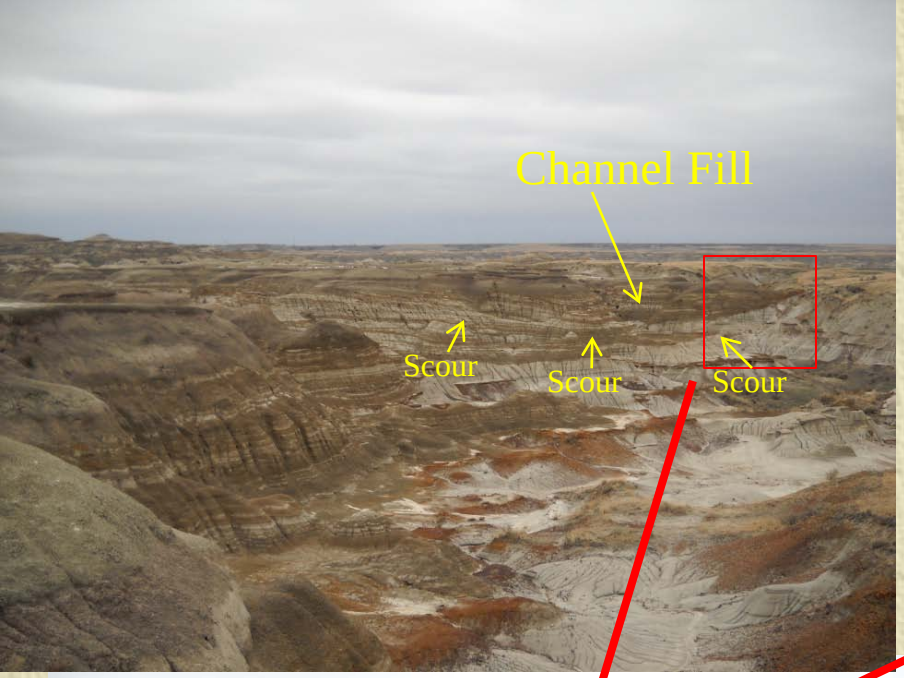
(Fisk, 1944)



(Saucier, 1994)

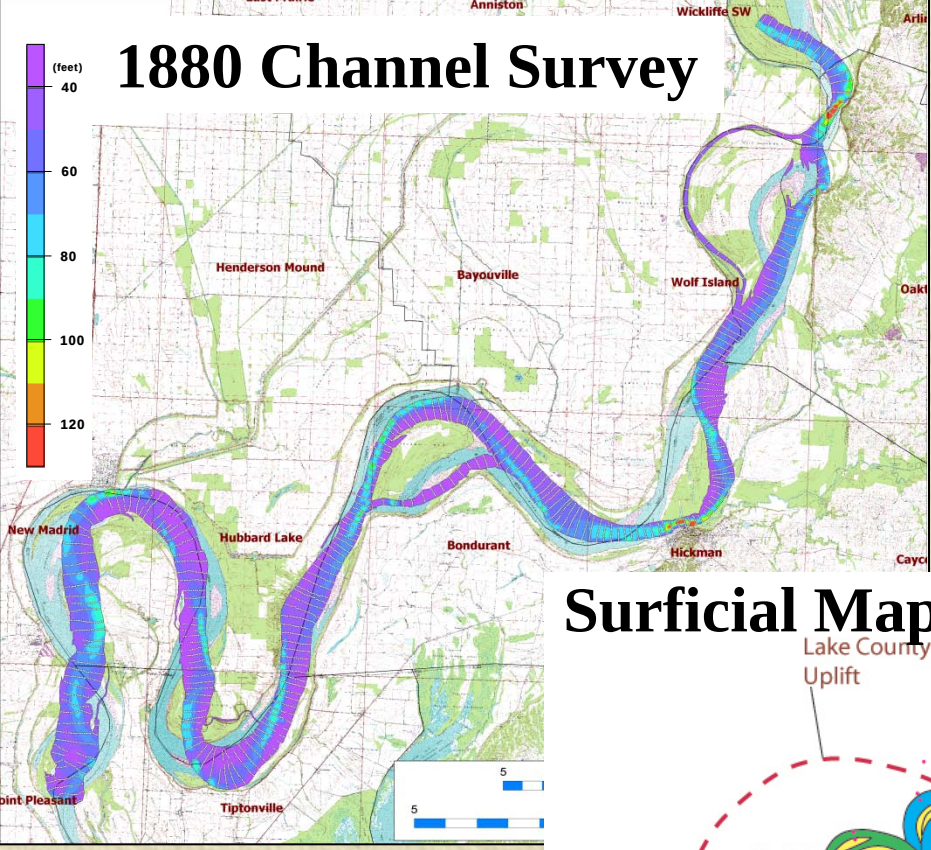


Channel-Fill Deposits

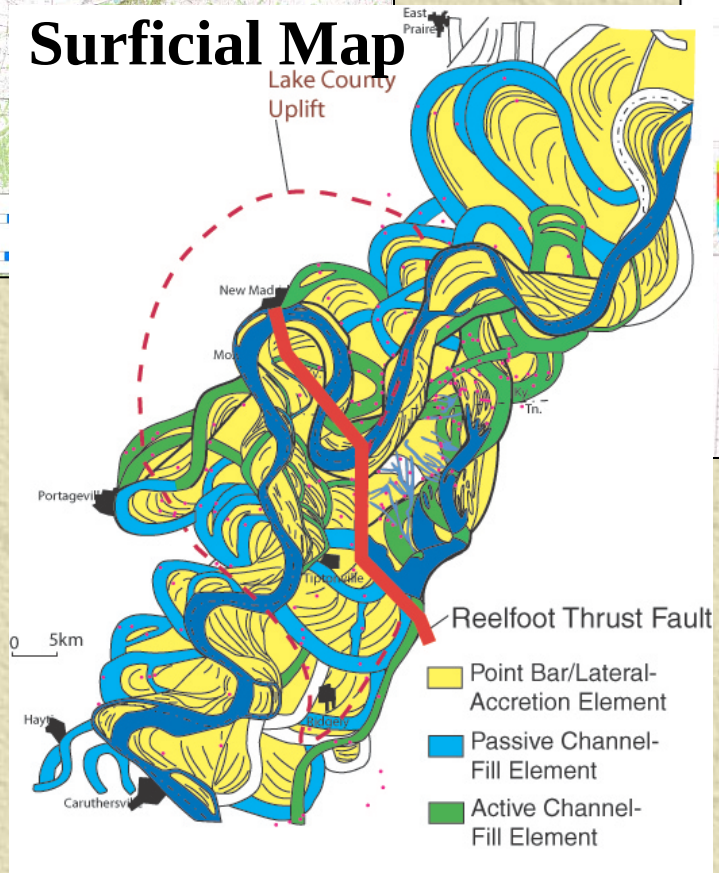


Typical Abandoned Channel Fill, K Belly River Fm, Canada

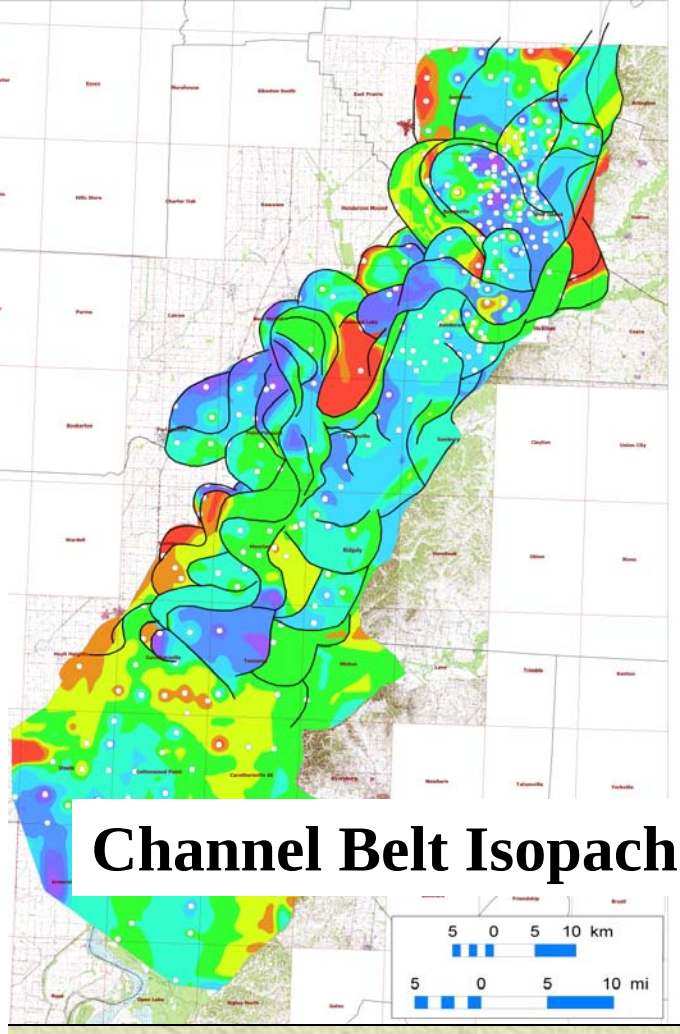
1880 Channel Survey



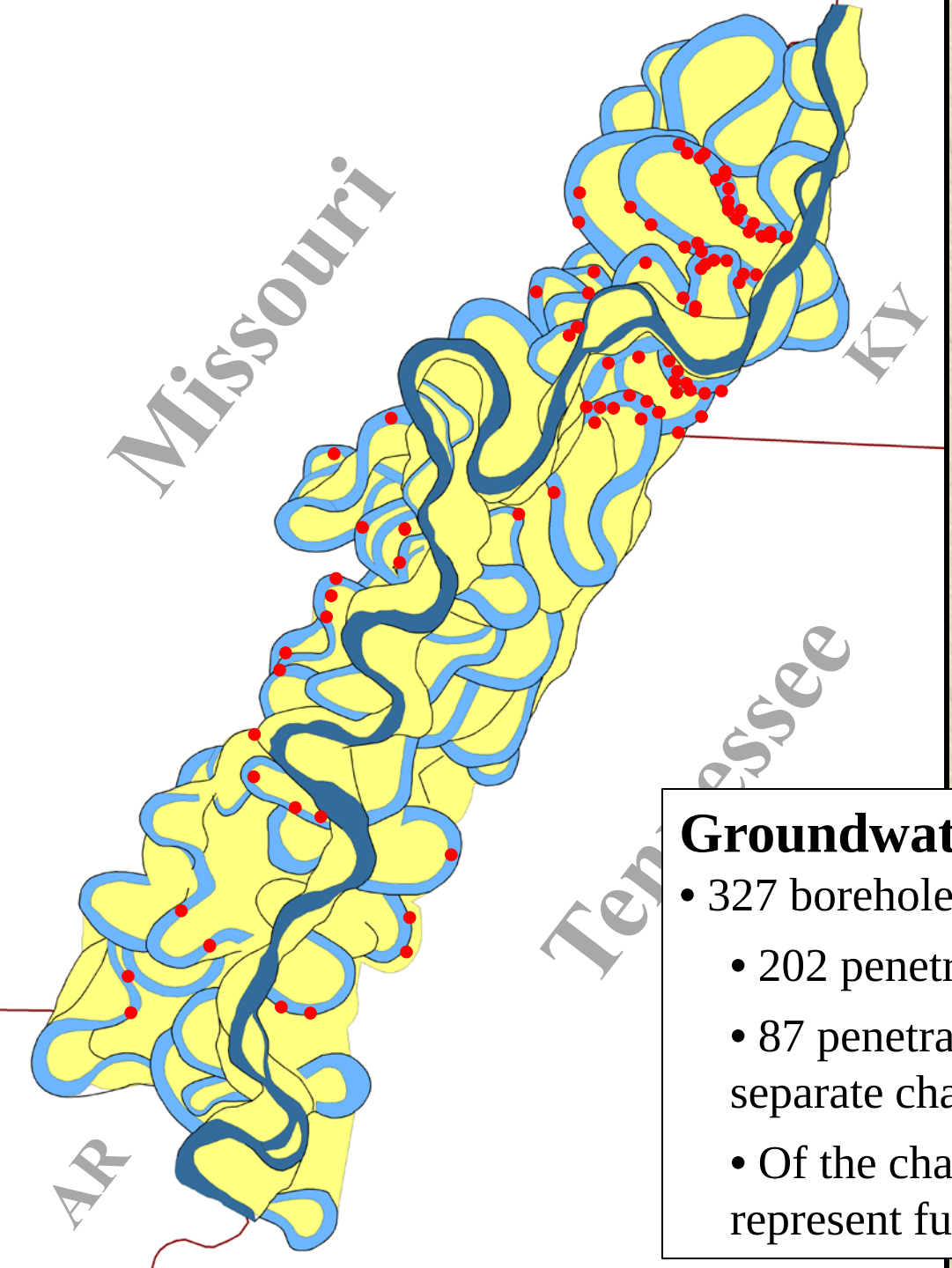
Surficial Map



Channel Belt Isopach



Data Sets



Modern Mississippi River

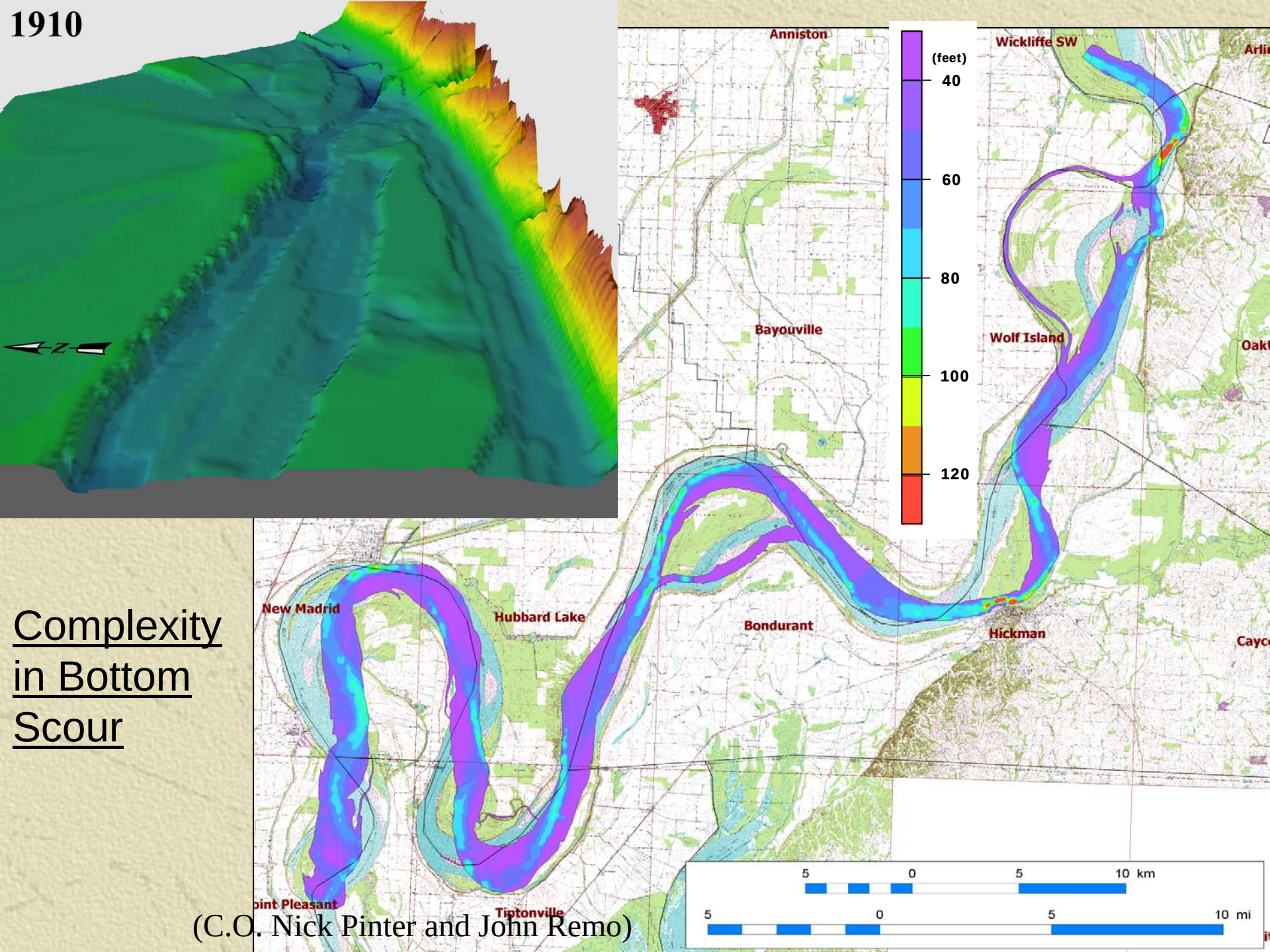
Abandoned Channel

Bar Facies

Borehole Record

Groundwater Institute (GWI) boreholes

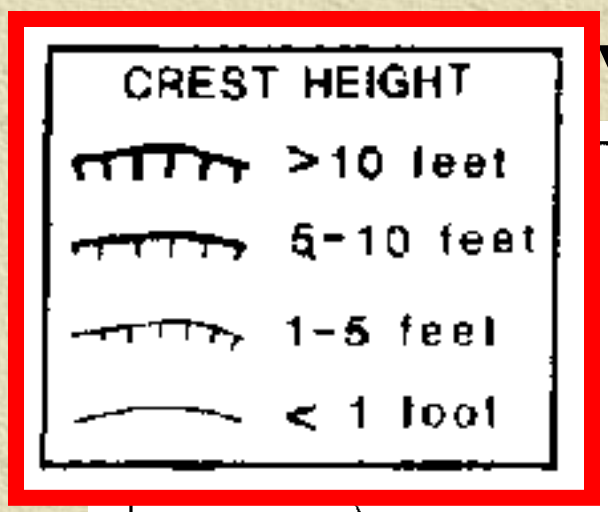
- 327 boreholes within the Holocene Belt
  - 202 penetrate bar facies
  - 87 penetrate channel facies, measuring ~ 23 separate channels
  - Of the channel borings, 33 were estimated to represent full channel thalweg depth.



Complexity in Bottom Scour

(C.O. Nick Pinter and John Remo)

ver Commission (MRC) channel surveys



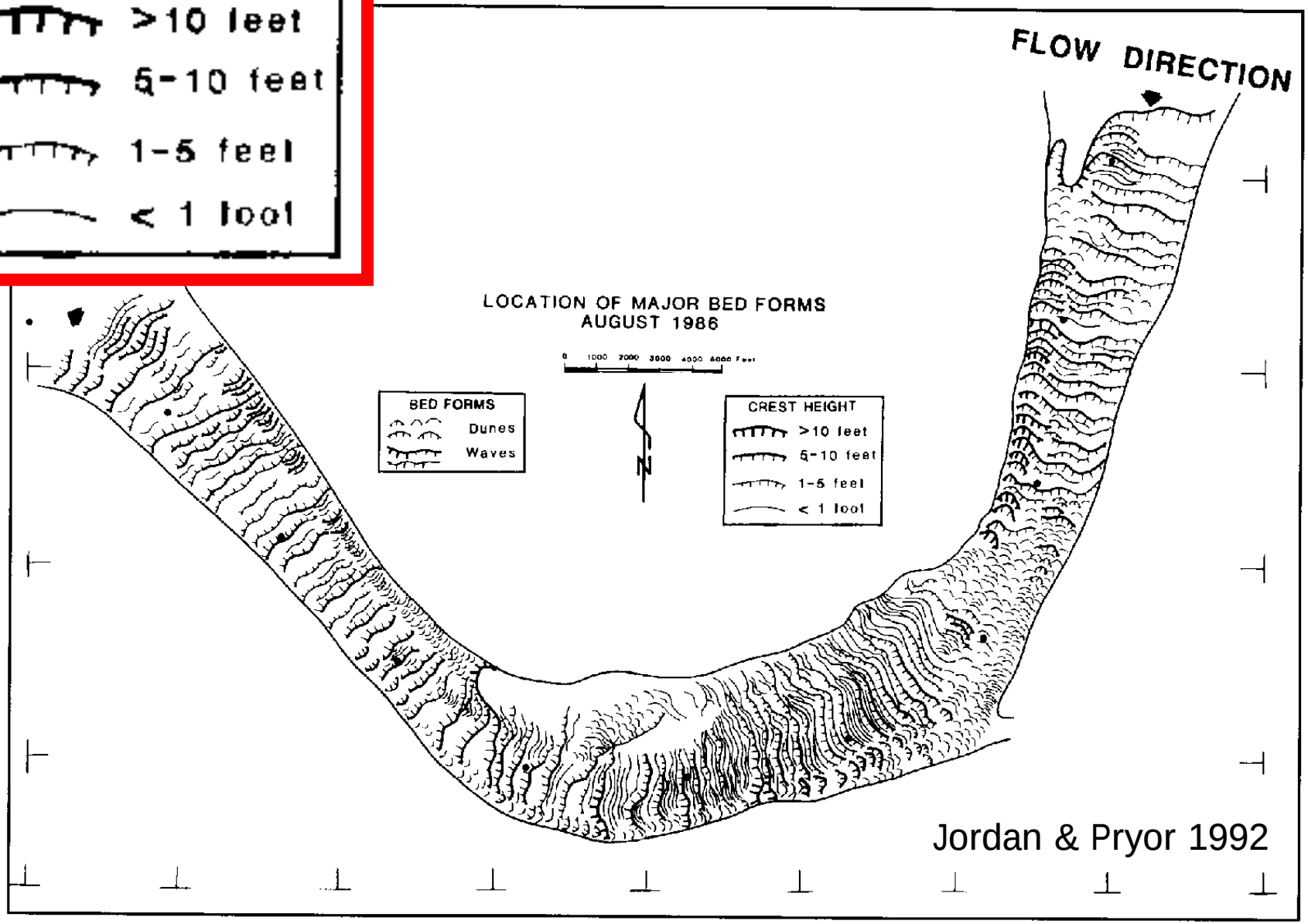


Figure 3—Bed forms in the Mississippi River channel in August 1986. Horizontal scale shown is 5000 ft (1525 m).

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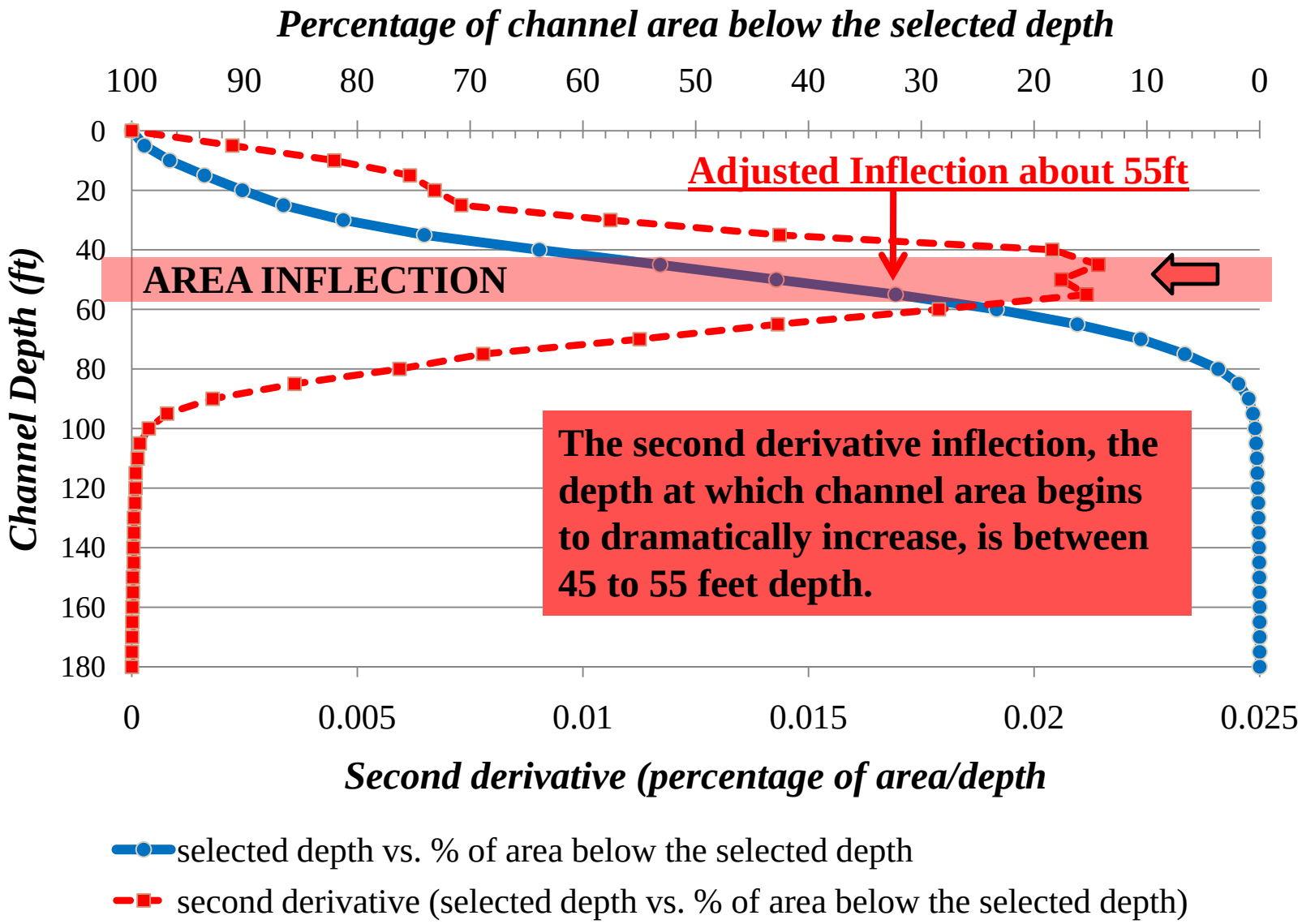
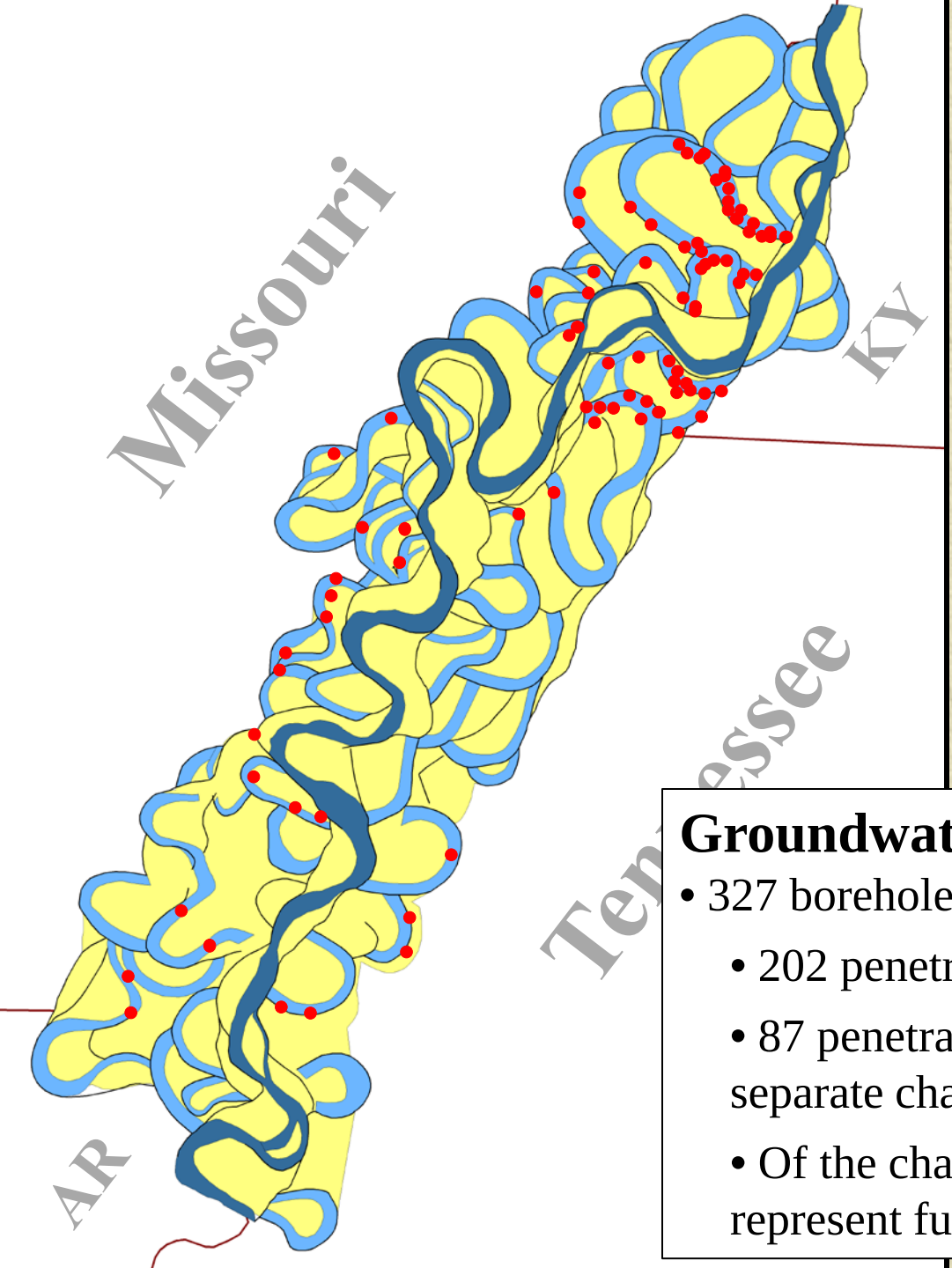
Determining the channel depth where channel area begins to dramatically increase





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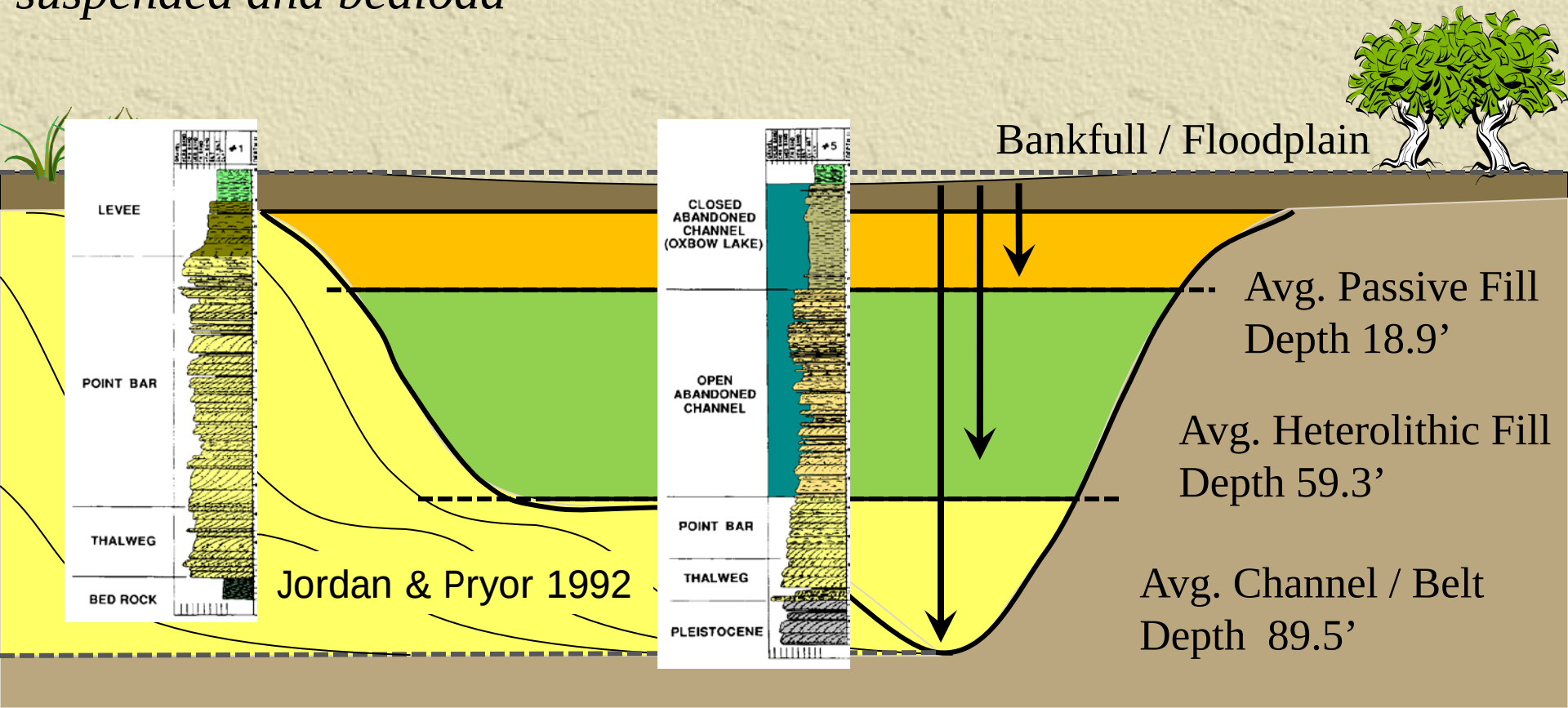
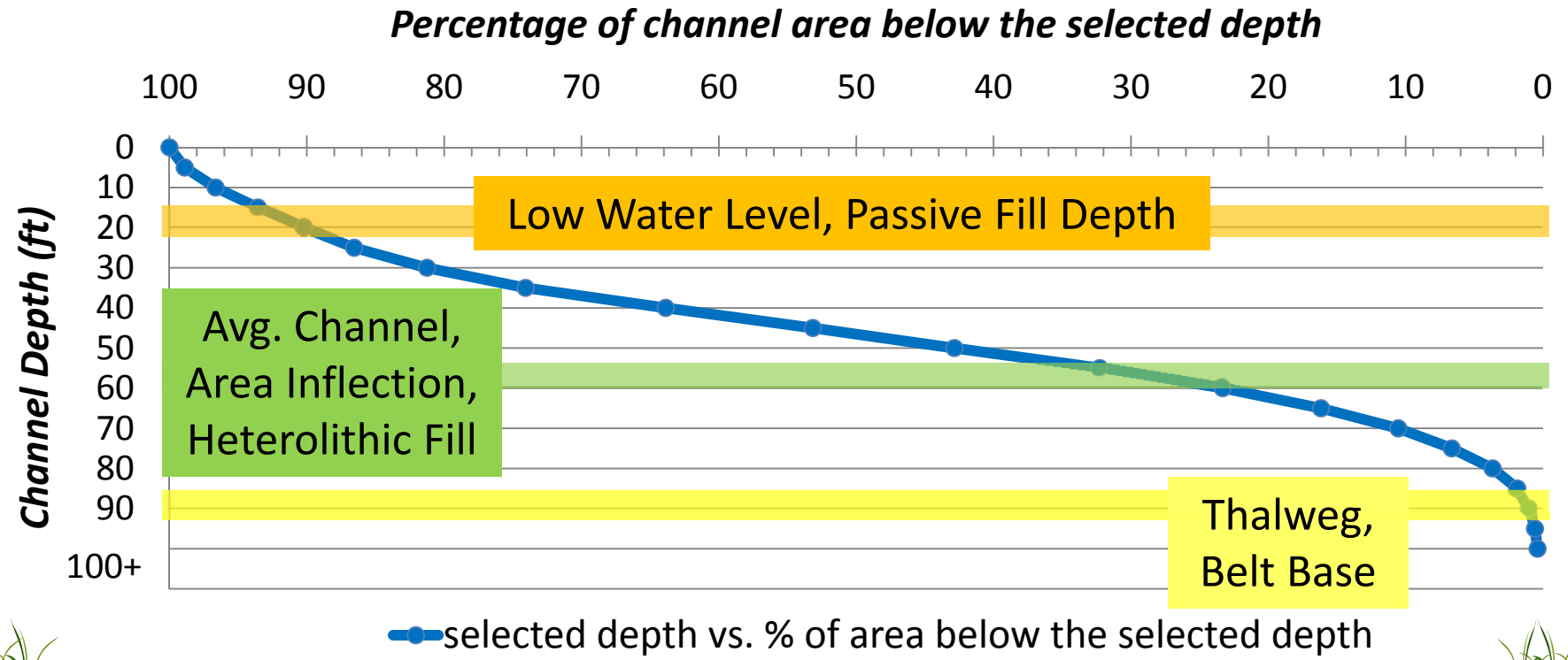
Groundwater Instiute (GWI) – University of Memphis
American Coal Company boring records

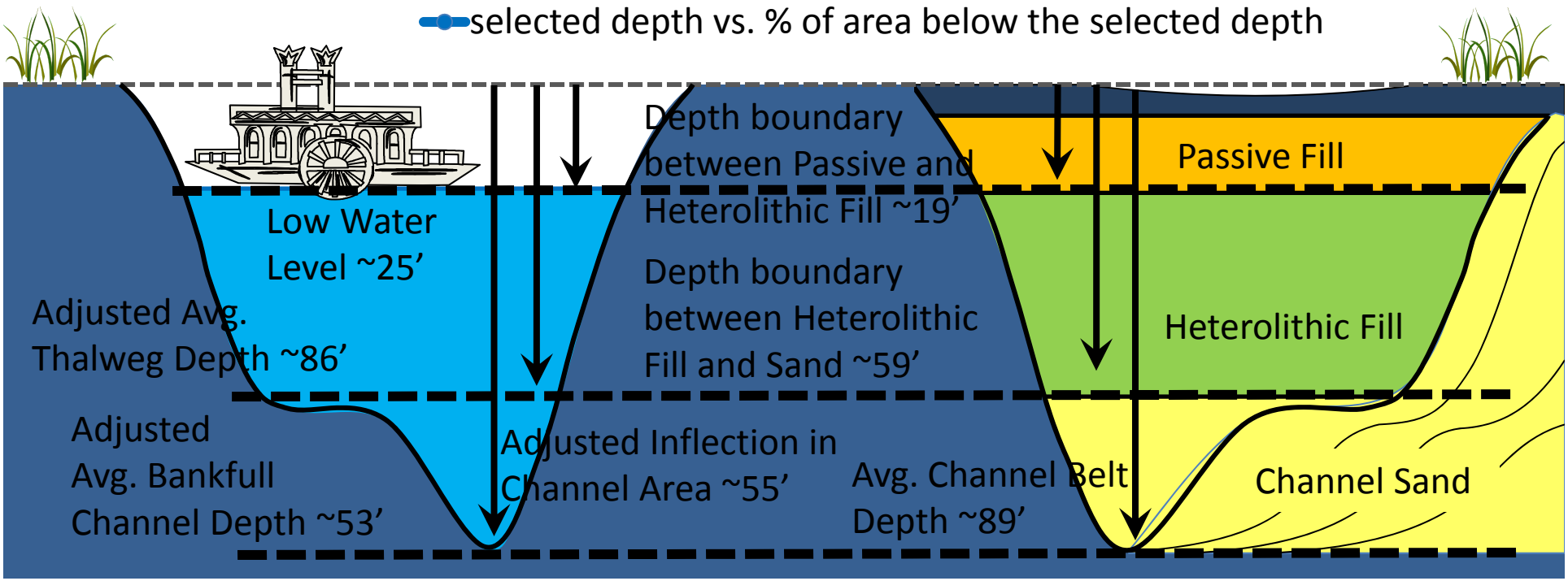
Core records were used to identify three facies types and their vertical distribution within abandoned channels.

Passive Fill is dominated by lacustrine mud and suspended load / overbank fines.

Heterolithic Fill is a mixture or clay, silt, and sand, representing a mix of suspended and bedload

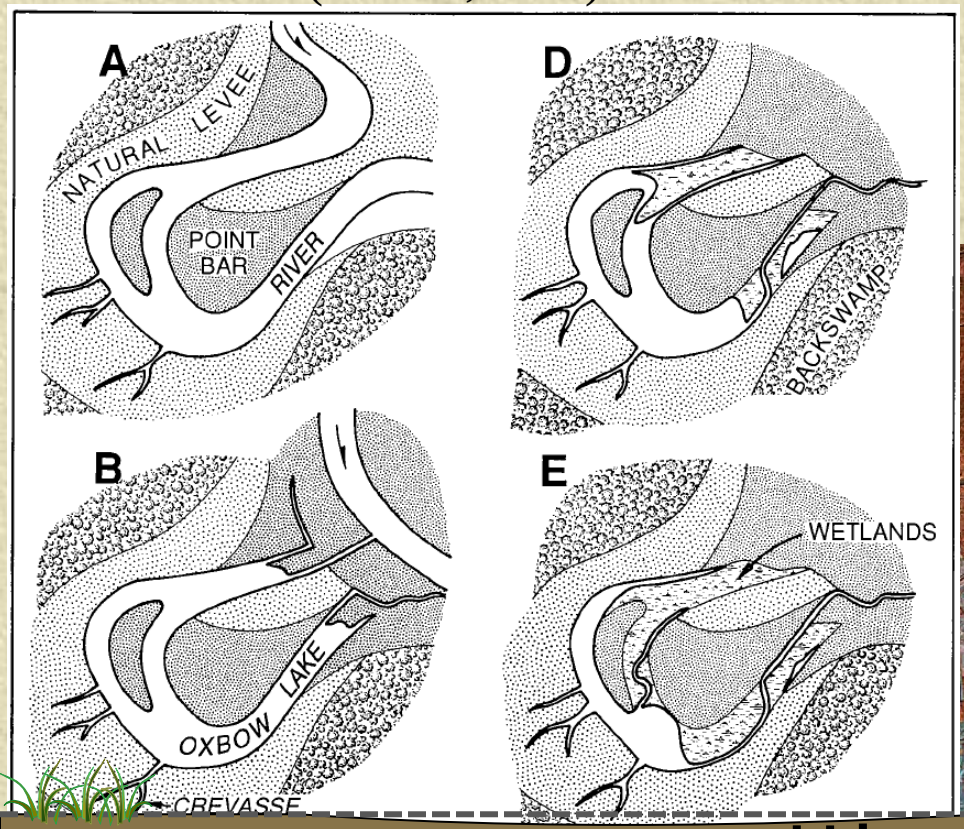


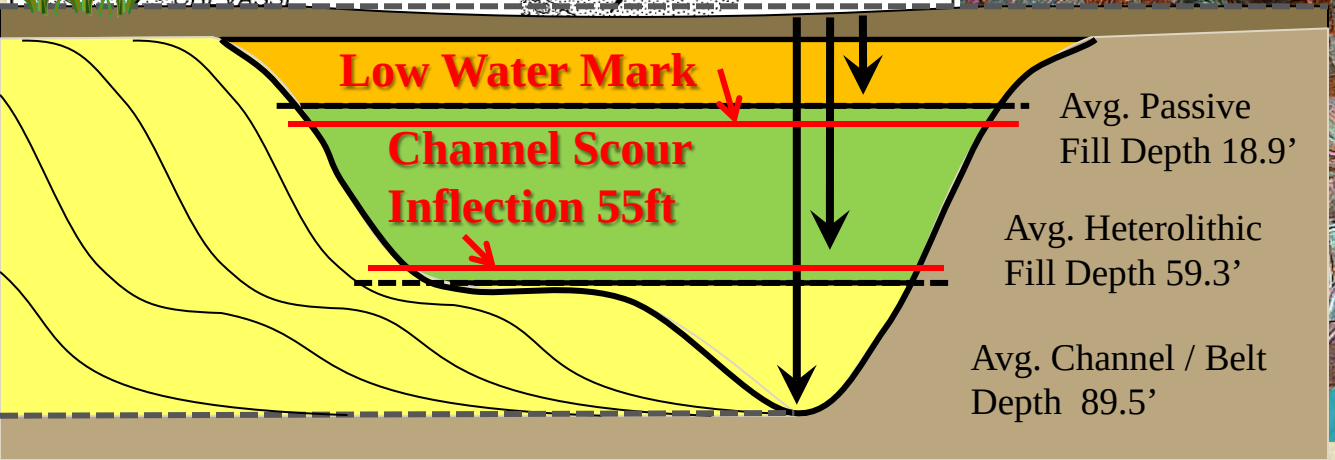

Percentage of channel area below the selected depth
100
90
80
70
60
50
40
30
20
10
0
Channel Depth (ft)
0
10
20
30
40
50
60
70
80
90
100+
Low Water Level, Passive Fill Depth
Avg. Channel, Area Inflection, Heterolithic Fill
Thalweg, Belt Base
selected depth vs. % of area below the selected depth


Depth boundary between Passive and Heterolithic Fill ~19'
Passive Fill
Low Water Level ~25'
Depth boundary between Heterolithic Fill and Sand ~59'
Heterolithic Fill
Adjusted Avg. Thalweg Depth ~86'
Adjusted Avg. Bankfull Channel Depth ~53'
Adjusted Inflection in Channel Area ~55'
Avg. Channel Belt Depth ~89'
Channel Sand

Oxbow Lake Fill Models

(Saucier, 1994)

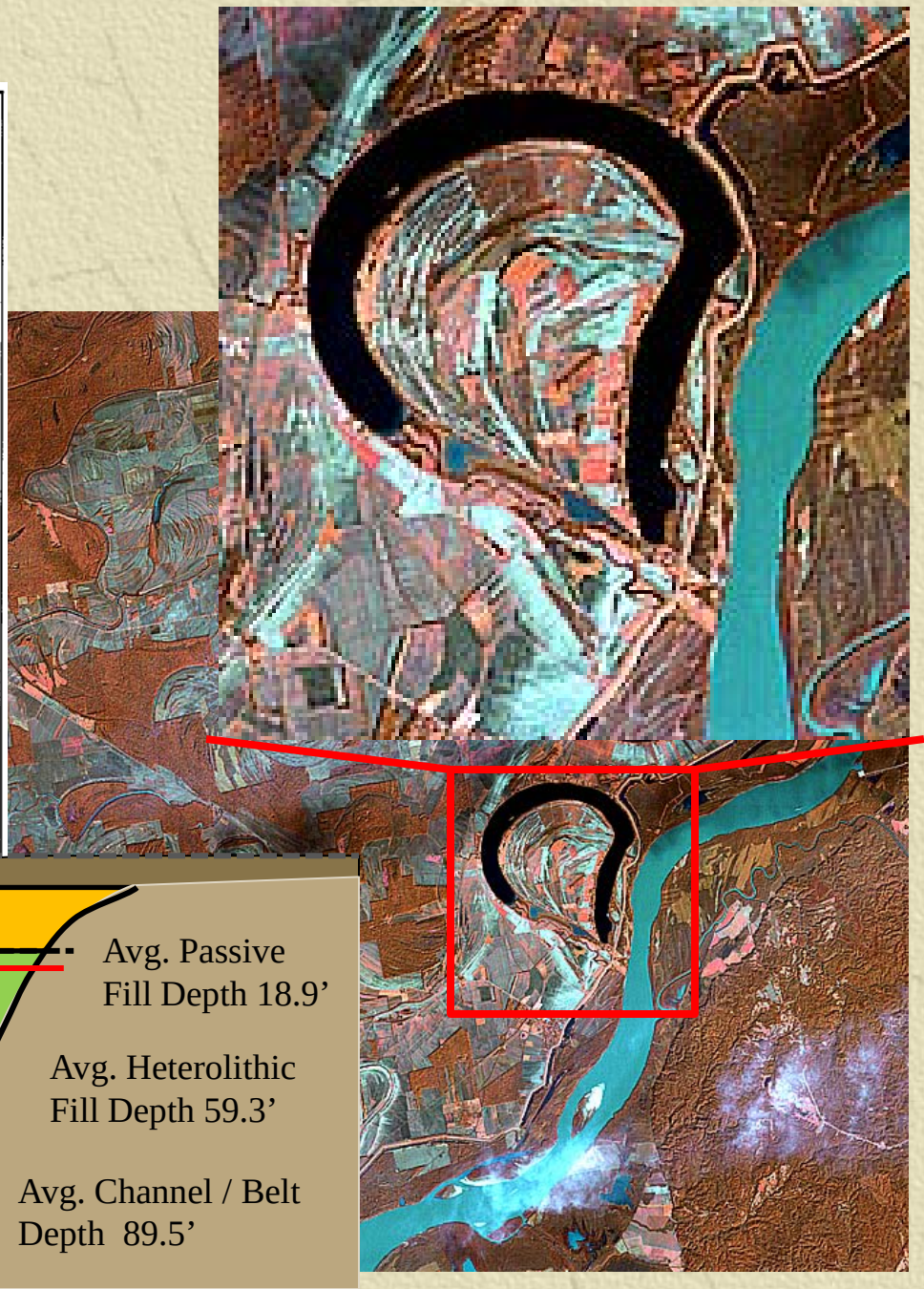




Avg. Passive Fill Depth 18.9’

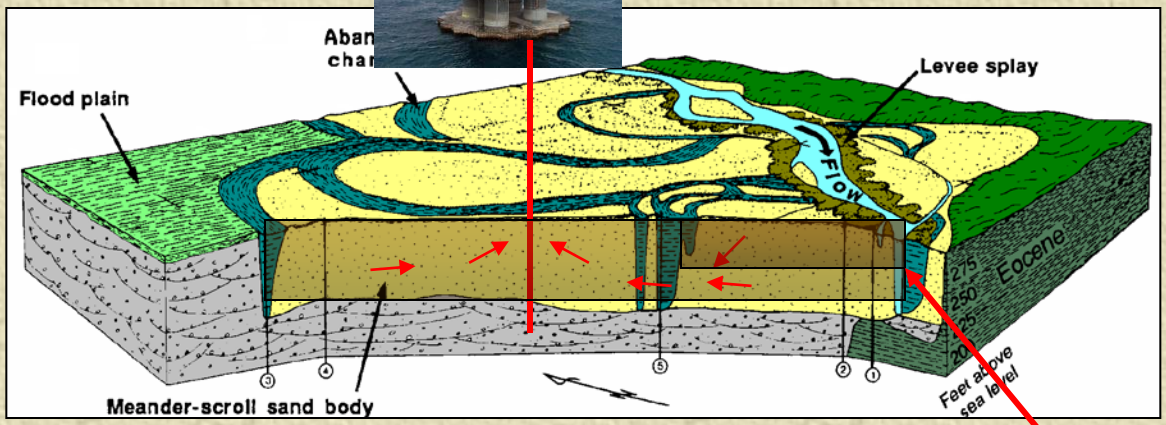
Avg. Heterolithic Fill Depth 59.3’

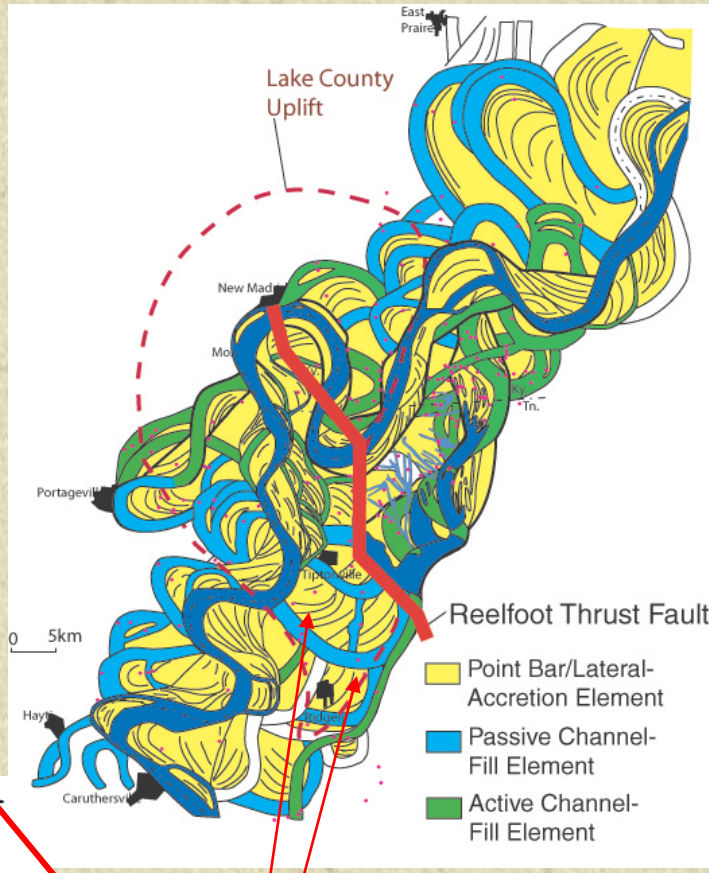
Avg. Channel / Belt Depth 89.5’

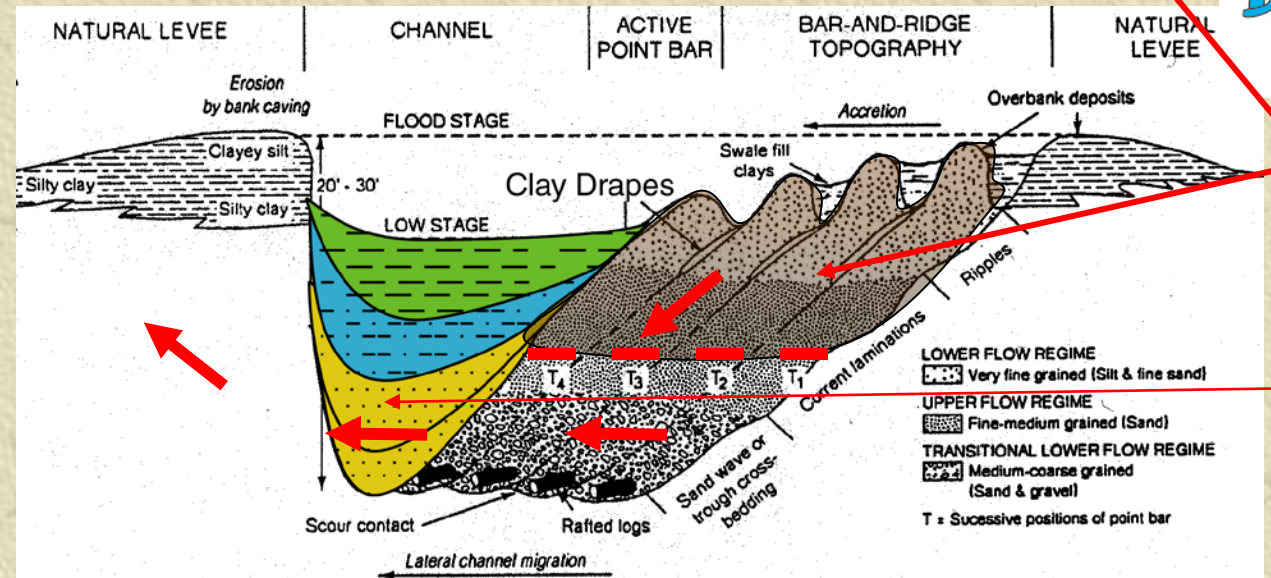


Connectivity Between Bars (Oil-Field Scale)

http://en.wikipedia.org/wiki/Oil_platform







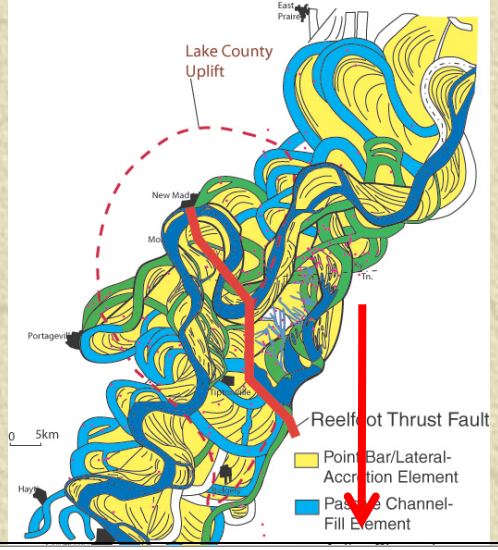
Trapped Product?

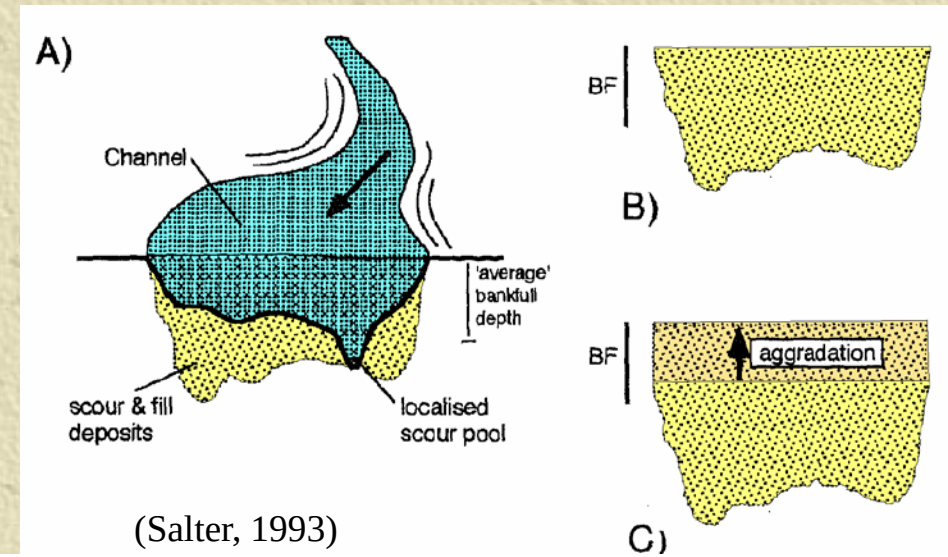
Connections?

Conclusions

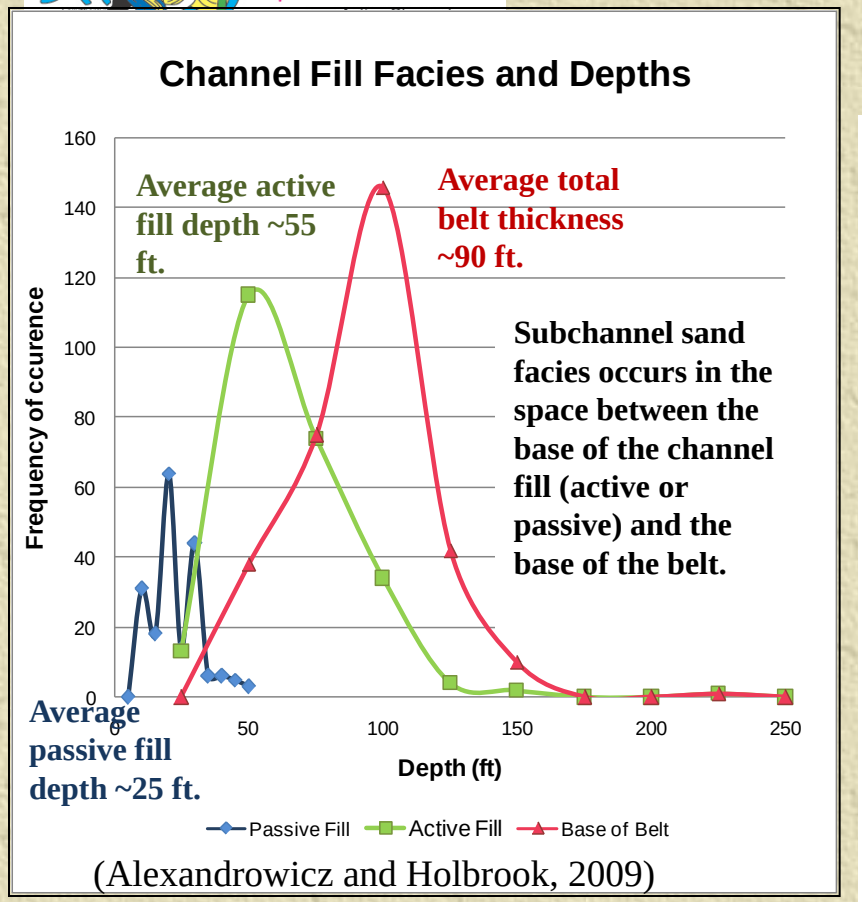
- Oxbow lakes fill abruptly to approximately average channel depth/area inflection with sandy fill.
- Heterolithic fill begins about average channel depth and continues to about the low-water mark where abandonment mud fill begins.
- The vertical section of an oxbow lake fill generally records an exponential decrease in fill rate.
- Connection is to be expected between bars up to about average channel depth.

Fill Relationships

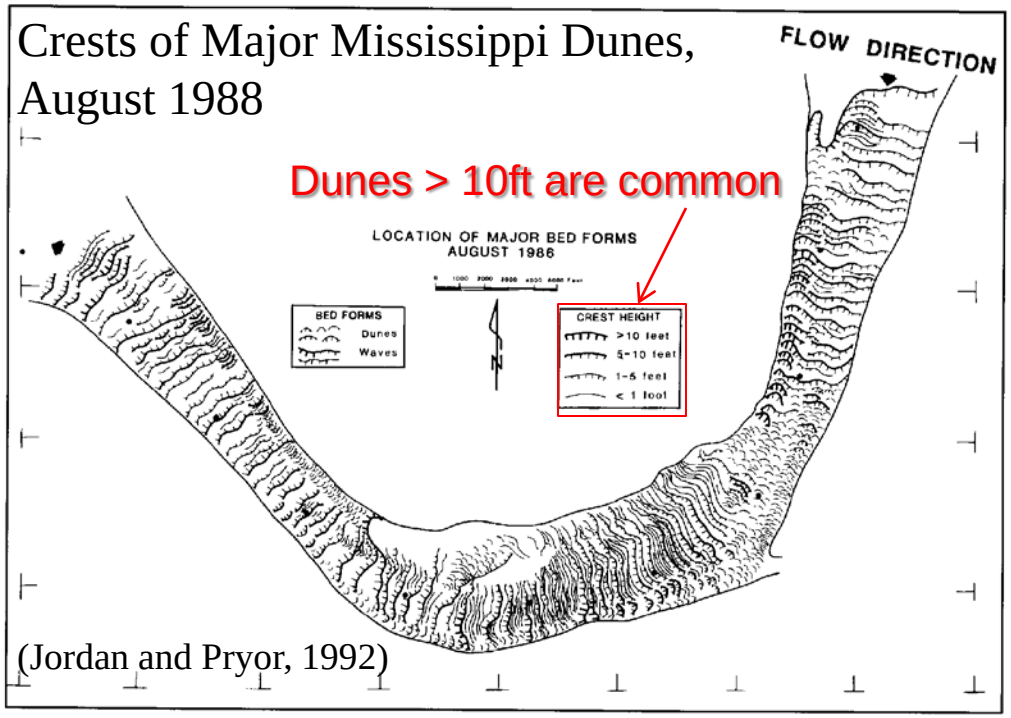




(Salter, 1993)



(Alexandrowicz and Holbrook, 2009)

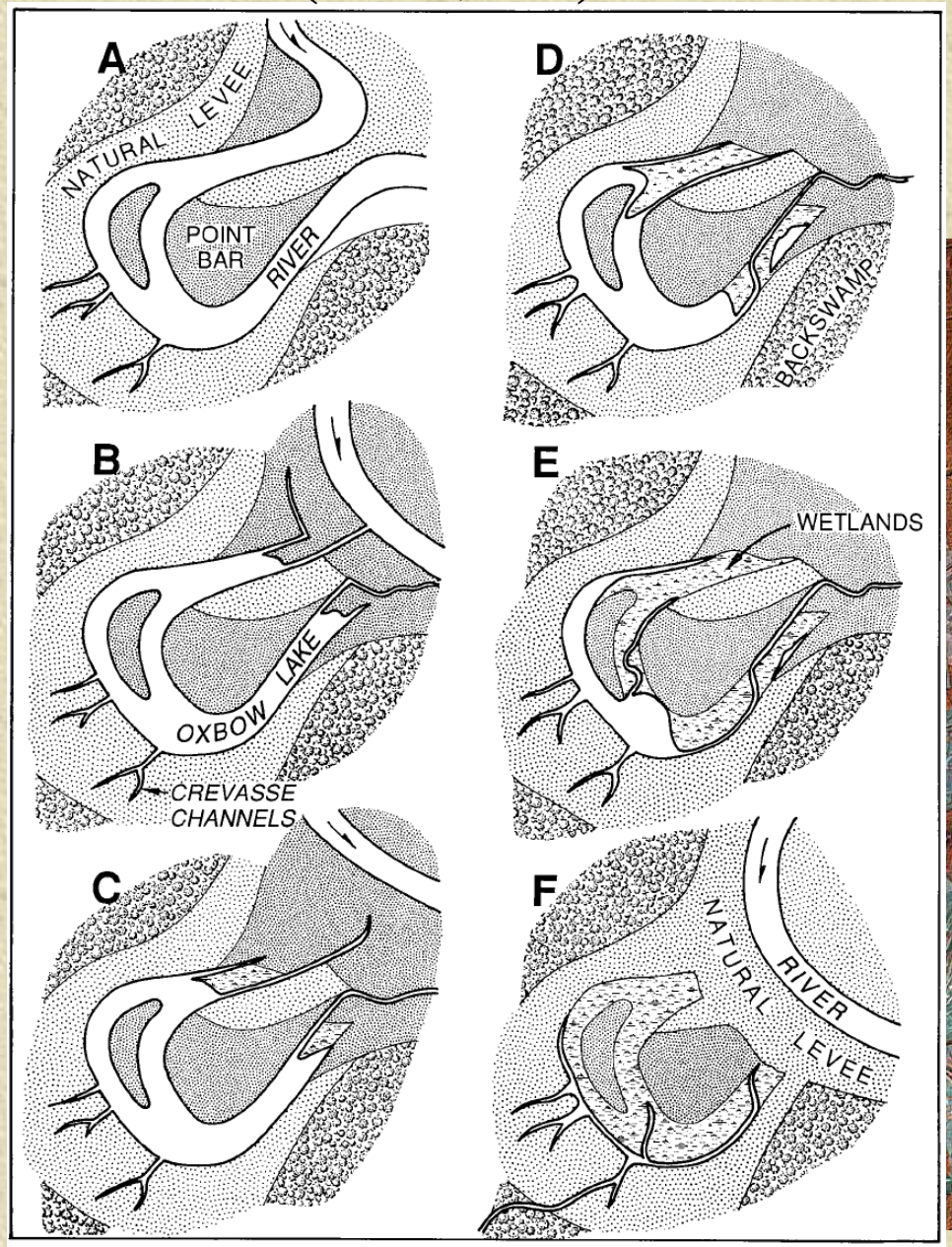


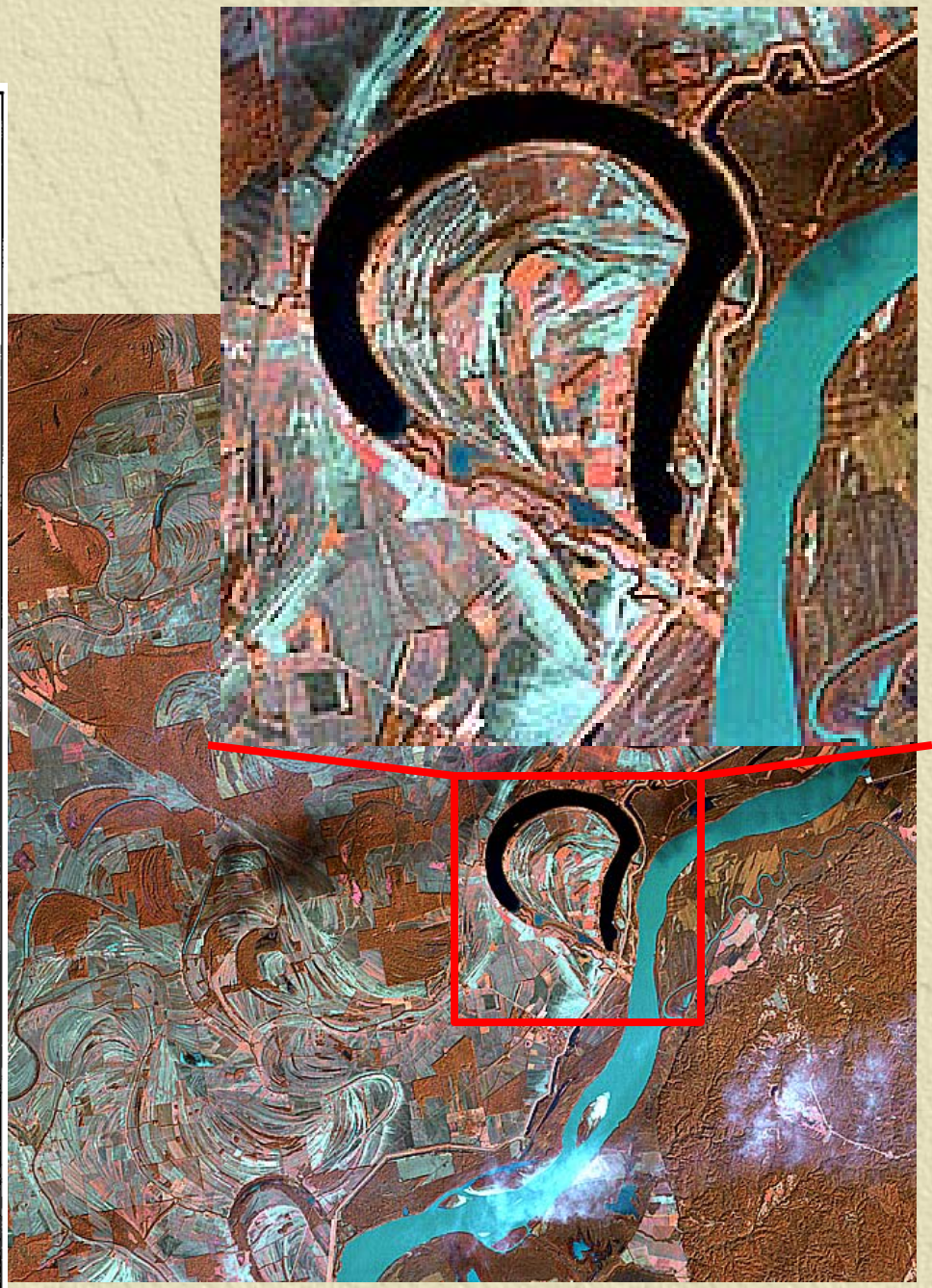
(Jordan and Pryor, 1992)

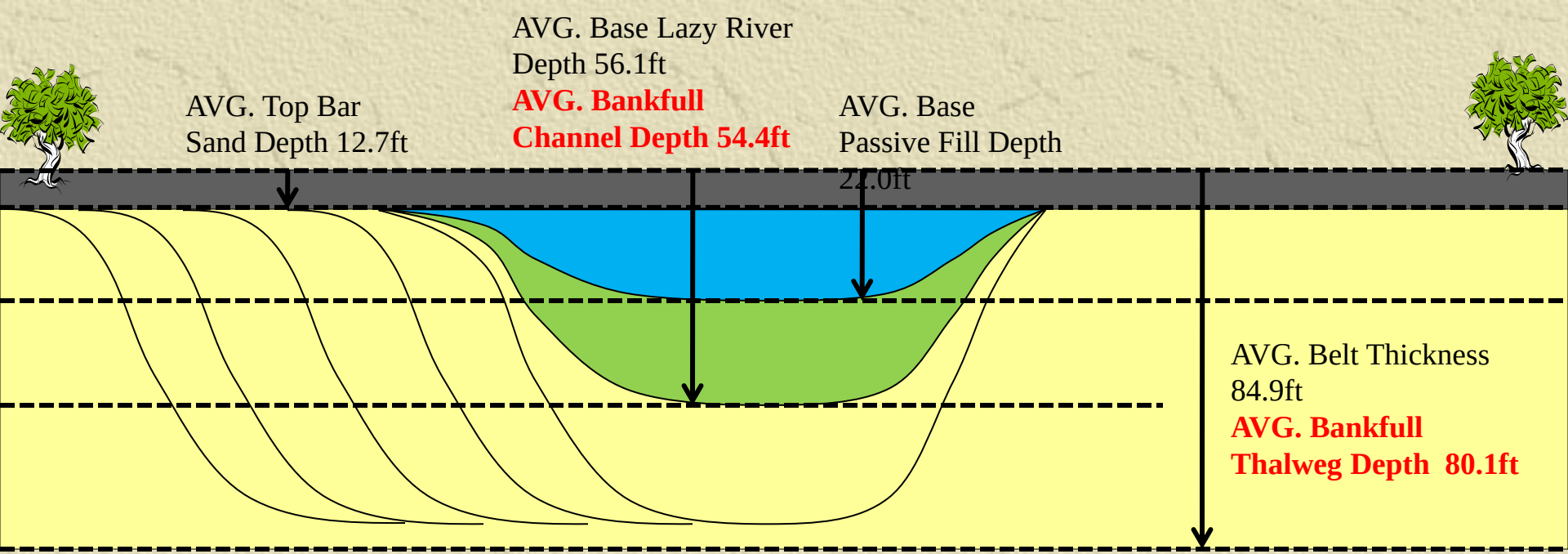
Figure 3—Bed forms in the Mississippi River channel in August 1986. Horizontal scale shown is 5000 ft (1525 m).

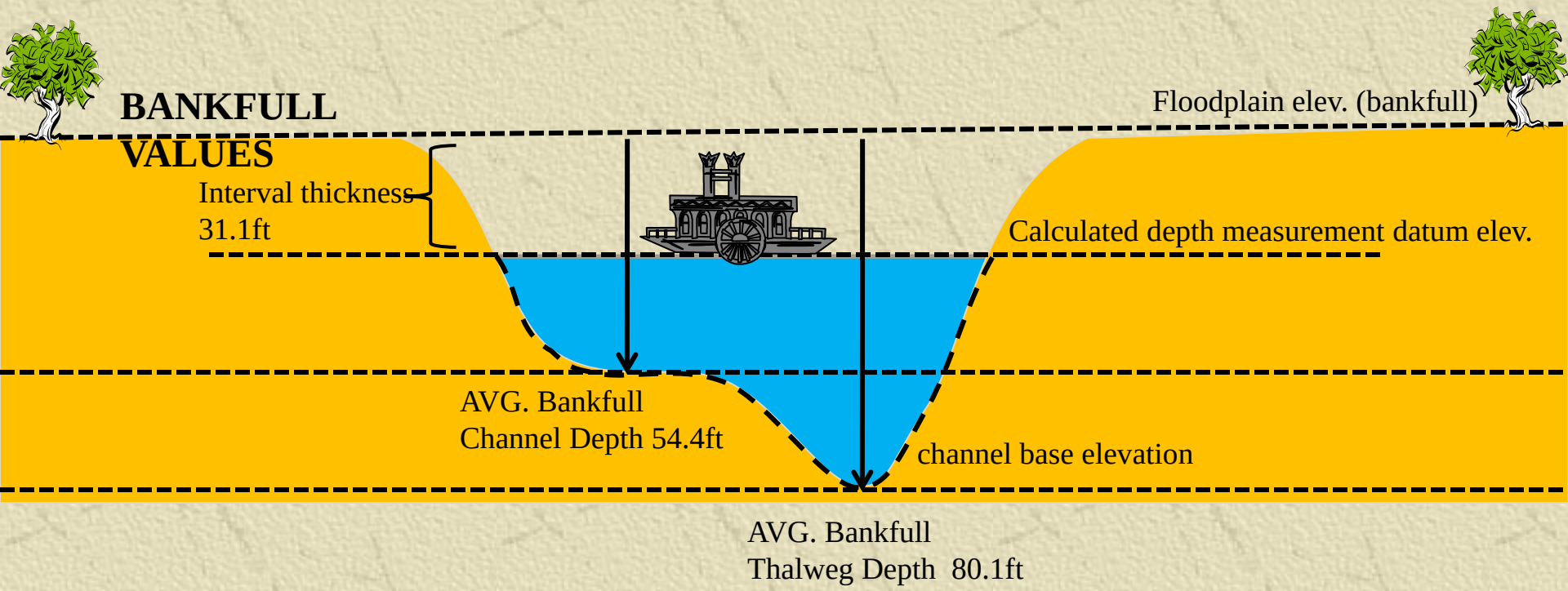
Oxbow Lake Fill Models

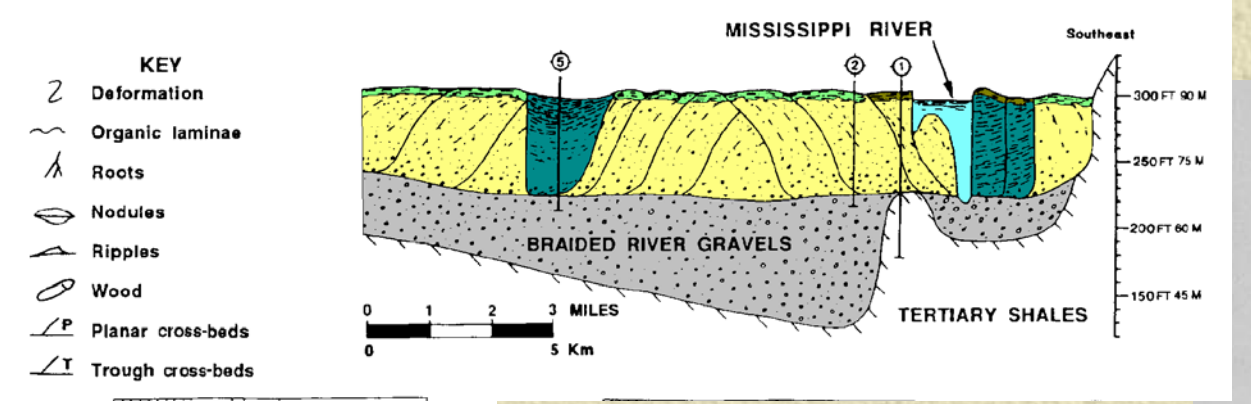
(Saucier, 1994)

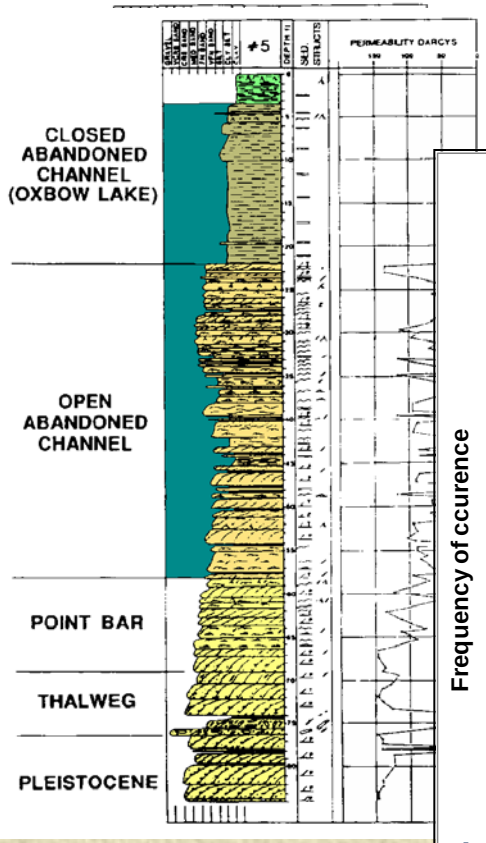


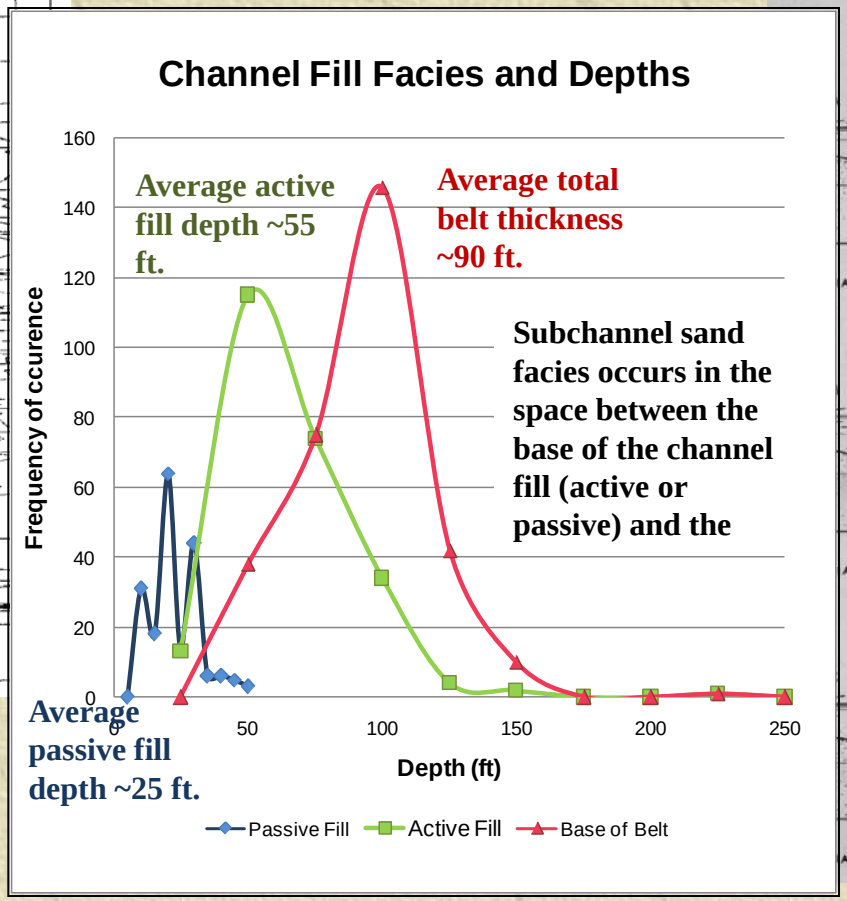


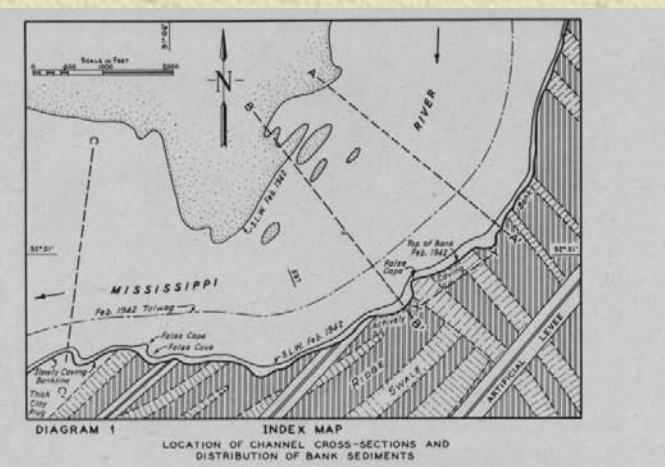

AVG. Base Lazy River
Depth 56.1ft
AVG. Bankfull
Channel Depth 54.4ft
AVG. Top Bar
Sand Depth 12.7ft
AVG. Base
Passive Fill Depth
22.0ft
AVG. Belt Thickness
84.9ft
AVG. Bankfull
Thalweg Depth 80.1ft

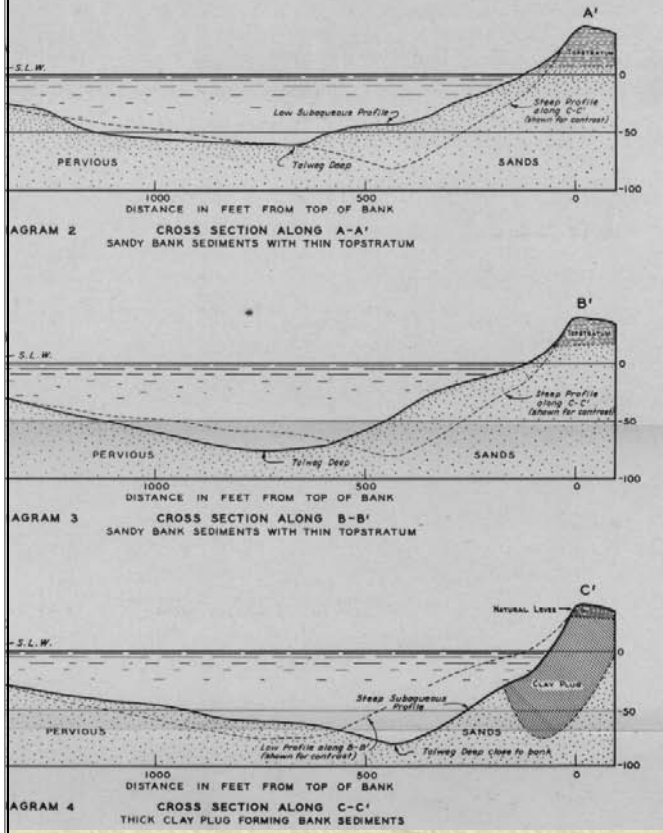

BANKFULL
VALUES
Floodplain elev. (bankfull)
Interval thickness
31.1ft
Calculated depth measurement datum elev.
AVG. Bankfull
Channel Depth 54.4ft
channel base elevation
AVG. Bankfull
Thalweg Depth 80.1ft

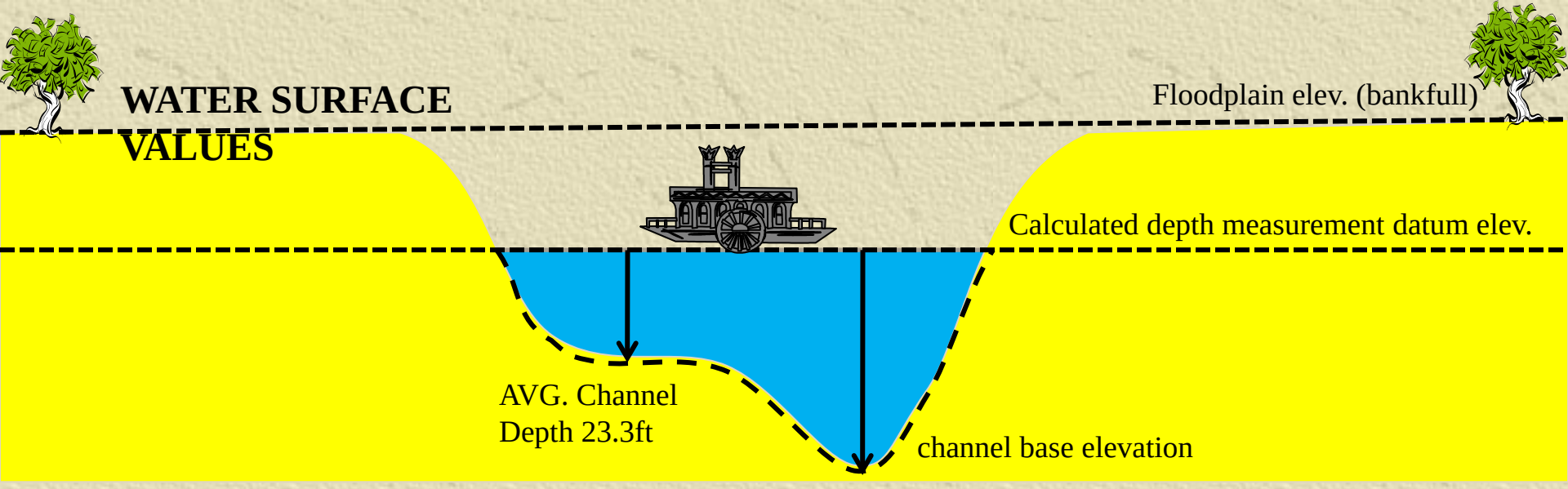

KEY
Deformation
Organic laminae
Roots
Nodules
Ripples
Wood
Planar cross-beds
Trough cross-beds
MISSISSIPPI RIVER
Southeast
BRAIDED RIVER GRAVELS
TERTIARY SHALES
300 FT 90 M
250 FT 75 M
200 FT 60 M
150 FT 45 M
0 1 2 3 MILES
0 5 Km

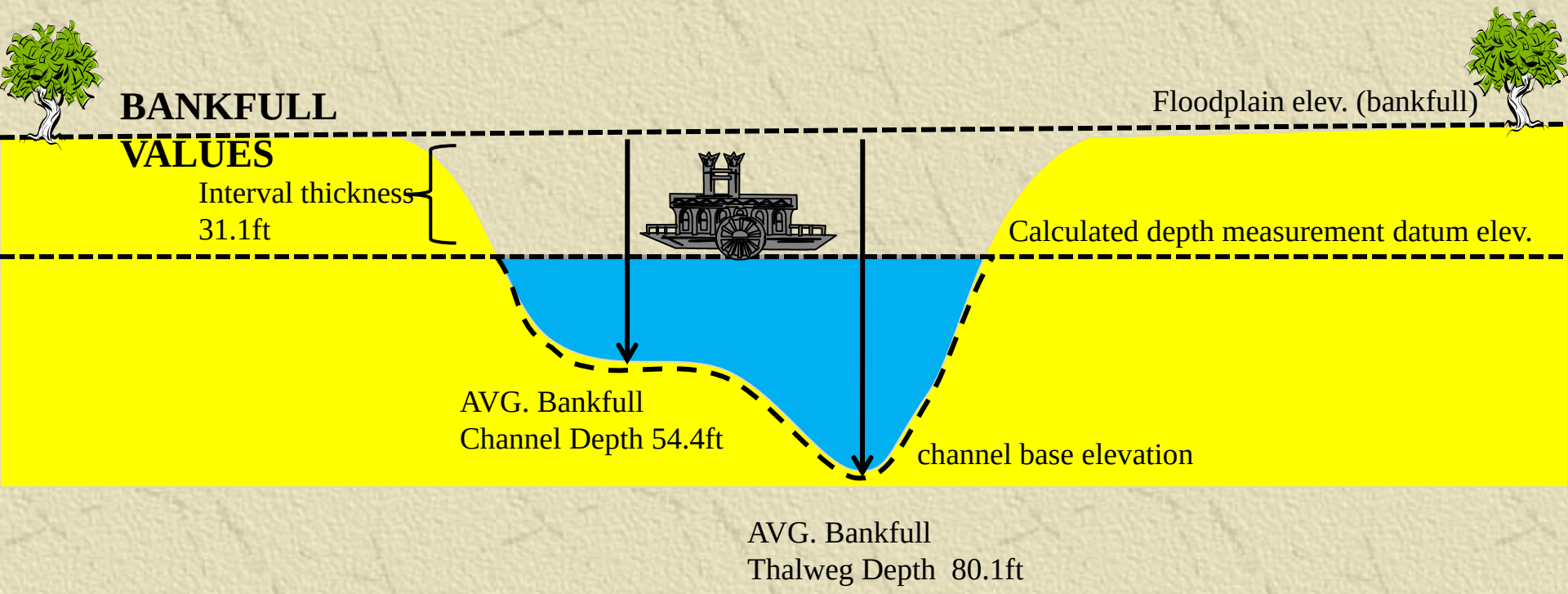

CLOSED ABANDONED CHANNEL (OXBOW LAKE)
OPEN ABANDONED CHANNEL
POINT BAR
THALWEG
PLEISTOCENE
PERMEABILITY DARCYS


Channel Fill Facies and Depths
Average active fill depth ~55 ft.
Average total belt thickness ~90 ft.
Subchannel sand facies occurs in the space between the base of the channel fill (active or passive) and the
Average passive fill depth ~25 ft.
Frequency of ccurence
Depth (ft)
0
20
40
60
80
100
120
140
160
0
50
100
150
200
250
Passive Fill
Active Fill
Base of Belt

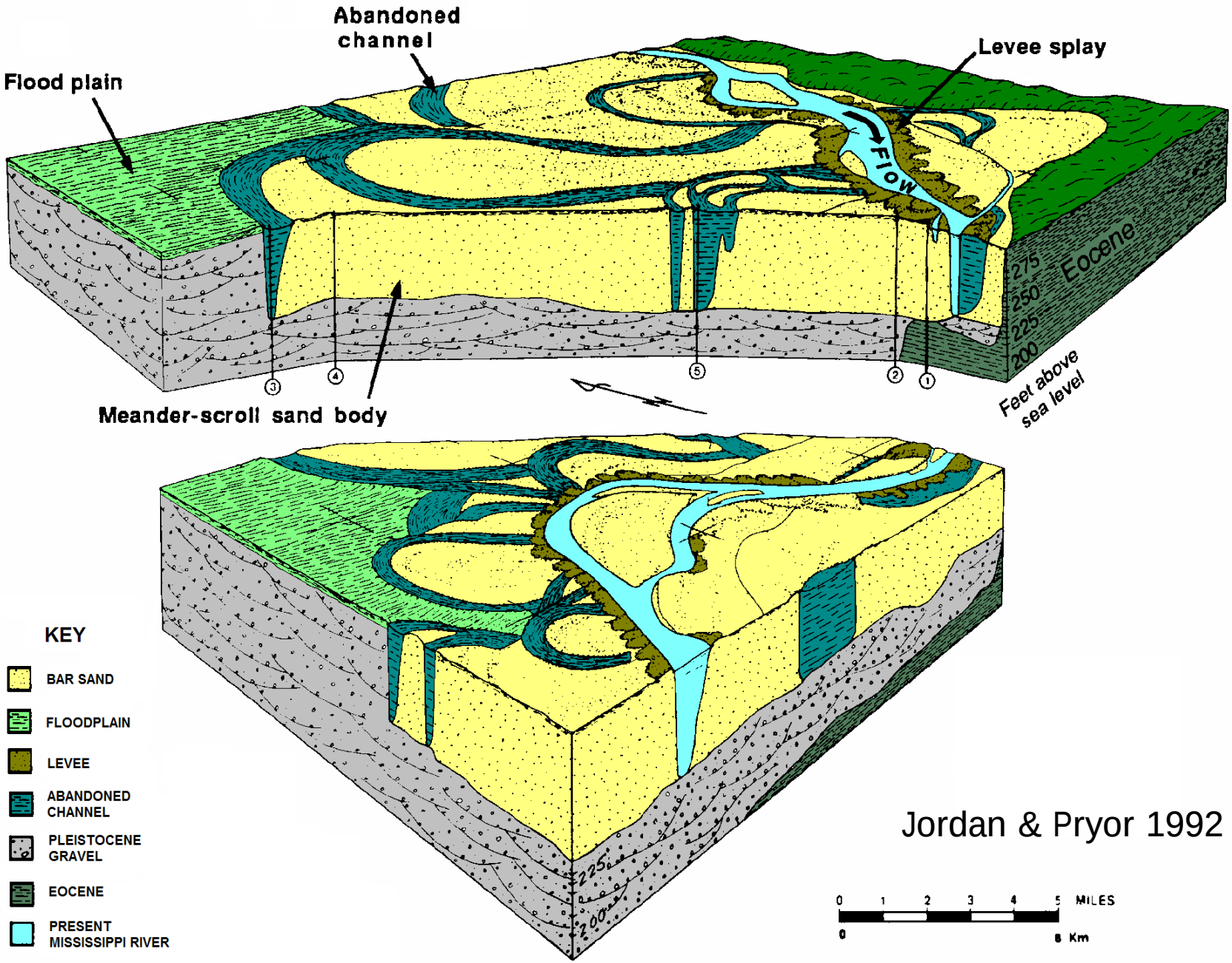

MISSISSIPPI
RIVER
DIAGRAM 1
INDEX MAP
LOCATION OF CHANNEL CROSS-SECTIONS AND DISTRIBUTION OF BANK SEDIMENTS


A'
PERVIOUS
SANDS
DISTANCE IN FEET FROM TOP OF BANK
CROSS SECTION ALONG A-A'
SANDY BANK SEDIMENTS WITH THIN TOPSTRATUM
B'
CROSS SECTION ALONG B-B'
SANDY BANK SEDIMENTS WITH THIN TOPSTRATUM
C'
CROSS SECTION ALONG C-C'
THICK CLAY PLUG FORMING BANK SEDIMENTS


WATER SURFACE VALUES
Floodplain elev. (bankfull)
Calculated depth measurement datum elev.
AVG. Channel Depth 23.3ft
channel base elevation
AVG. Thalweg Depth 49.0ft

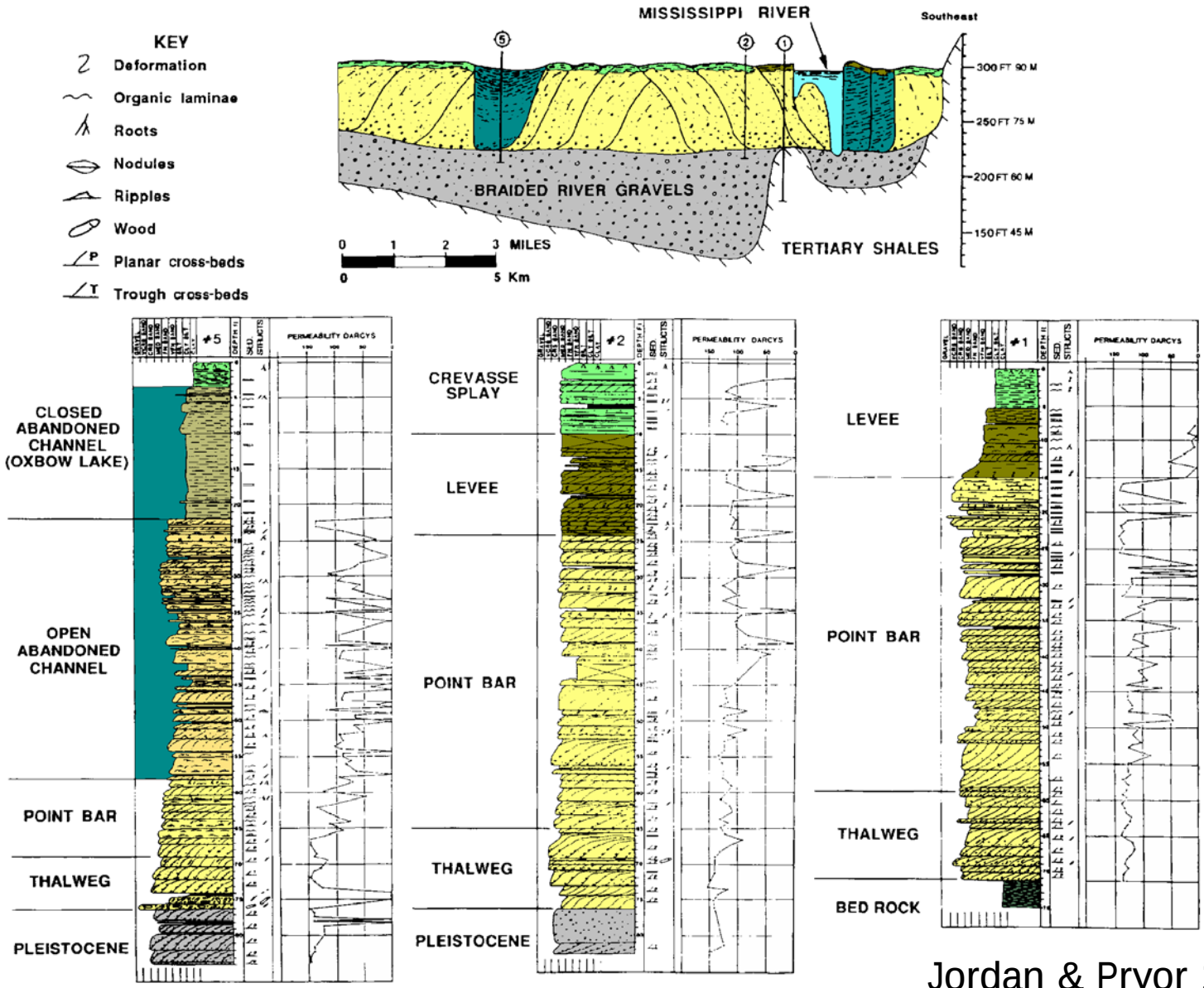

BANKFULL VALUES
Floodplain elev. (bankfull)
Interval thickness 31.1ft
Calculated depth measurement datum elev.
AVG. Bankfull Channel Depth 54.4ft
channel base elevation
AVG. Bankfull Thalweg Depth 80.1ft

LEVEL 1 HETEROGENEITY



Jordan & Pryor 1992

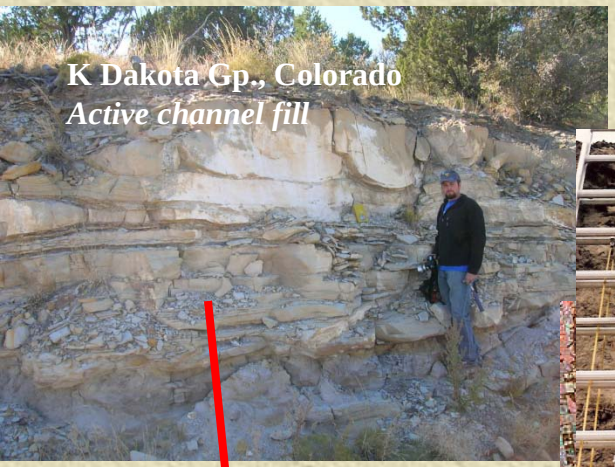
LEVEL 2 HETEROGENEITY

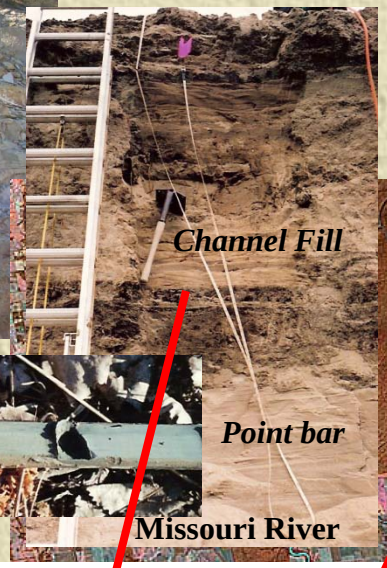


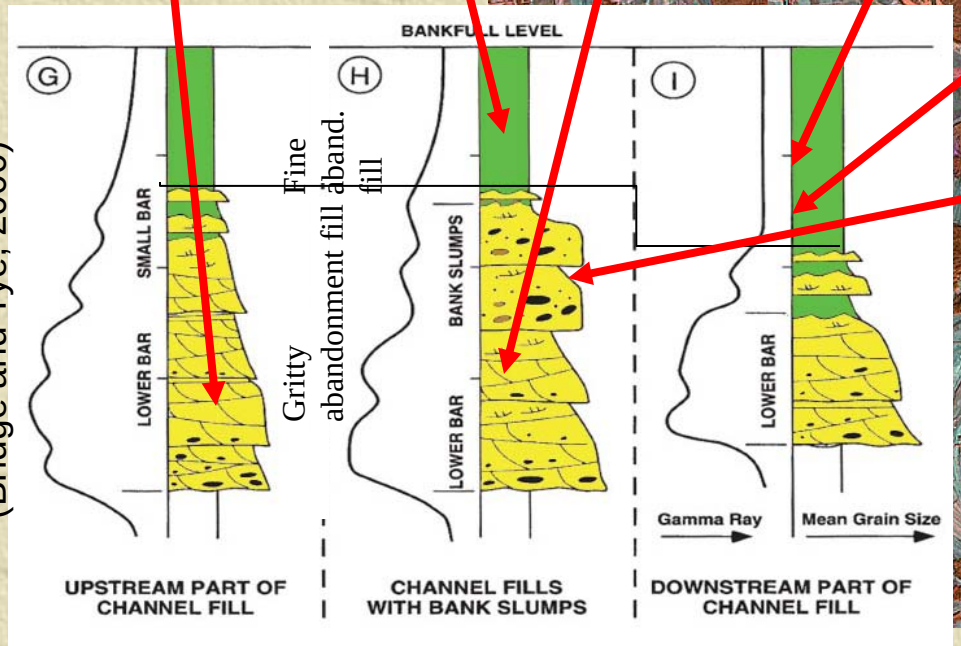
Jordan & Pryor 1992

Figure 6—The second level of heterogeneity. A single meander loop (analogous to an oil pool) is isolated by an abandoned-channel clay plug. Three continuous cores show the sequence within the meander loop and clay plug. Trough/tangential (T), planar (P), ripples, roots, wood fragments, and mud clasts shown next to the depth track in the individual logs. Pleistocene section modified after Fisk (1944, 1947).

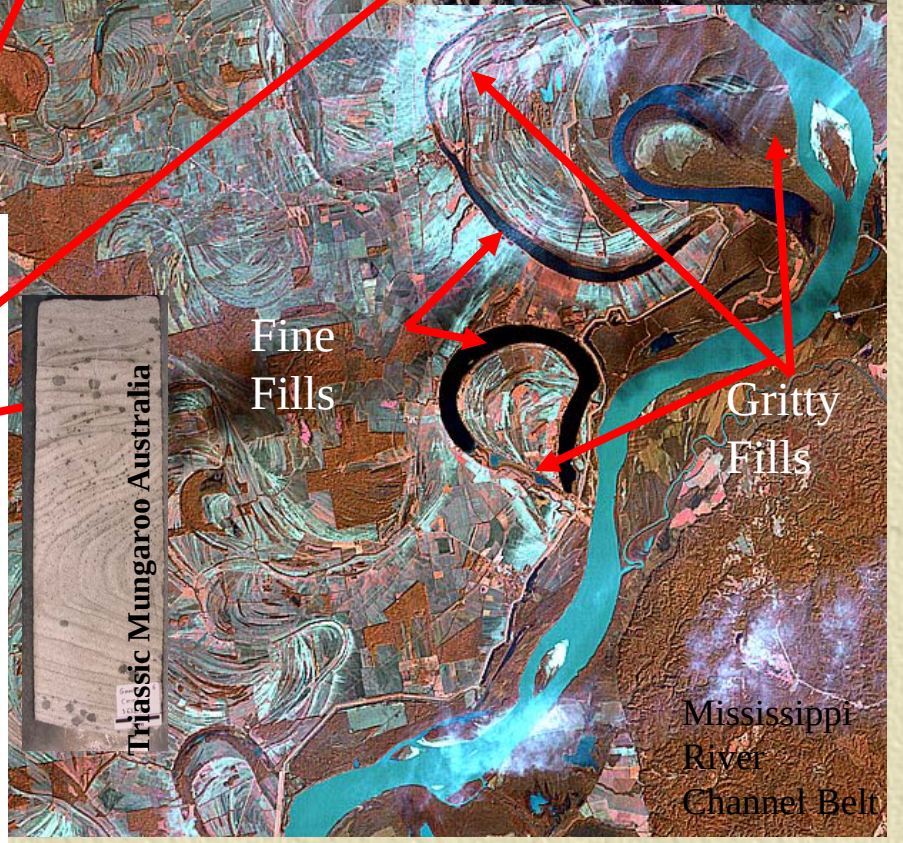
Channel-Fill Deposits



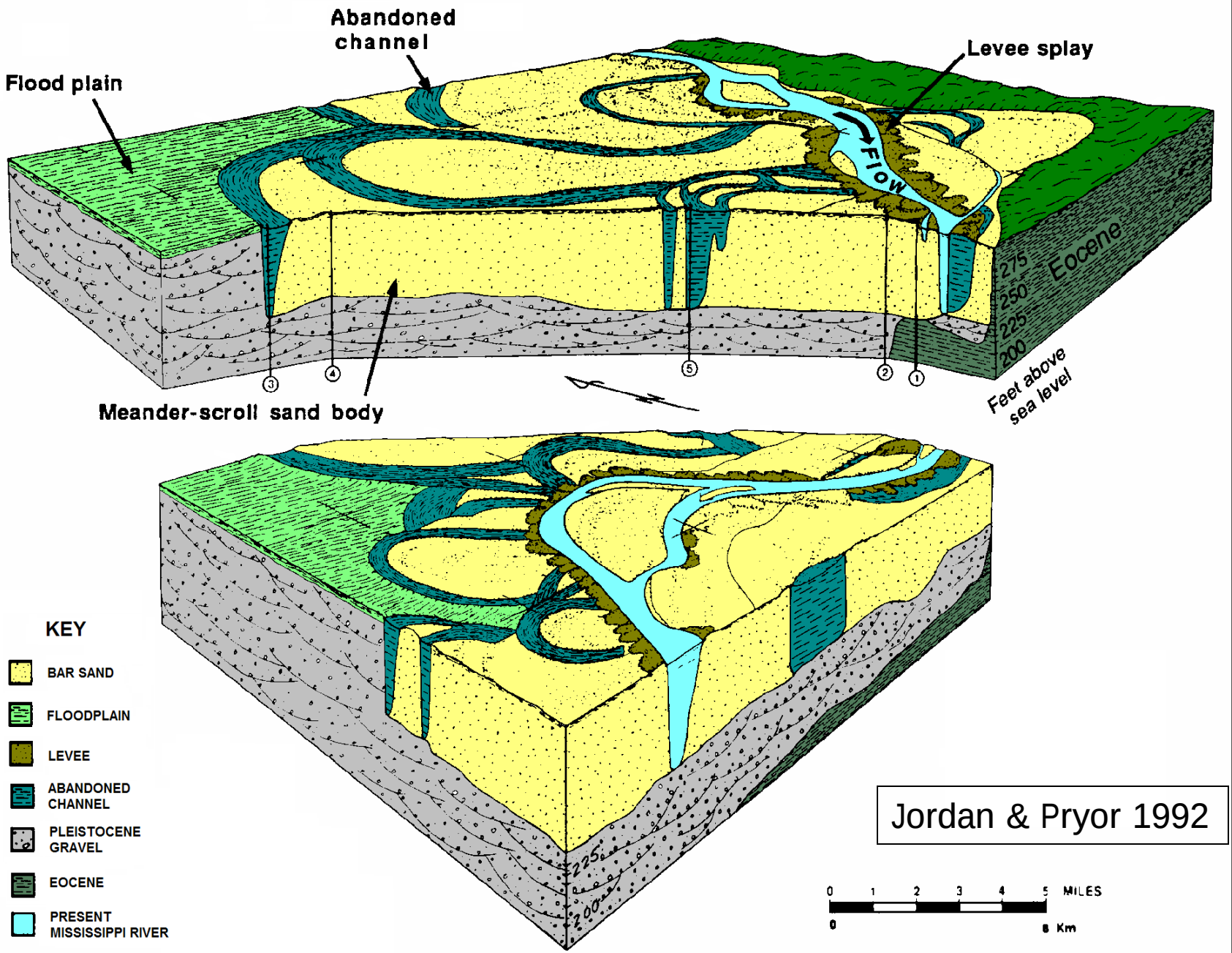




(Bridge and Tye, 2000)

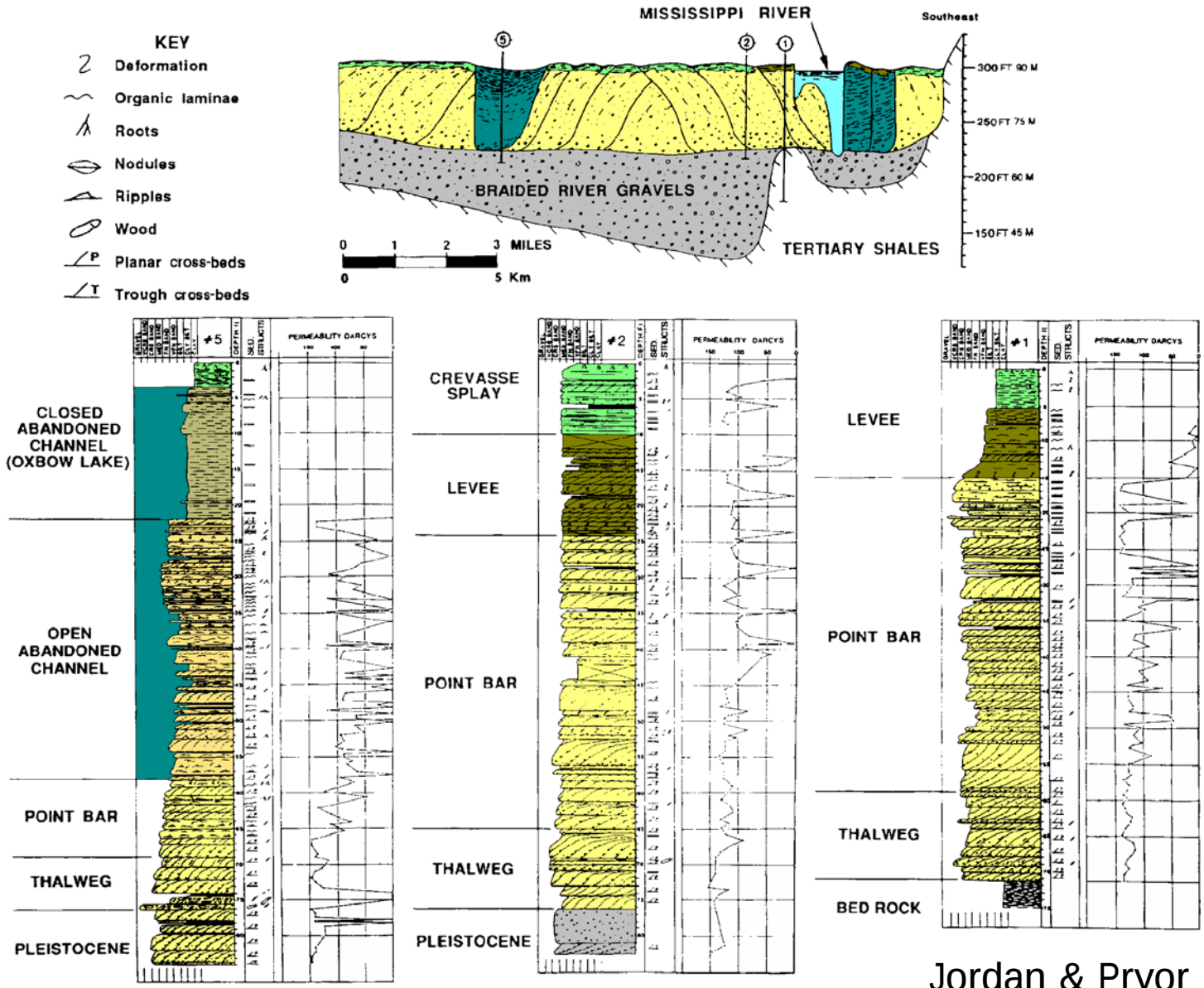


LEVEL 1 HETEROGENEITY



Jordan & Pryor 1992

LEVEL 2 HETEROGENEITY



Jordan & Pryor 1992

Figure 6—The second level of heterogeneity. A single meander loop (analogous to an oil pool) is isolated by an abandoned-channel clay plug. Three continuous cores show the sequence within the meander loop and clay plug. Trough/tangential (T), planar (P), ripples, roots, wood fragments, and mud clasts shown next to the depth track in the individual logs. Pleistocene section modified after Fisk (1944, 1947).