Progress toward Quaternary displacement rates on the Meeman-Shelby fault and Joiner Ridge horst, eastern Arkansas

Alex Ward
University of Memphis

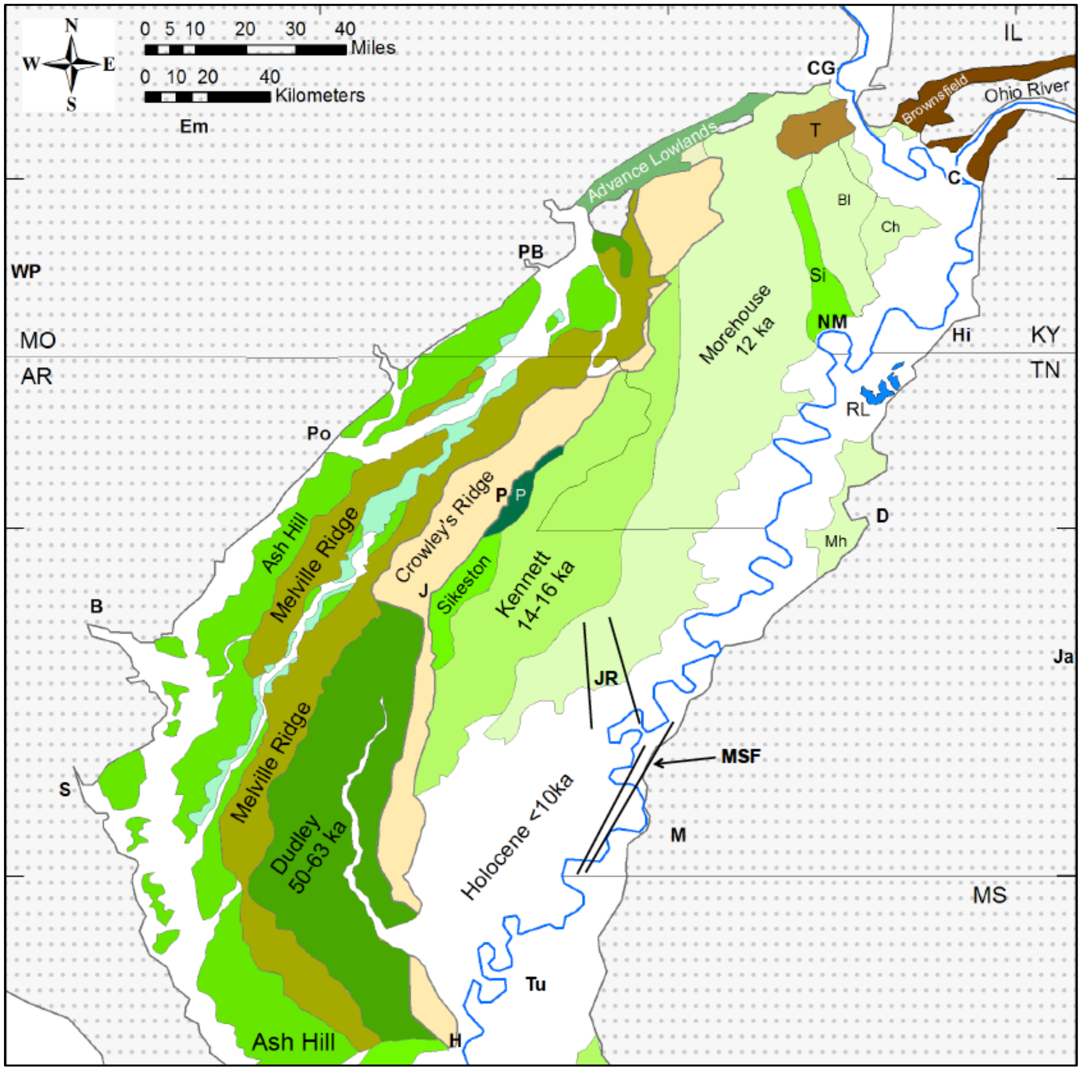
Ronald Counts
U.S. Geological Survey

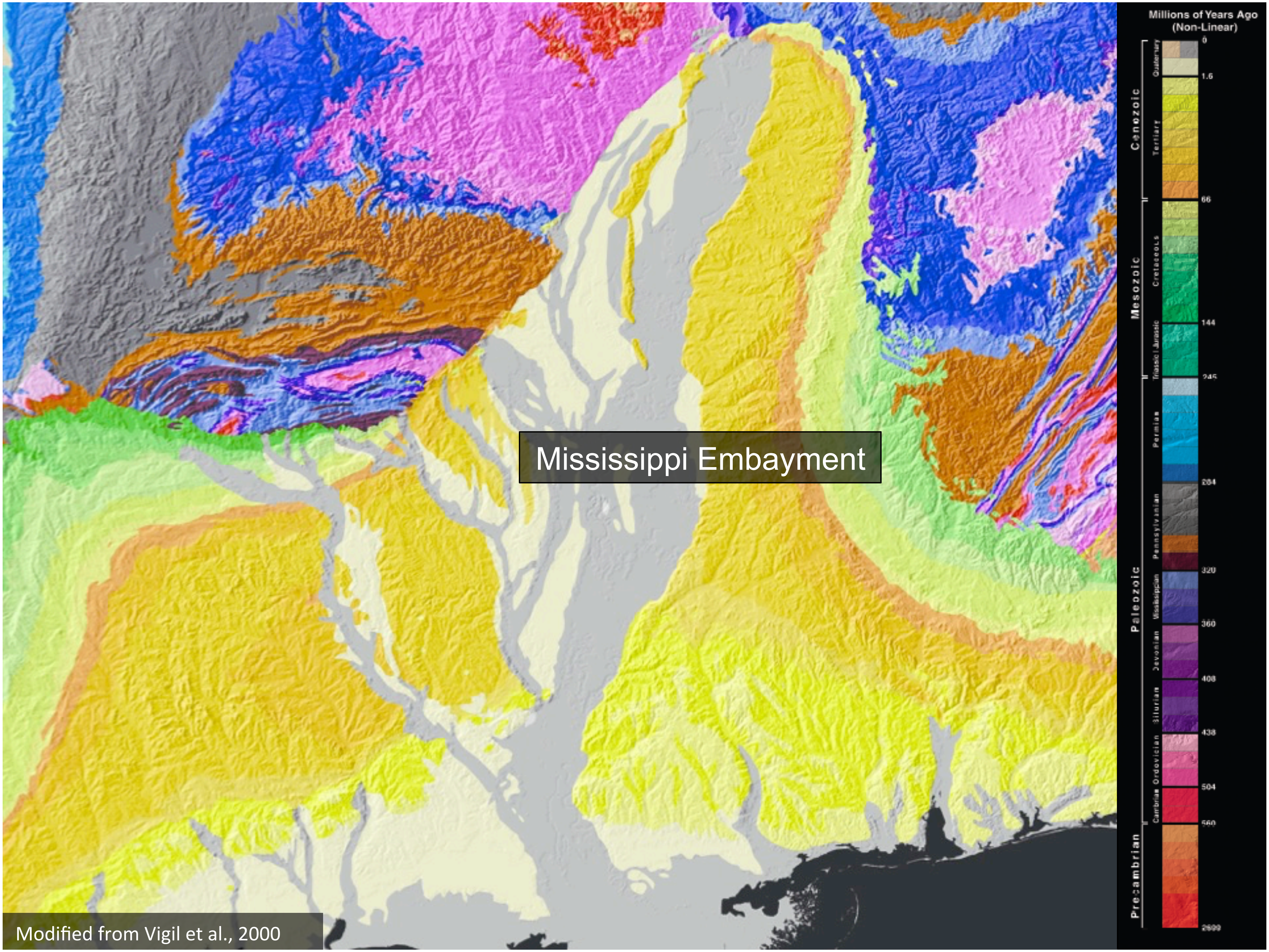
Roy Van Arsdale
University of Memphis

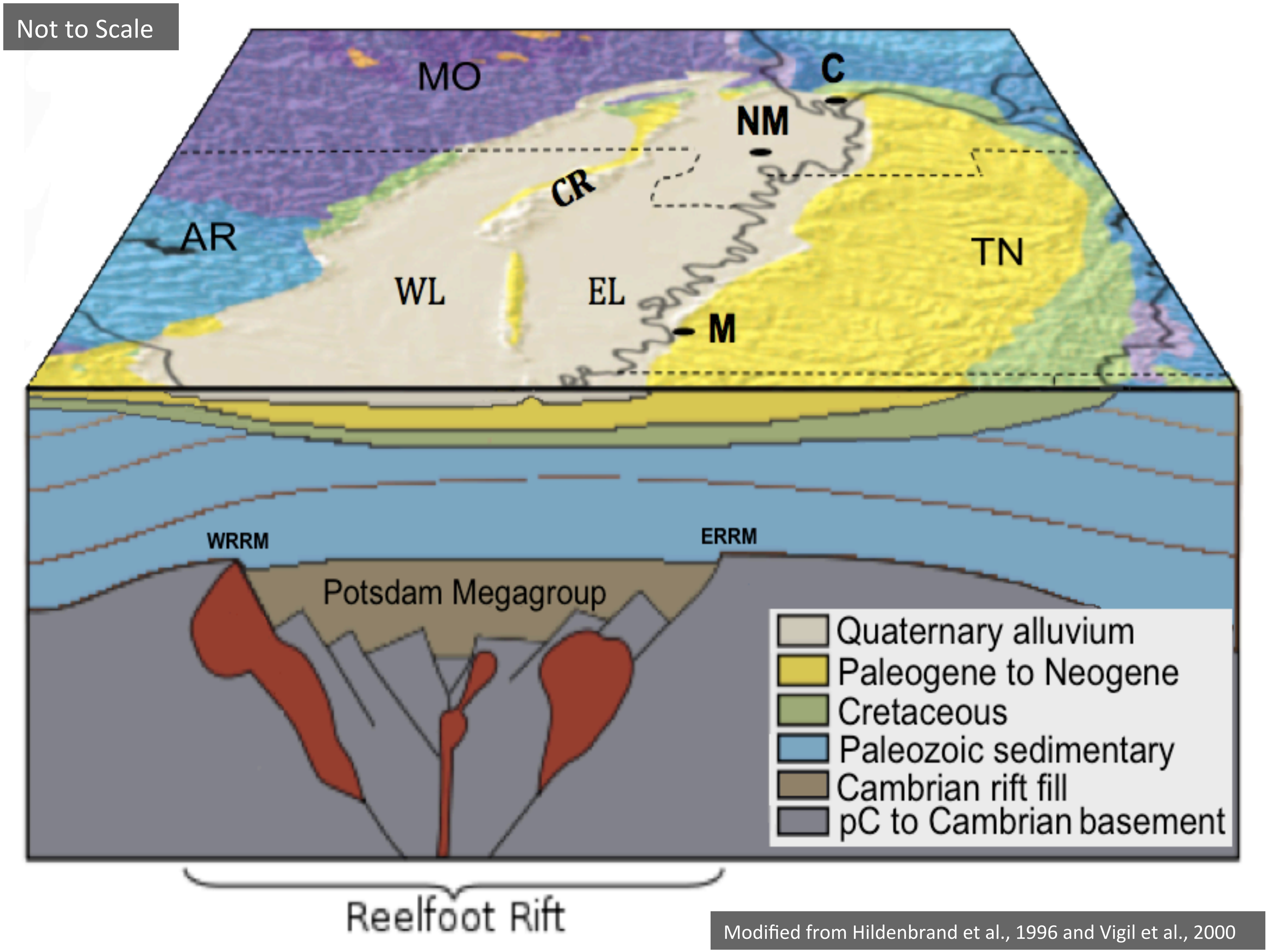
Daniel Larsen
University of Memphis

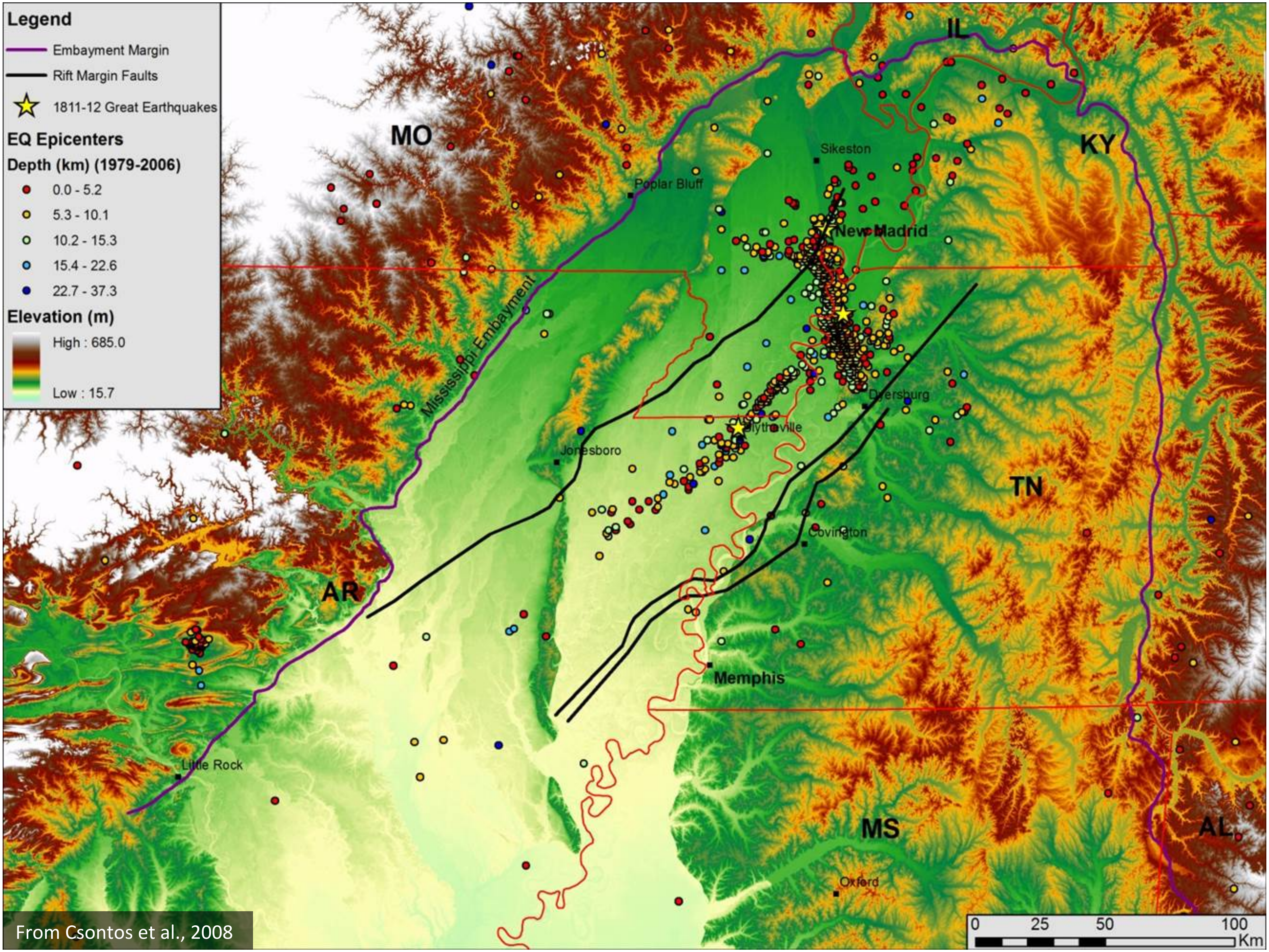
John Carmichael
U.S. Geological Survey

Gregg Hileman
U.S. Geological Survey



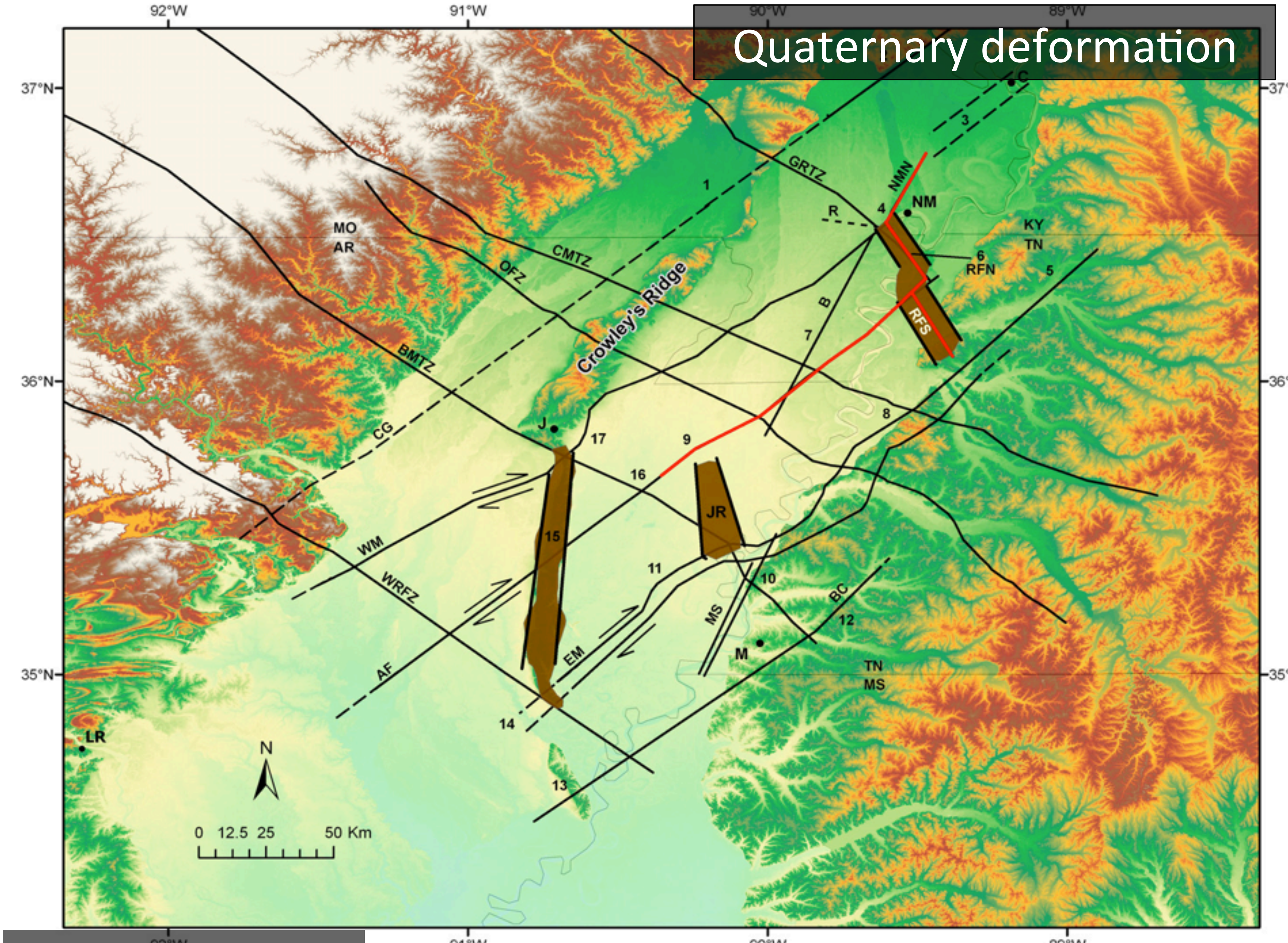

Mississippi Embayment
Millions of Years Ago
(Non-Linear)
Cenozoic
Quaternary
Tertiary
Mesozoic
Cretaceous
Triassic Jurassic
Paleozoic
Permian
Pennsylvanian
Mississippian
Devonian
Silurian
Ordovician
Cambrian
Precambrian
0
1.6
66
144
245
284
320
360
408
438
504
560
2600
Modified from Vigil et al., 2000


Not to Scale
MO
C
NM
CR
AR
TN
WL
EL
M
WRRM
ERRM
Potsdam Megagroup
Quaternary alluvium
Paleogene to Neogene
Cretaceous
Paleozoic sedimentary
Cambrian rift fill
pC to Cambrian basement
Reelfoot Rift
Modified from Hildenbrand et al., 1996 and Vigil et al., 2000



Legend
Embayment Margin
Rift Margin Faults
1811-12 Great Earthquakes
EQ Epicenters
Depth (km) (1979-2006)
0.0 - 5.2
5.3 - 10.1
10.2 - 15.3
15.4 - 22.6
22.7 - 37.3
Elevation (m)
High : 685.0
Low : 15.7
MO
IL
KY
TN
AR
MS
AL
Sikeston
Poplar Bluff
New Madrid
Mississippi Embayment
Dyersburg
Blytheville
Jonesboro
Covington
Memphis
Little Rock
Oxford
0 25 50 100 Km
From Csontos et al., 2008

Quaternary deformation



From Van Arsdale and Cupples, 2013

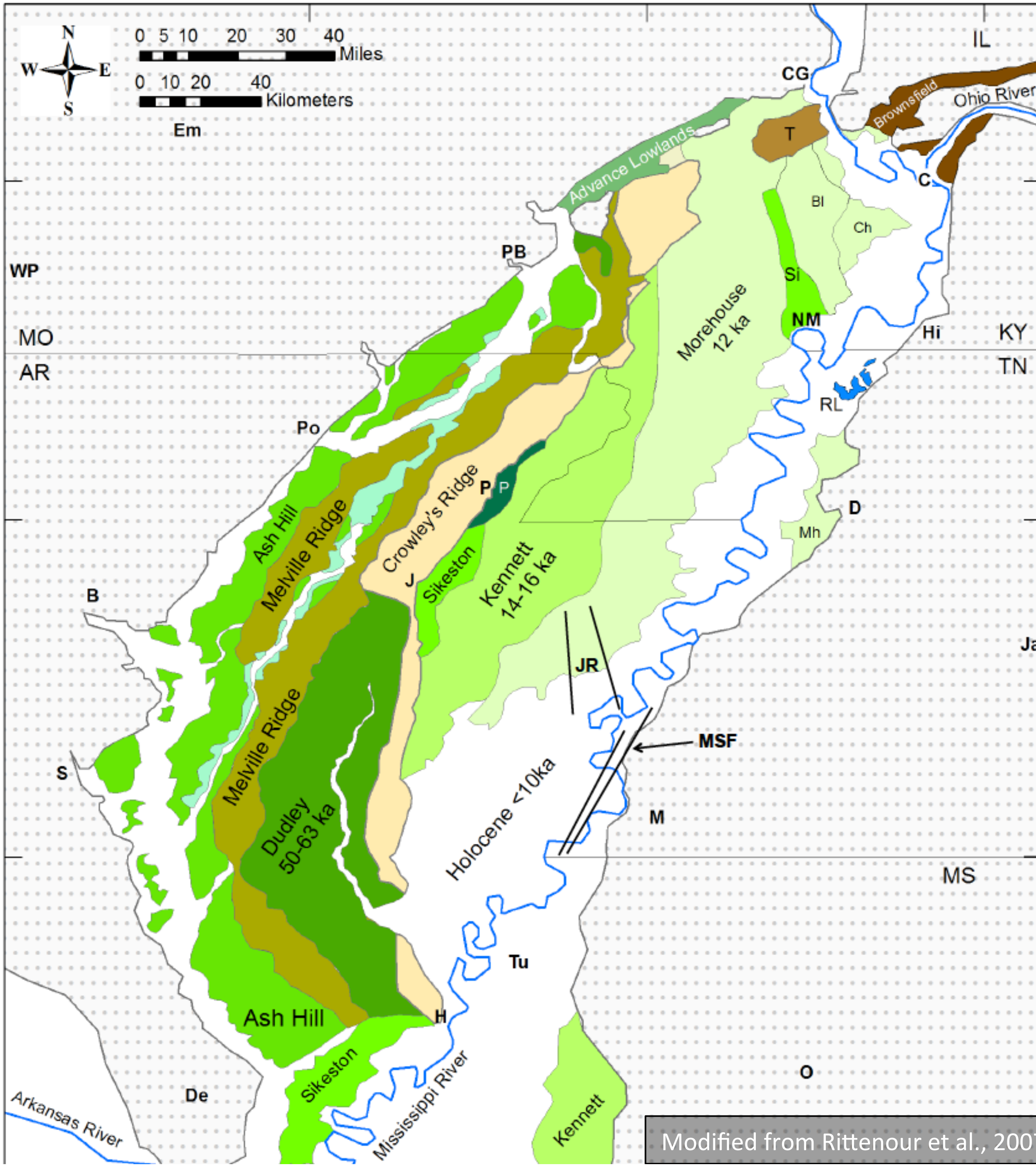
Seismicity of the New Madrid Seismic Zone and Reelfoot Rift

Characteristics:

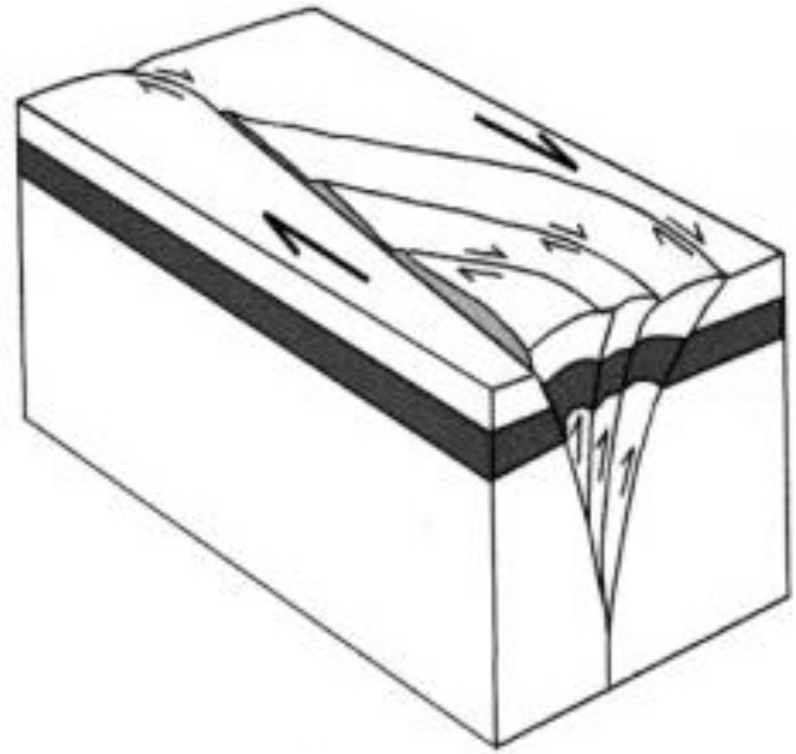
- Structural features covered by Mississippi River valley alluvium
- Non-steady state movement (GPS velocity in CEUS near zero)
- Epicentral patterns relatively diffuse
- Temporal and spatial clustering of large mag earthquakes

Big picture question:

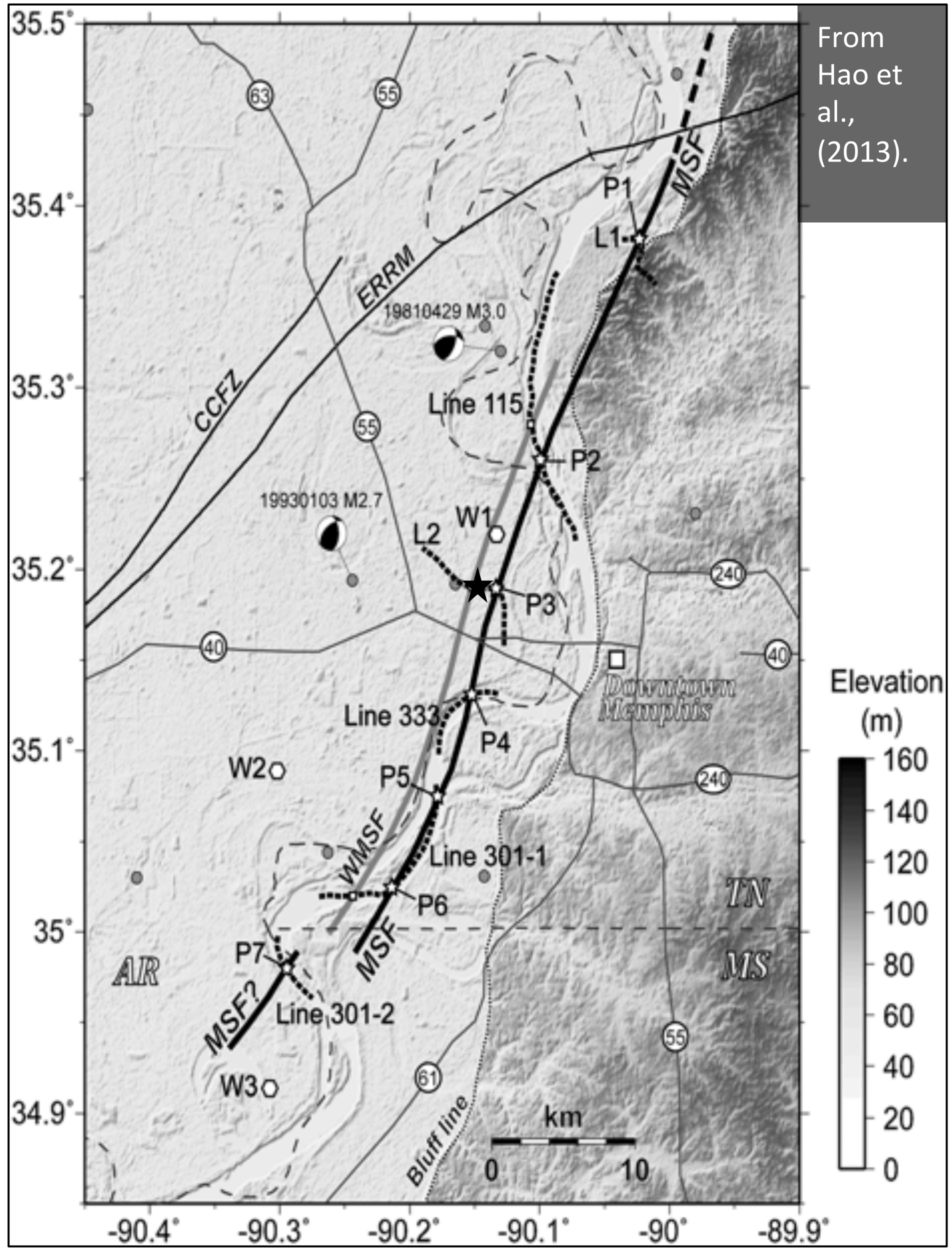
How do we better constrain temporal and spatial patterns of faulting when faults are rarely evident at the surface?



Modified from Rittenour et al., 2007

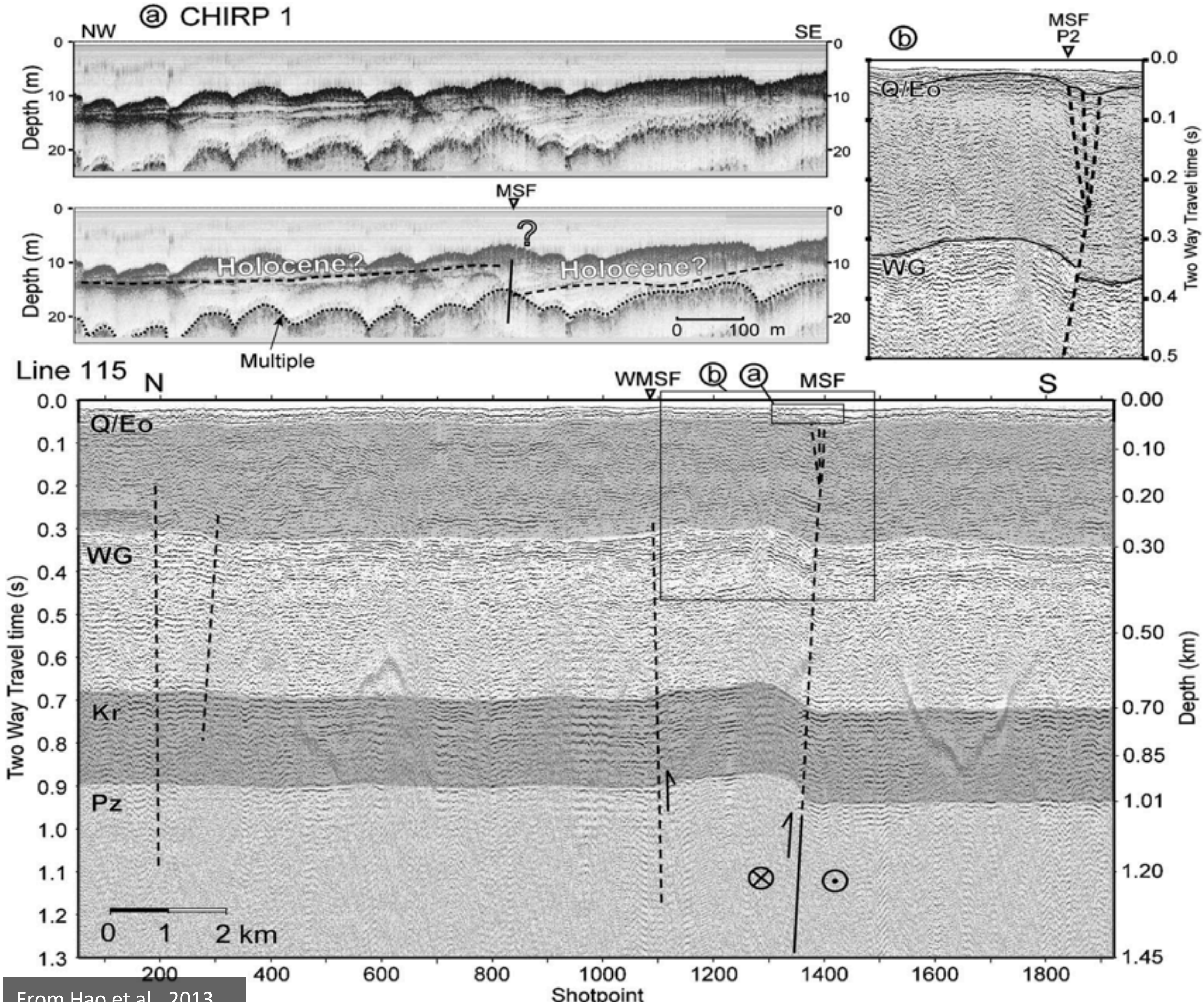


The Meeman-Shelby fault

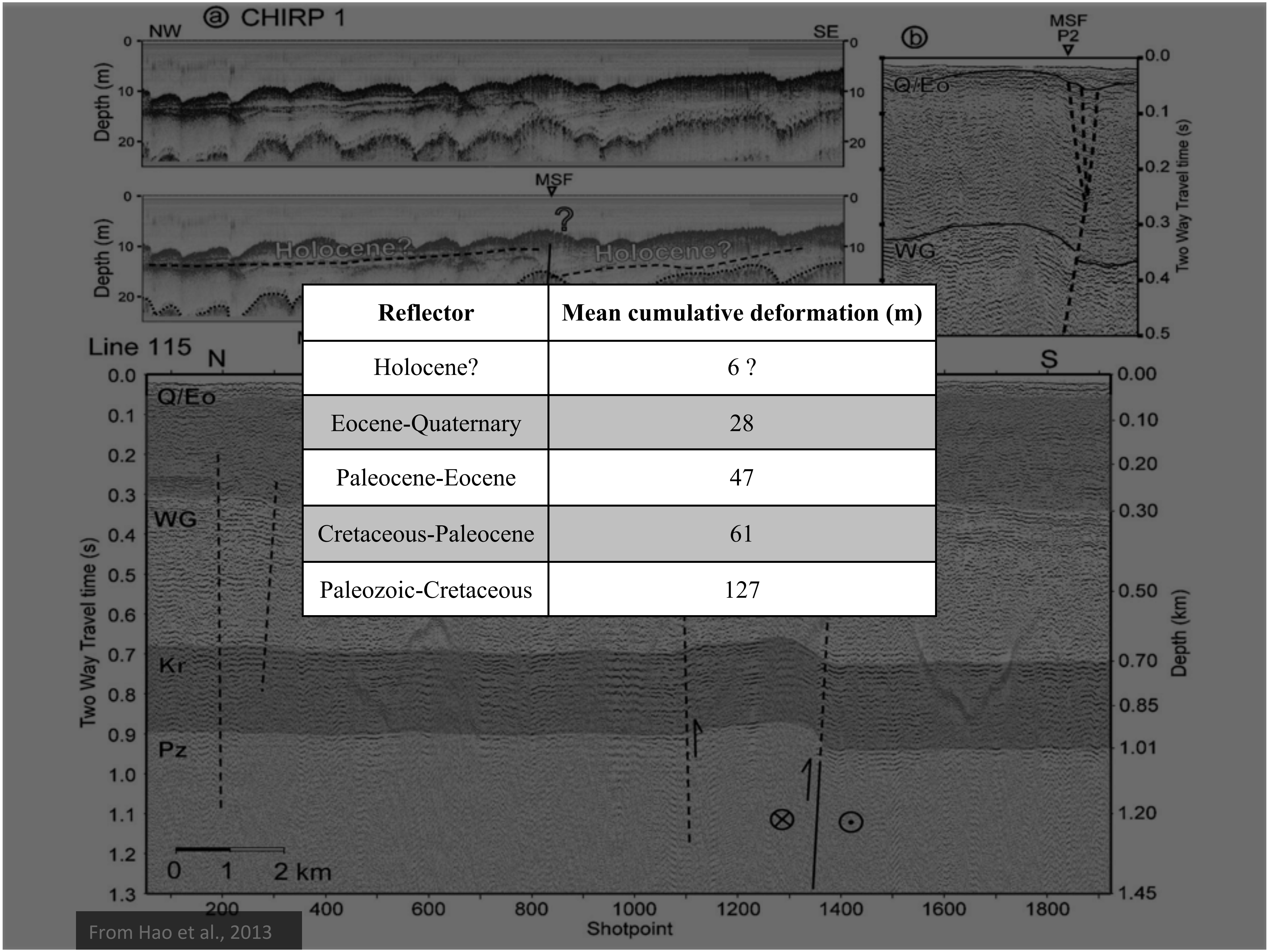


From Hao et al., (2013).

- Low recent seismicity
- Minimum of 10 km from downtown Memphis
- Strike: N25°E for 45 km
- Dip: 83° NW
- Interpreted as positive flower structure



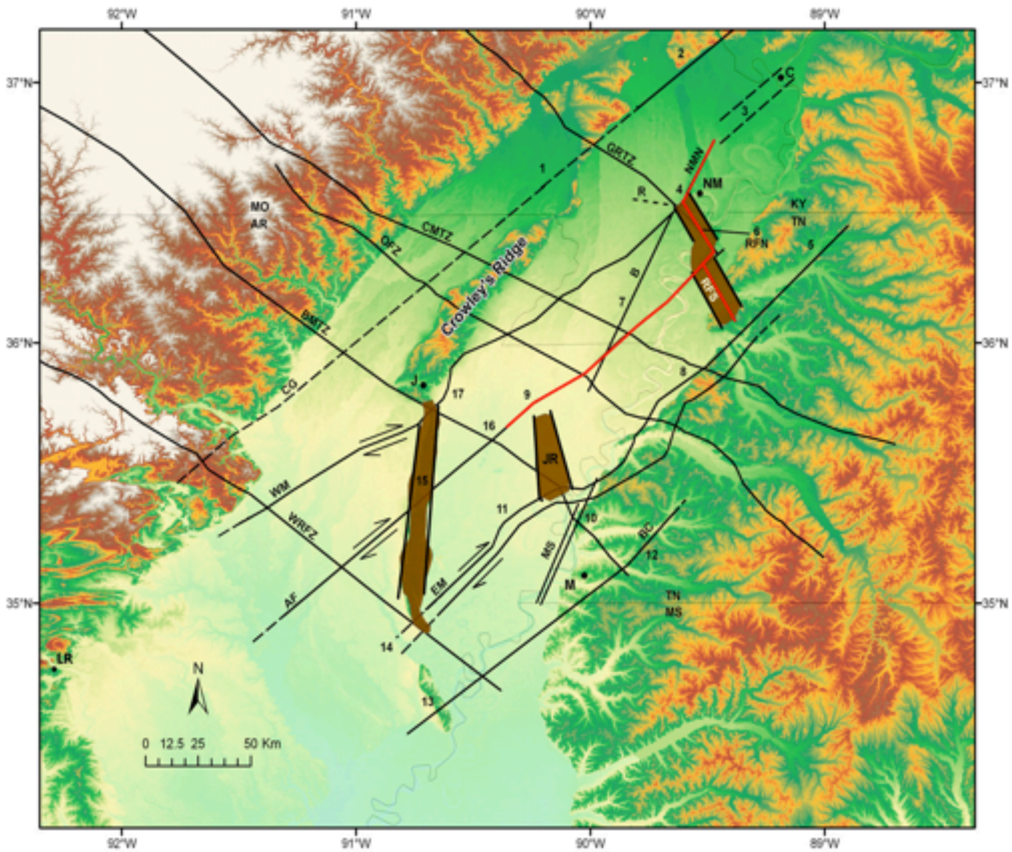
From Hao et al., 2013



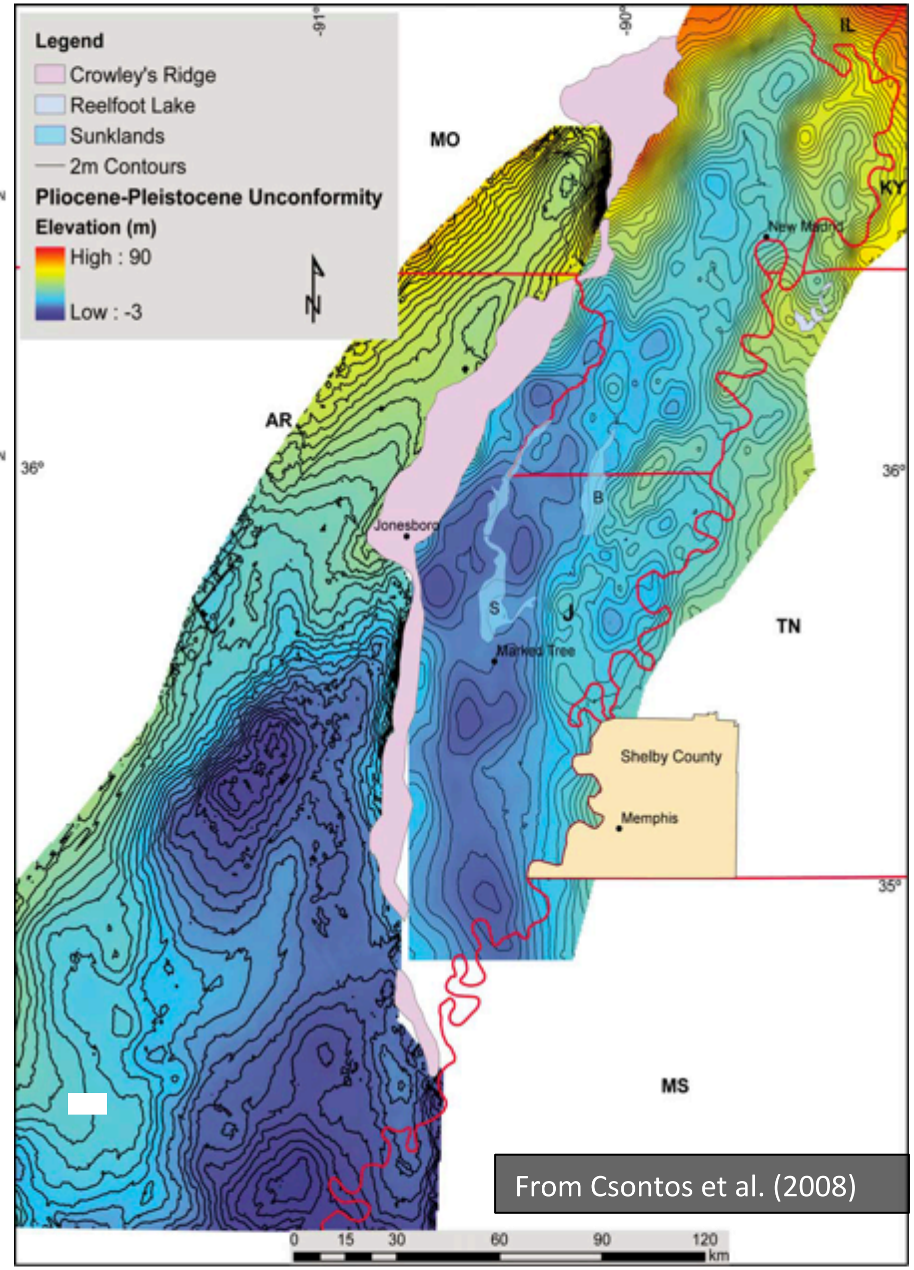
Reflector	Mean cumulative deformation (m)
Holocene?	6 ?
Eocene-Quaternary	28
Paleocene-Eocene	47
Cretaceous-Paleocene	61
Paleozoic-Cretaceous	127

From Hao et al., 2013

Joiner Ridge horst



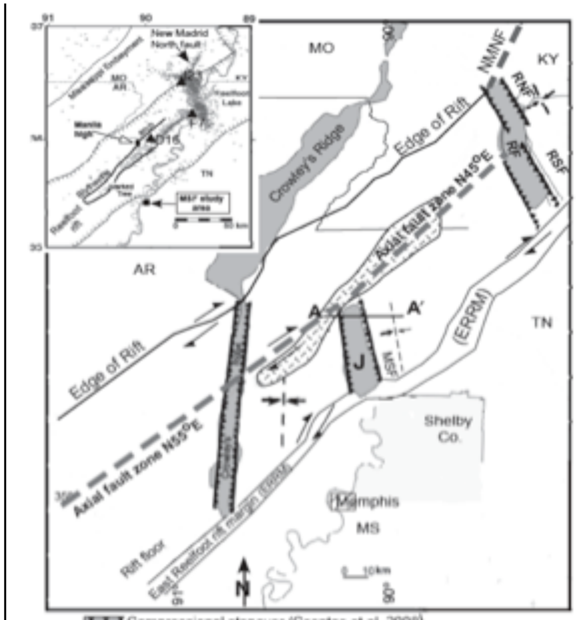
- Compressional stepover horst
- Minimum distance of 50 km from downtown Memphis
- Trends N13°W w/ steep bounding faults
- Approximately 50 km long by 10 to 15 km wide

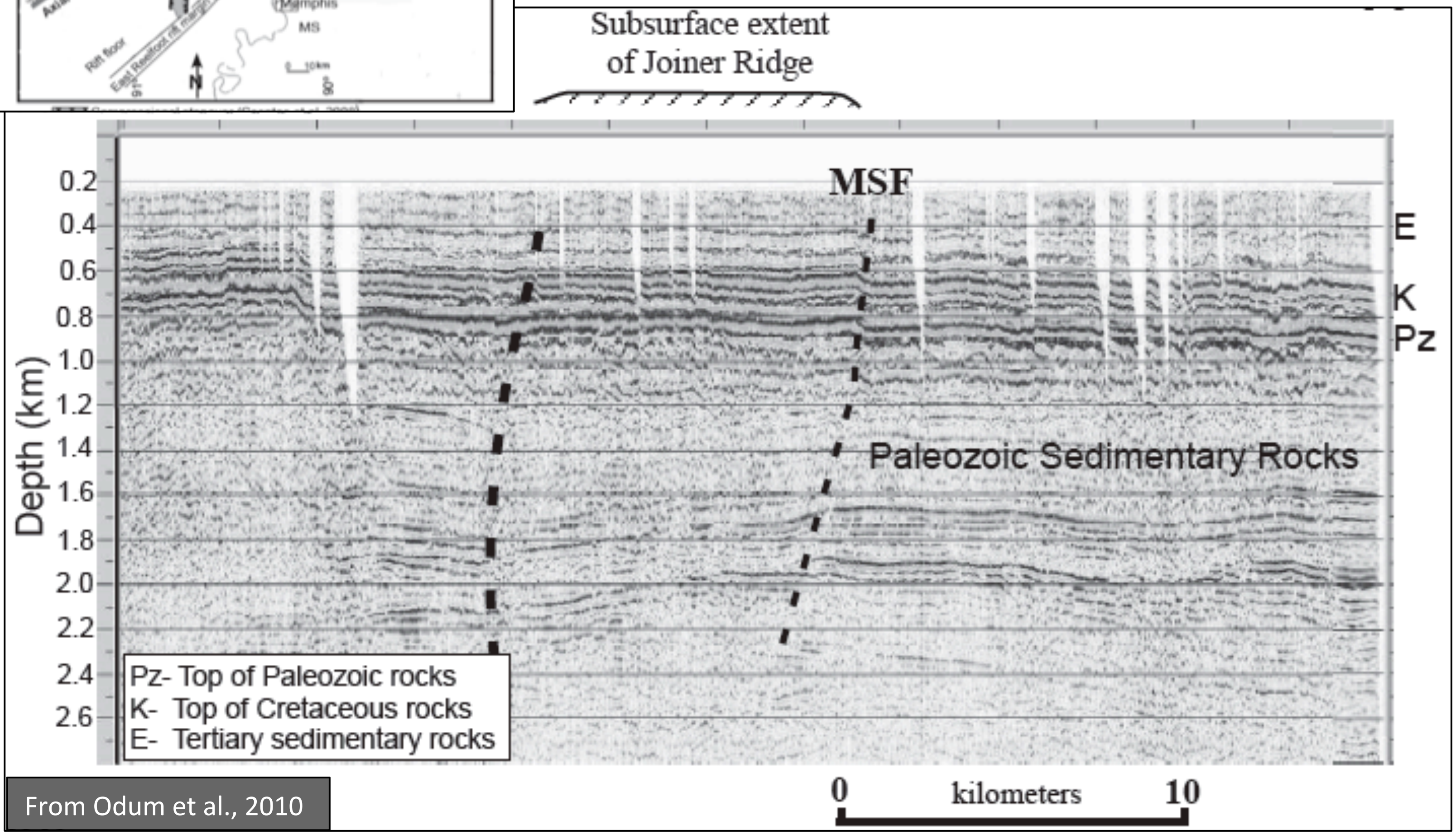


From Csontos et al. (2008)

Joiner Ridge horst

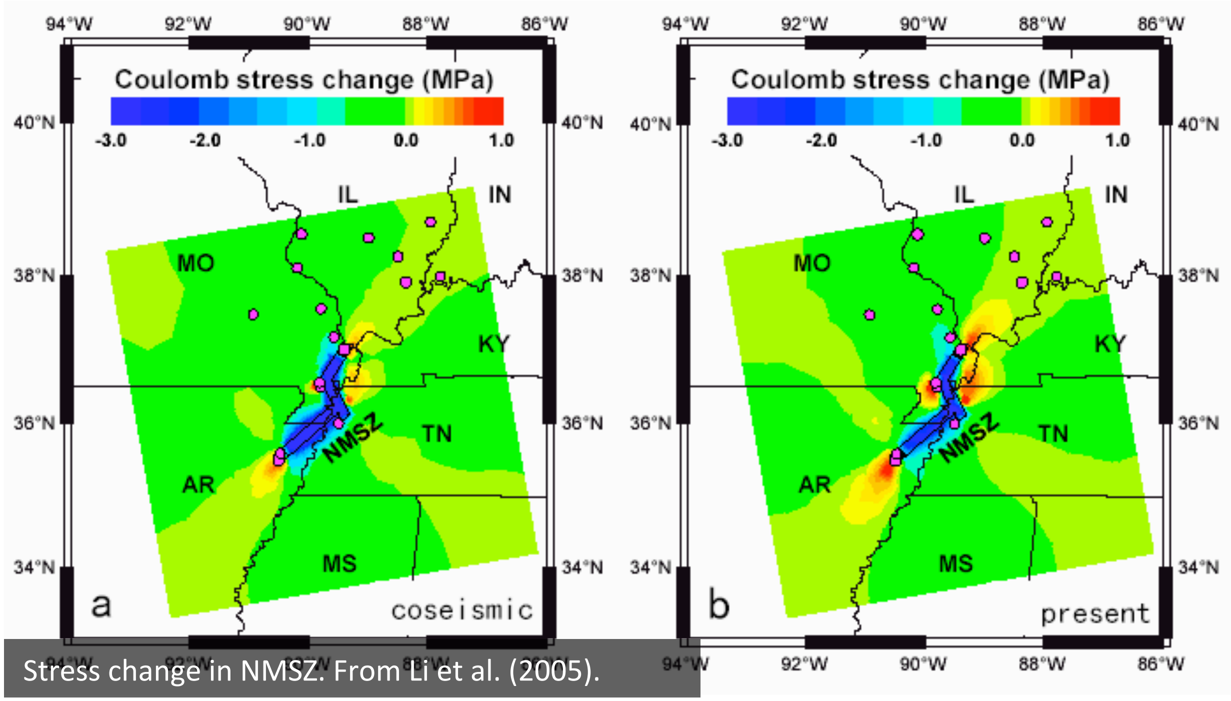
Reflector	Mean vertical deformation (m)
Eocene/ Quaternary	15 - 20
Cretaceous/ Paleocene	40
Paleozoic/ Cretaceous	55





From Odum et al., 2010

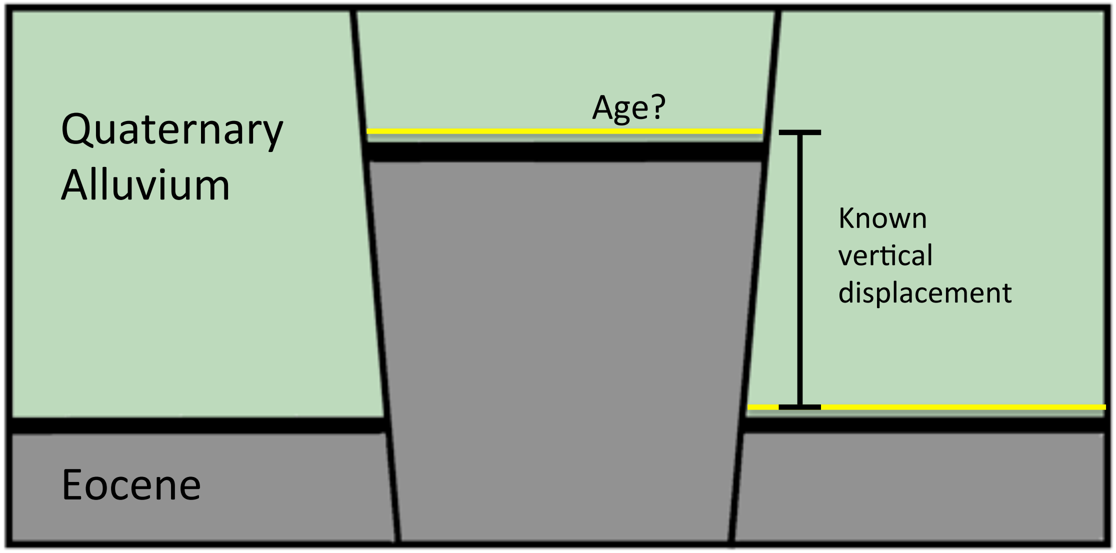
Significance



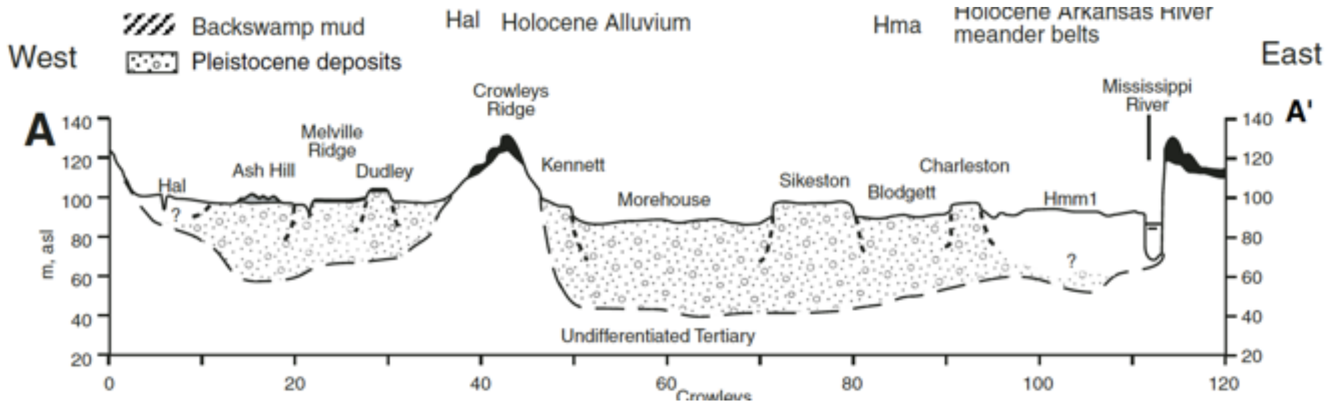
Stress change in NMSZ. From Li et al. (2005).

- Recent seismicity is not indicative of long term seismicity because earthquakes are clustered and migrate
- MSF has the potential to generate a M 6.9 earthquake based on empirical fault length relationships
- Increased stress in eastern Arkansas since 1811-1812 events

Problem



- Meeman-Shelby fault and Joiner Ridge displace subsurface alluvium at Eocene-Quaternary disconformity
- Vertical displacement amount known, but age of displaced subsurface alluvium unknown
- Assuming basal alluvial strata are continuous across fault trace, age of basal alluvium allows for vertical slip rate calculation



From Rittenour et al. (2007)

Hypothesis

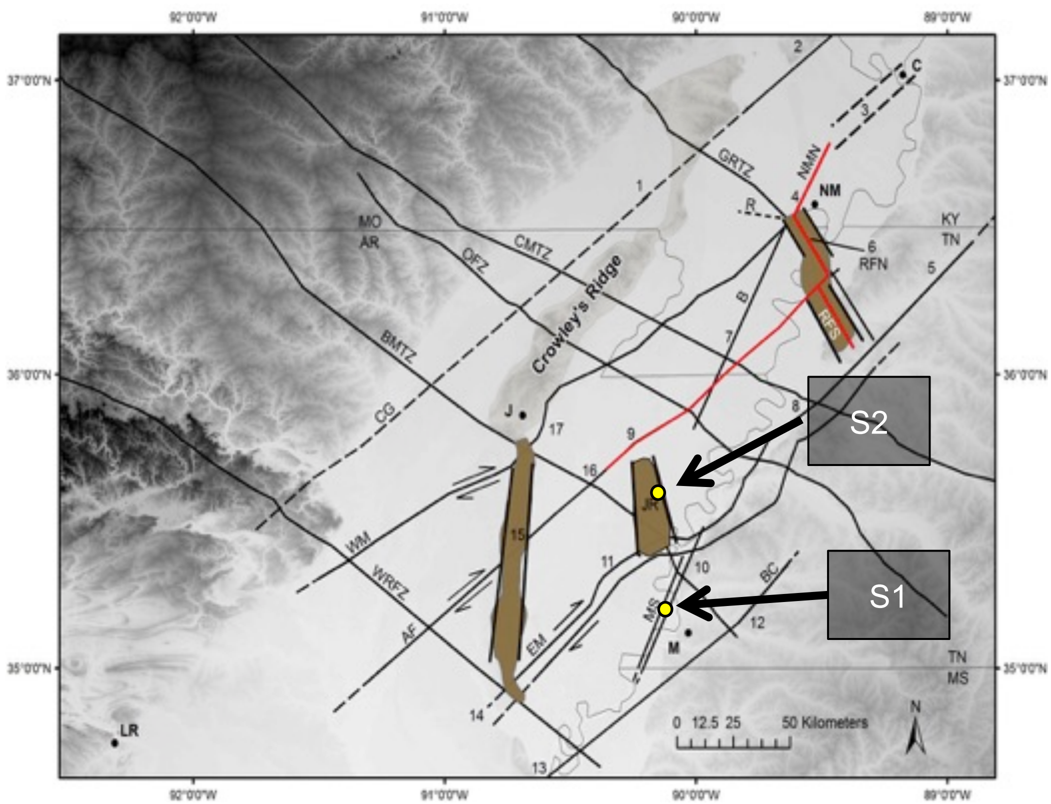
- Mississippi River alluvium is approximately the same age from the surface to the Eocene-Quaternary disconformity

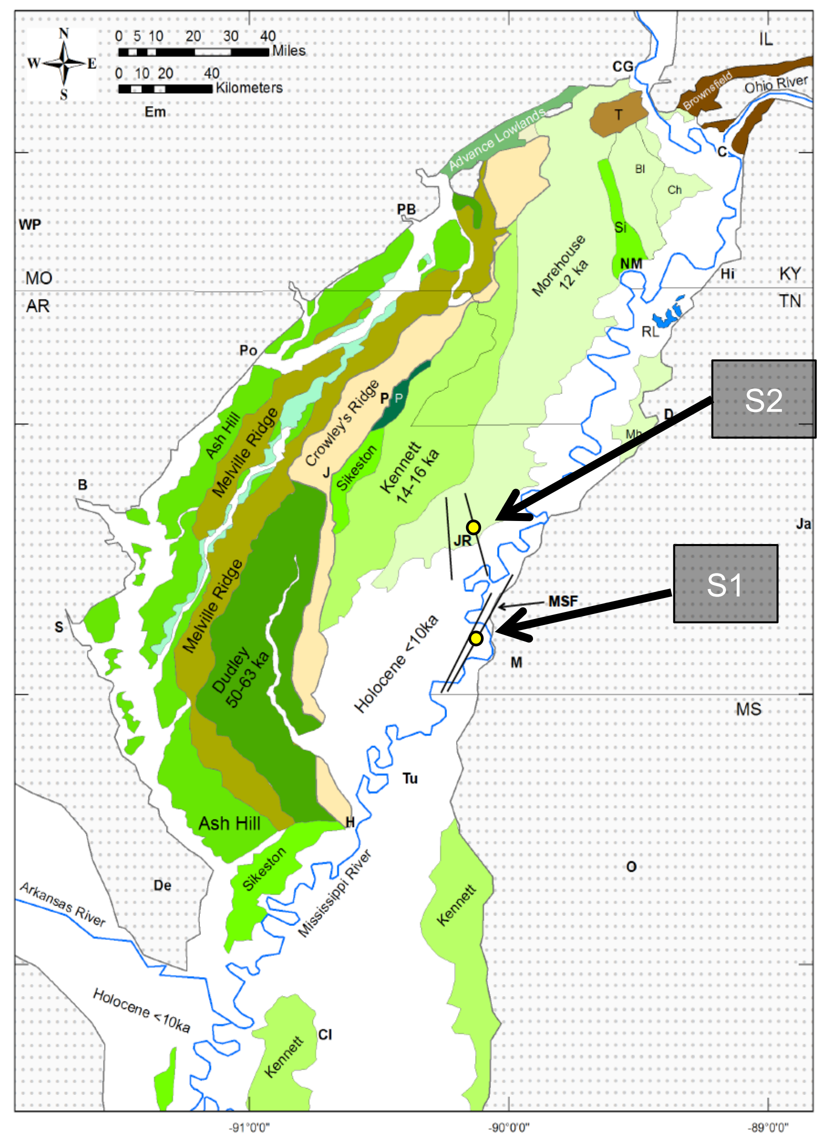
Testing the hypothesis:

- Utilize continuous core drilling to obtain sediment cores of entire thickness of Mississippi River alluvium

- Obtain OSL dates of basal alluvium

Site selection



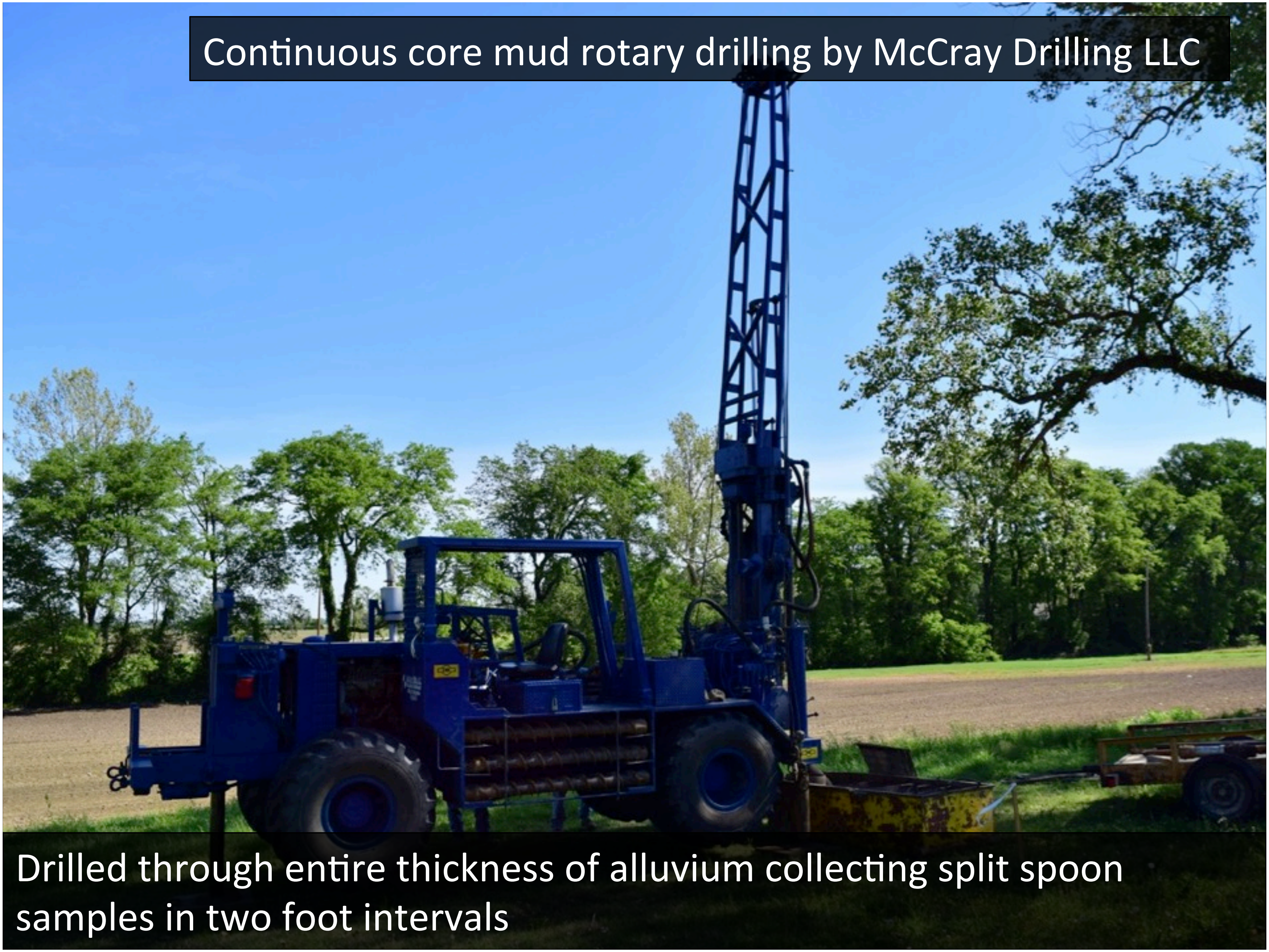


Site	Structure	Surface elevation (m)	Latitude	Longitude	Thickness of alluvium	Age of surface alluvium
S1	MSF	65.53	35.19032806	-90.12998141	45 meters	~10 ka
S2	Joiner Ridge horst	69.5	35.61070792	-90.14998943	40 meters	~12 ka

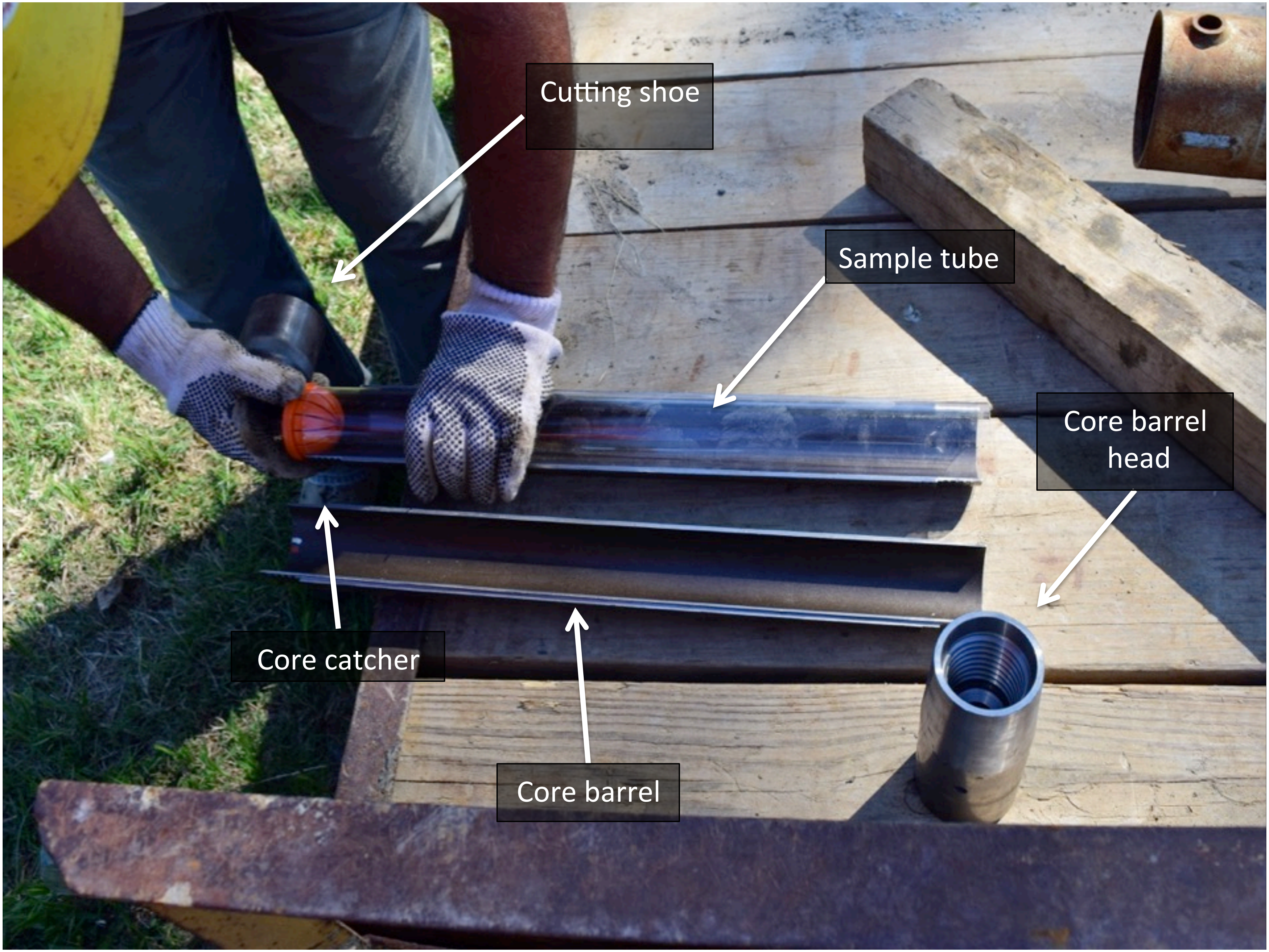

Meeman-Shelby fault site
Credit: Ronald Counts


Joiner Ridge horst site

Continuous core mud rotary drilling by McCray Drilling LLC



Drilled through entire thickness of alluvium collecting split spoon samples in two foot intervals


Cutting shoe
Sample tube
Core barrel head
Core catcher
Core barrel


Mobile dark lab
Utilized mobile dark lab to preserve OSL samples


Mobile dark lab
Utilized mobile dark lab to preserve OSL samples


Mobile dark lab
Split sample tubes in mobile dark lab to produce an OSL-split and physical core description split

Photography tent

Photography tent to obtain images of split core samples upon recovery


Scotch


OSL
130ft
OSL
OSL

Data collection

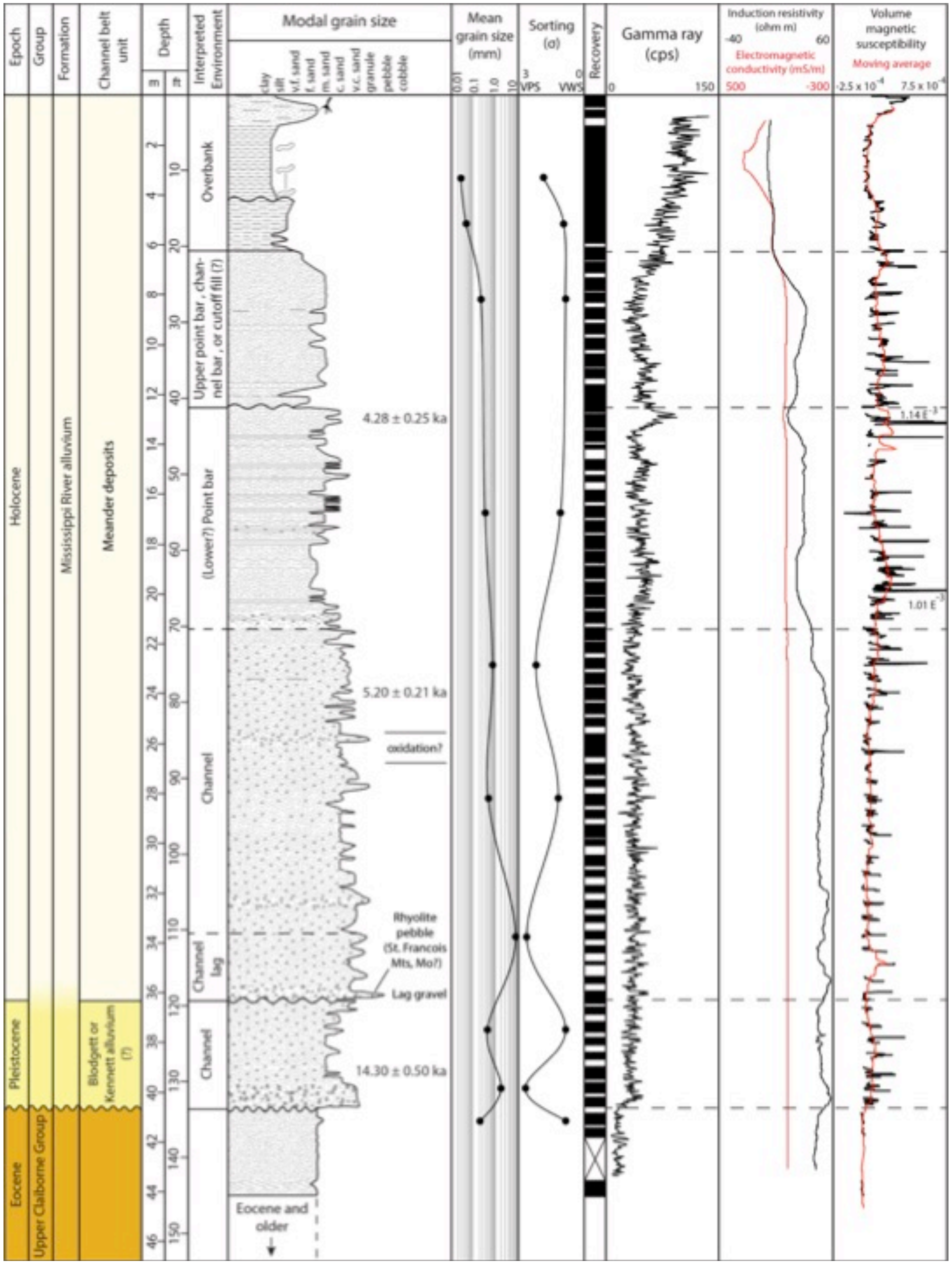
- Physical core descriptions
- Grain size analyses
- Volume magnetic susceptibility logging at the Kentucky Geological Survey
- Geophysical logging by USGS Water Science Center
  - Natural gamma ray
  - Induction resistivity
  - Electromagnetic conductivity
- Radiocarbon dating of calcite vein in Joiner Ridge core at Beta Analytic in Miami, Florida
- Optically Stimulated Luminescence (OSL) dating at USGS Luminescence Lab in Denver, Colorado

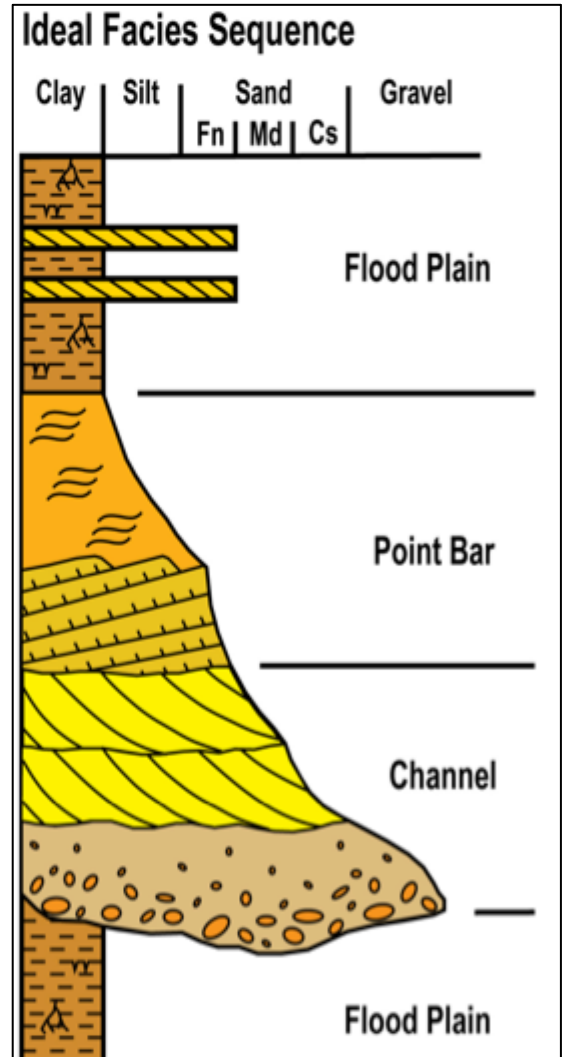
Drilling and core recovery

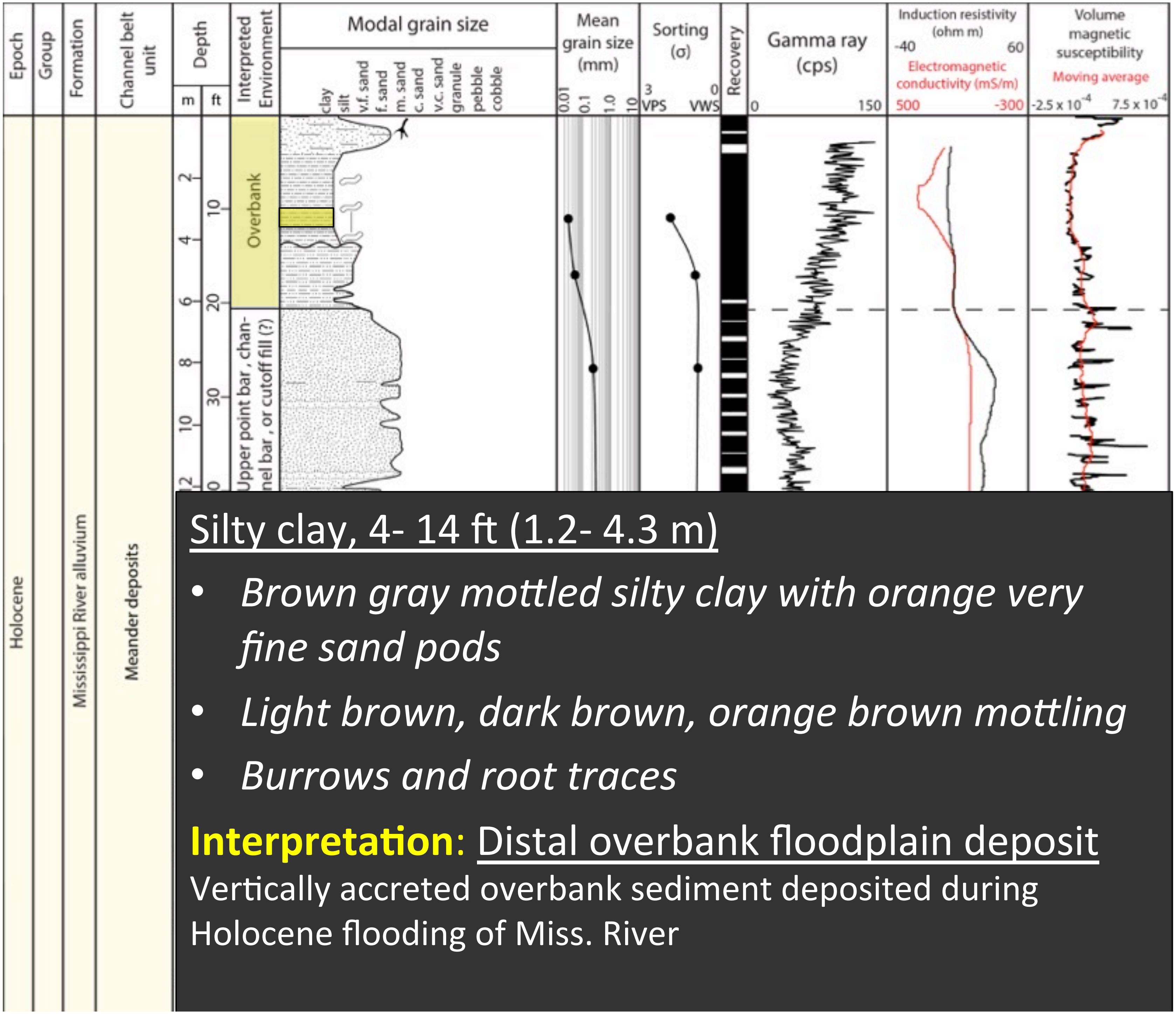
Site	Structure	Surface elevation		Bottom hole depth (elev. ASL)		Q-Eo disconformity depth (elev. ASL)	
		ft	m	ft	m	ft	m
S1	MSF	215.0	65.5	144.8 (70.2)	44.1 (21.4)	133.5 (81.5)	40.7 (24.8)
S2	Joiner Ridge horst	228.0	69.5	132.1 (95.9)	40.3 (29.2)	116.7 (111.32)	35.6 (33.9)

Site	Total Core Recovery (%)	Quaternary alluvium		Eocene sediment recovery (%)
		Silty clay to vf sand recovery (%)	Sand and gravel recovery (%)	
S1	65.2	80.5	62.2	69.9 *medium sand*
S2	76.1	88.5	69.8	85.1 *lignitic coarse silt*

Meeman-Shelby fault core stratigraphy





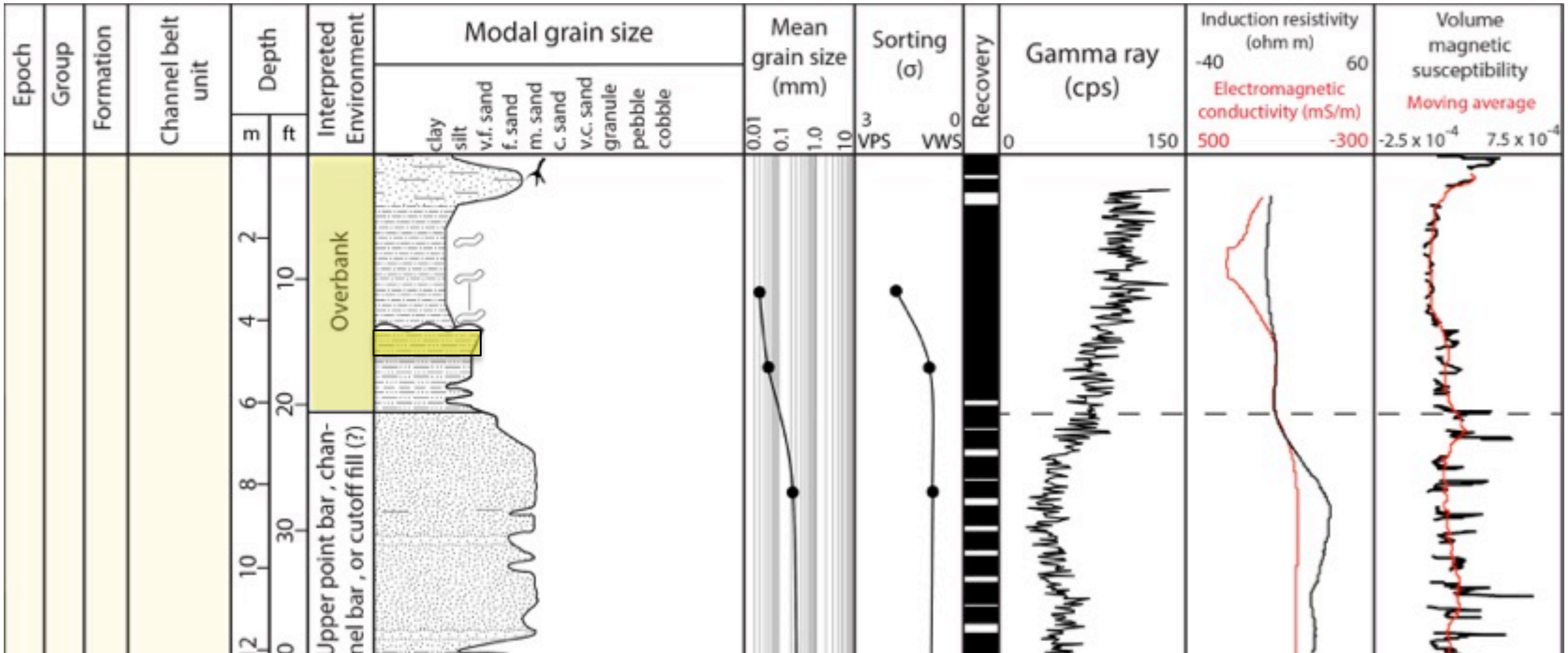


<u>Silty clay, 4- 14 ft (1.2- 4.3 m)</u>

- *Brown gray mottled silty clay with orange very fine sand pods*
- *Light brown, dark brown, orange brown mottling*
- *Burrows and root traces*

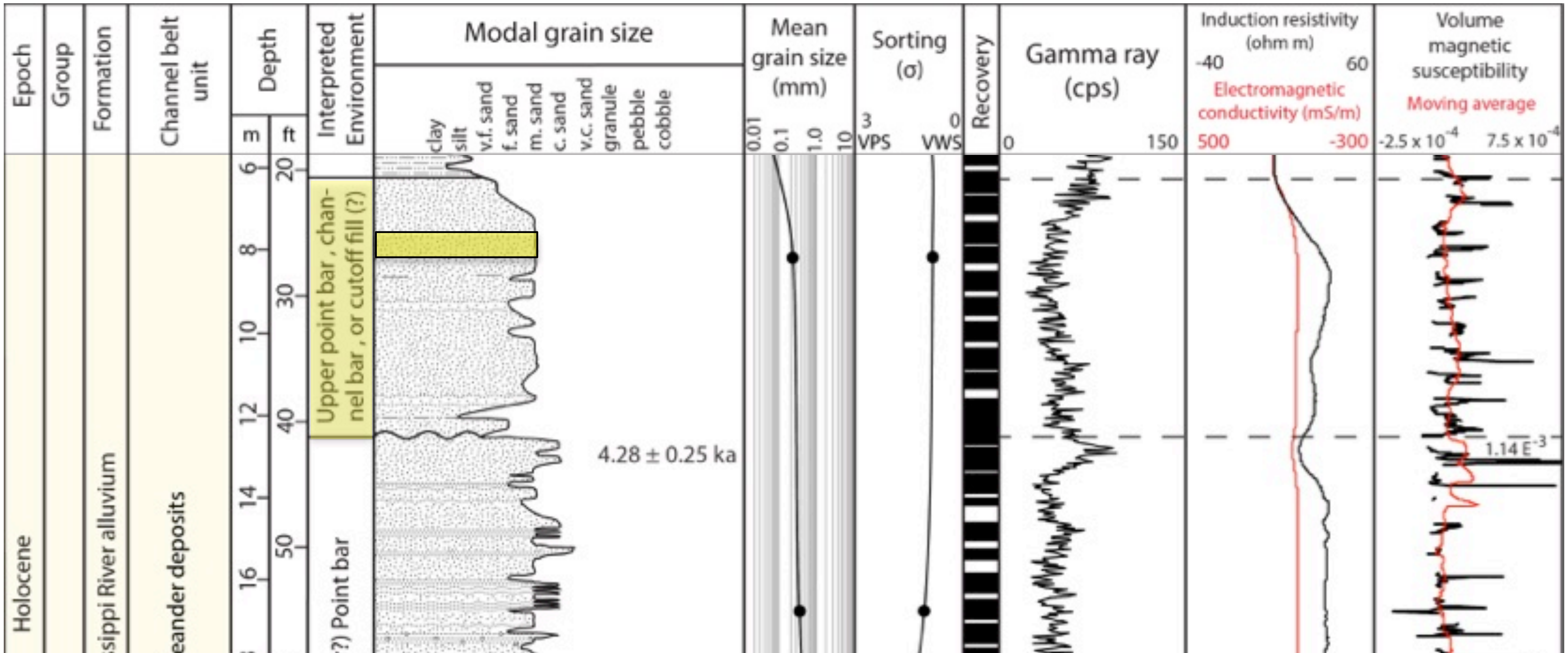
Interpretation: <u>Distal overbank floodplain deposit</u>

Vertically accreted overbank sediment deposited during Holocene flooding of Miss. River



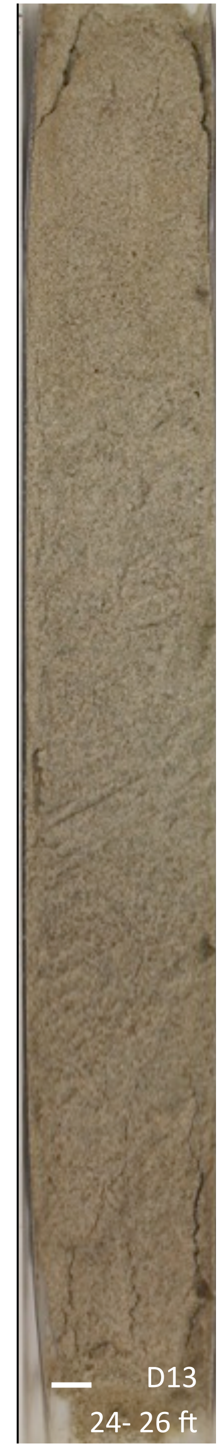
Silt to very fine sand, 14- 21 ft (4.3- 6.4 m)

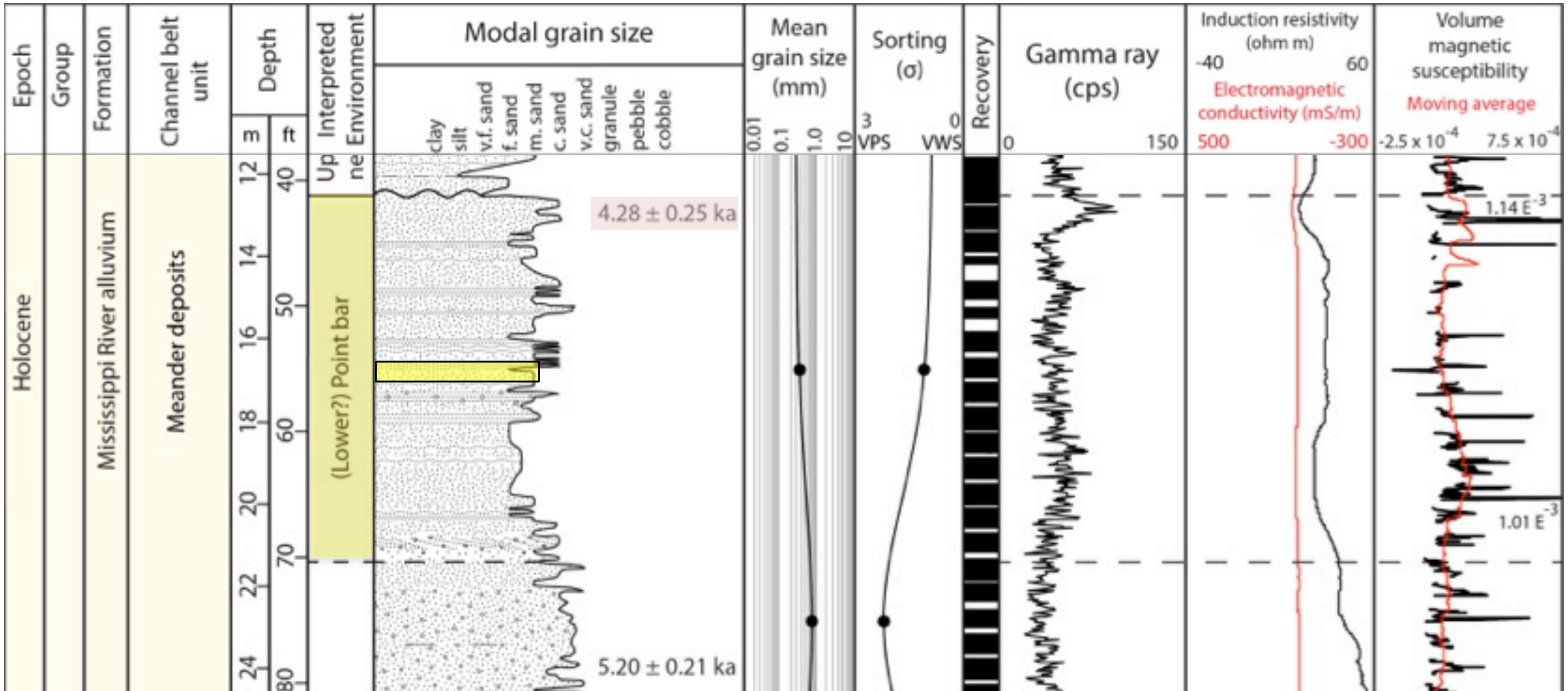
- *Brown to gray brown quartz, chert, muscovite silt to sand with orange brown mottles*
- *Easily liquefies when shaken and exhibits bright sheen upon recovery*
- *Grain size fines toward base of unit*
- *Abrupt planar contact with underlying unit*

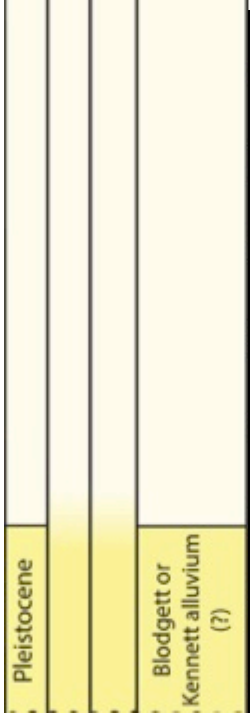


Fine to medium sand, 21- 41 ft (6.4- 12.5 m)

- *Fine to medium quartz and chert sand with some muscovite*
- *Moderately to well sorted*
- *Some cross and parallel laminations, especially toward base*
- *Sparse allochthonous lignite in sand beds/ lamination*

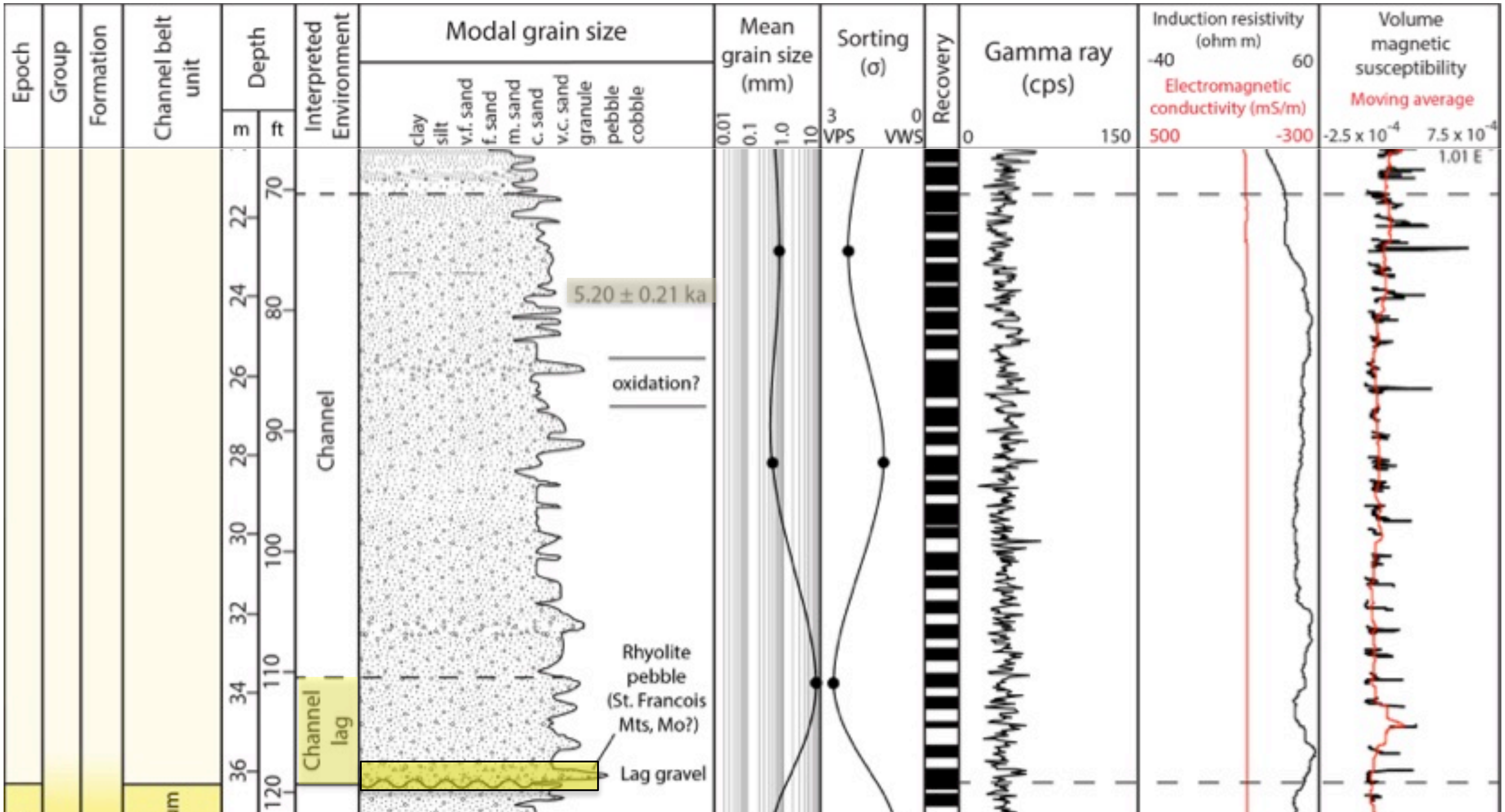


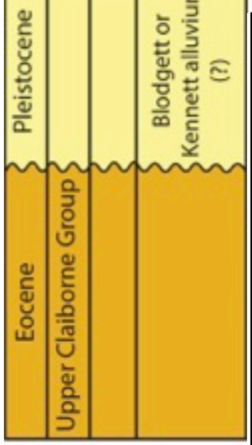




Medium to coarse sand, 41-68.5 ft (12.5- 20.9m)

- *Light brownish gray to dark brownish gray quartz and chert sand*
- *Abundant parallel and cross laminations, occasionally deformed*
- *Variable grain size, but generally increases with depth, fine interval from 59-65 ft*

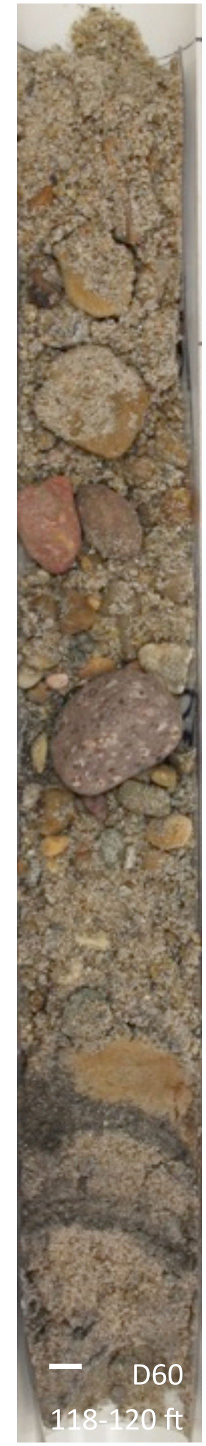


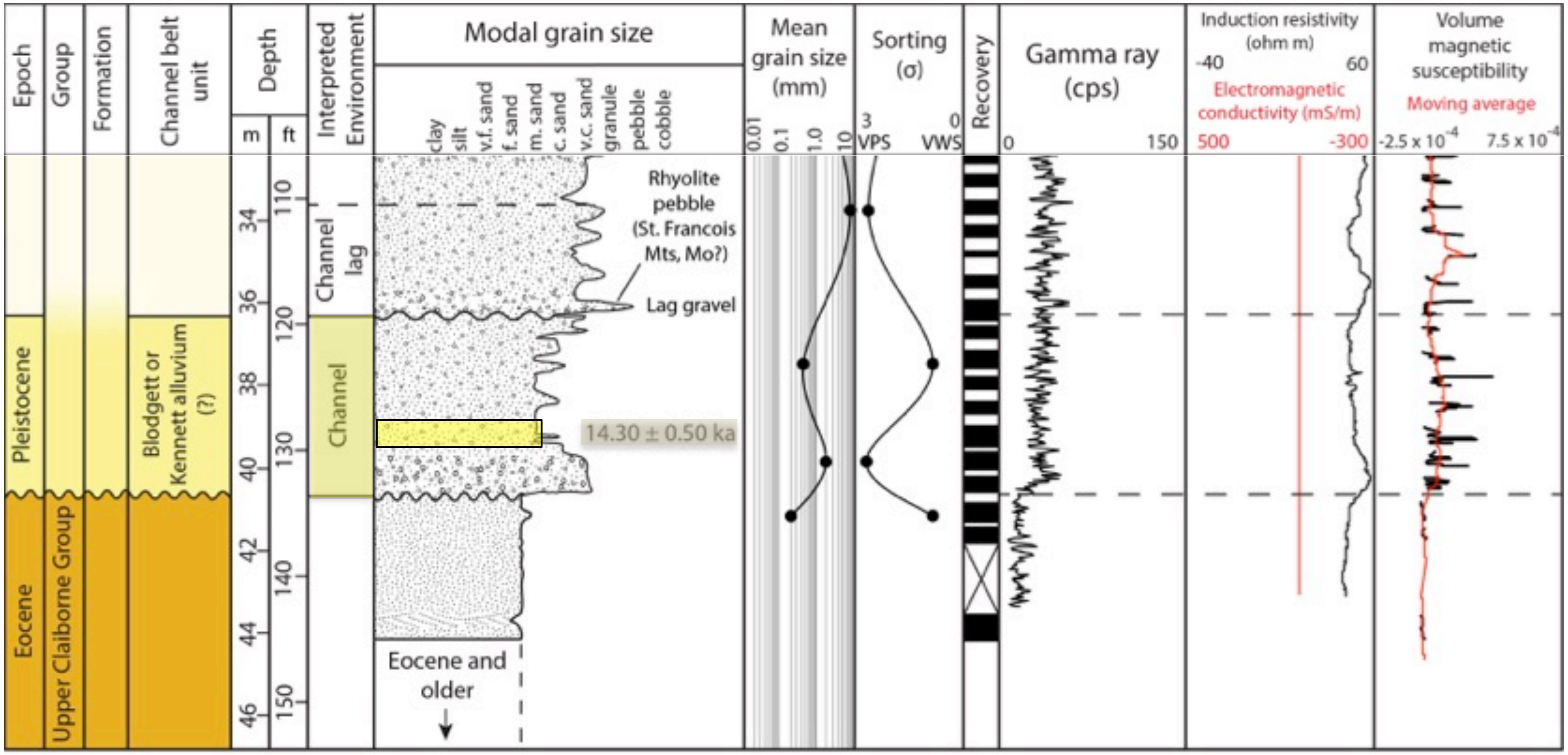


Medium to very coarse sand and gravel, 68.5-119 ft (20.9- 36.3 m)

Interpretation: Channel deposits of the Holocene Mississippi River with basal lag

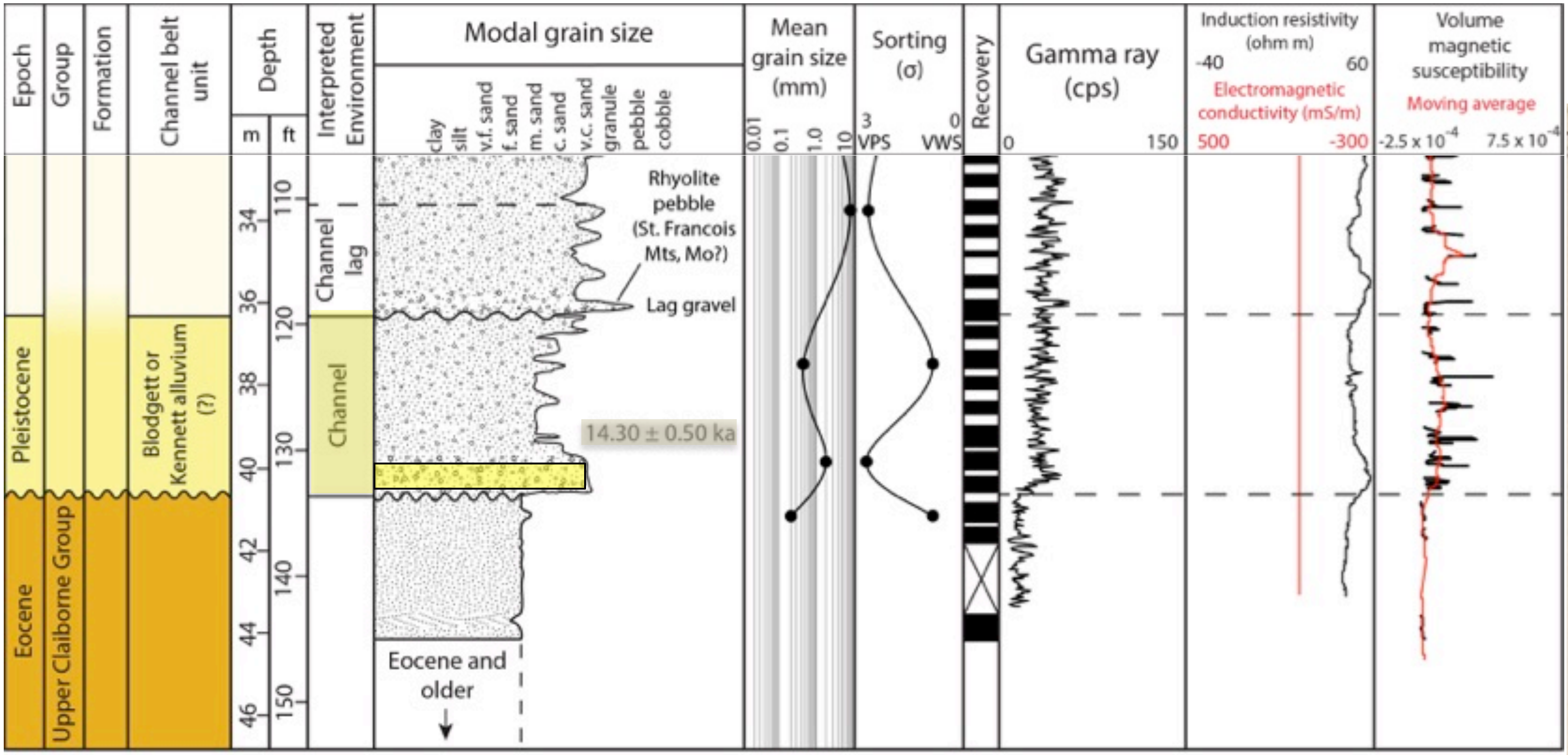
- Winnowing of fines represents channel lag and maximum flow energy/ transport capacity
- Rhyolite pebble from St. Francois Mts, MO suggesting Miss. River deposition
- Very fine sand clast (lag gravel) from slumping at cut bank
- Abrupt contact is the erosional base of the meandering Mississippi River





Medium to coarse sand with basal gravel, 119- 133.5 ft (36.3-40.7 m)

- *Medium sand in upper portion of unit coarsening to very coarse sand and gravel at base*
- *Dark grayish brown to brown quartz and chert sand with primarily chert gravel*
- *Very poorly sorted at base of unit but moderately sorted at top*
- *Basal contact with Eocene sediment abrupt but not captured*

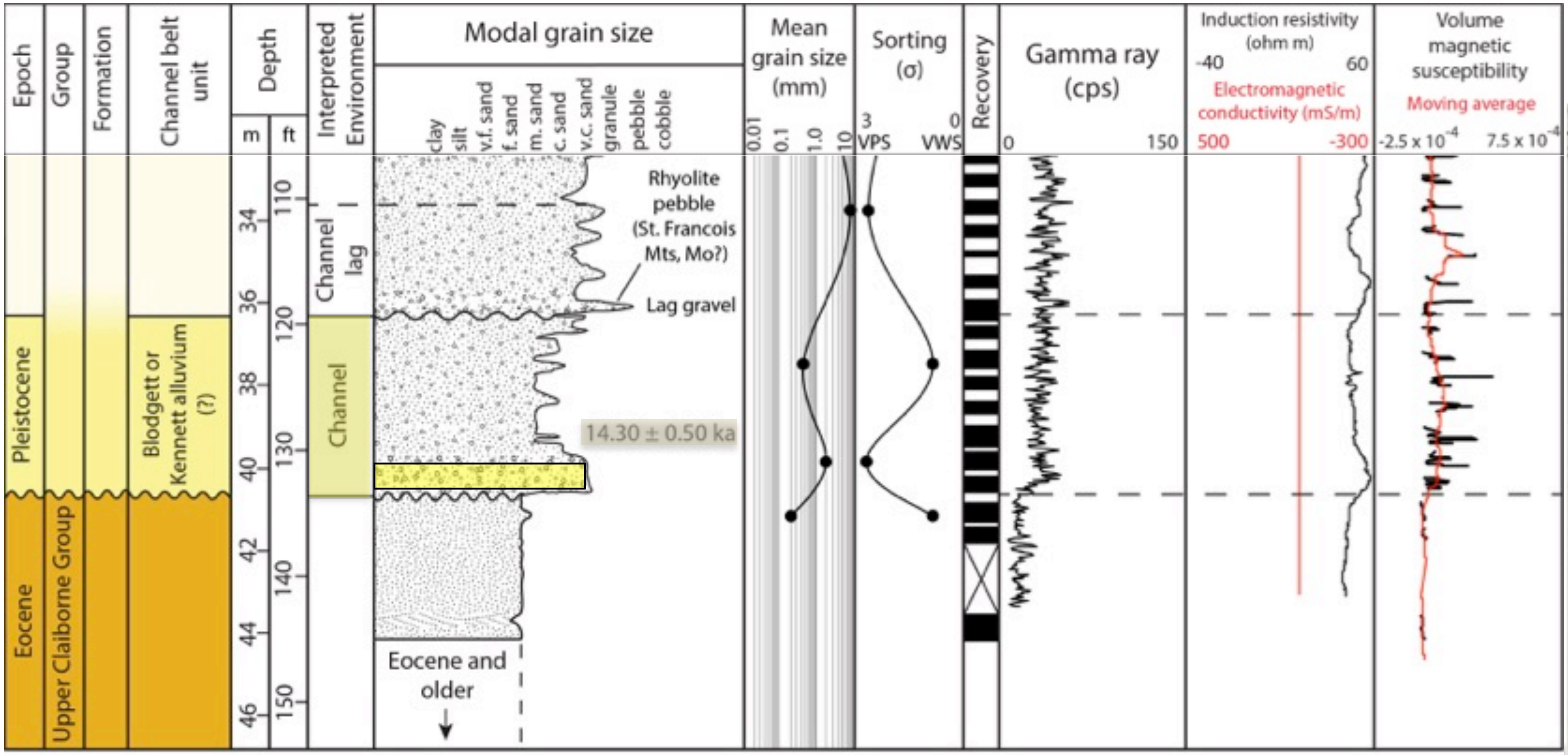


Medium to coarse sand with basal gravel, 119- 133.5 ft (36.3-40.7 m)

- *Medium sand in upper portion of unit coarsening to very coarse sand and gravel at base*
- *Dark grayish brown to brown quartz and chert sand with primarily chert gravel*
- *Very poorly sorted at base of unit but moderately sorted at top*
- *Basal contact with Eocene sediment abrupt but not captured*

D67

132- 134 ft



D67
132- 134 ft

Medium to coarse sand with basal gravel,

119- 133.5 ft (36.3- 40.7 m)

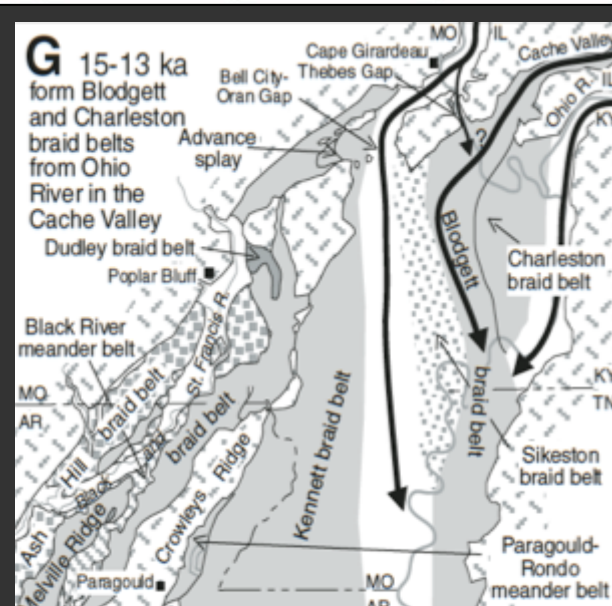
Interpretation: Pleistocene glacial outwash deposit beneath Holocene meandering river

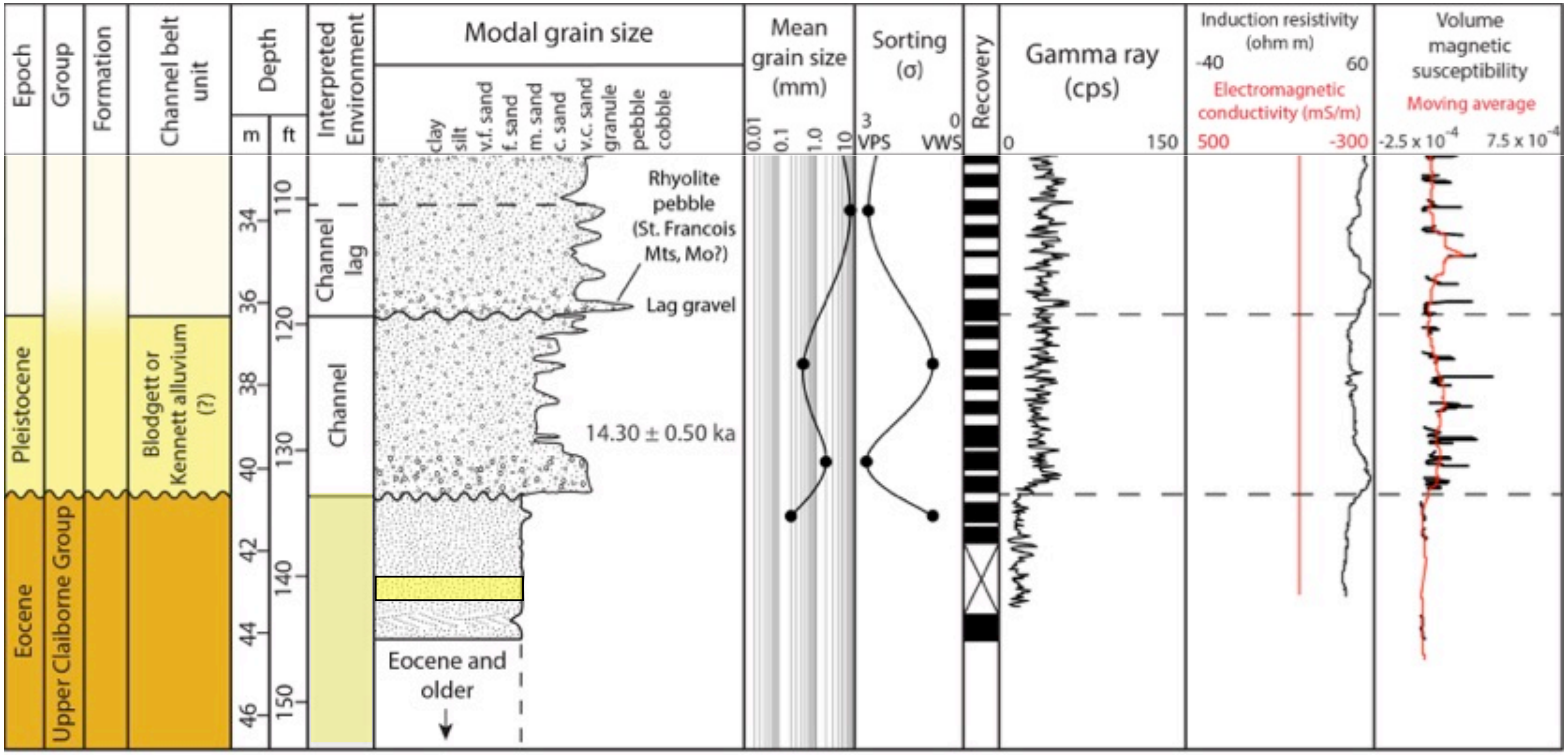
Age consistent with:

14.1- 14.9 ka Charleston (Miss R./Ohio R.)

14.4- 16.1 ka Kennett (Miss R.)

13.0- 13.6 ka Blodgett (Miss R./ Ohio R.)



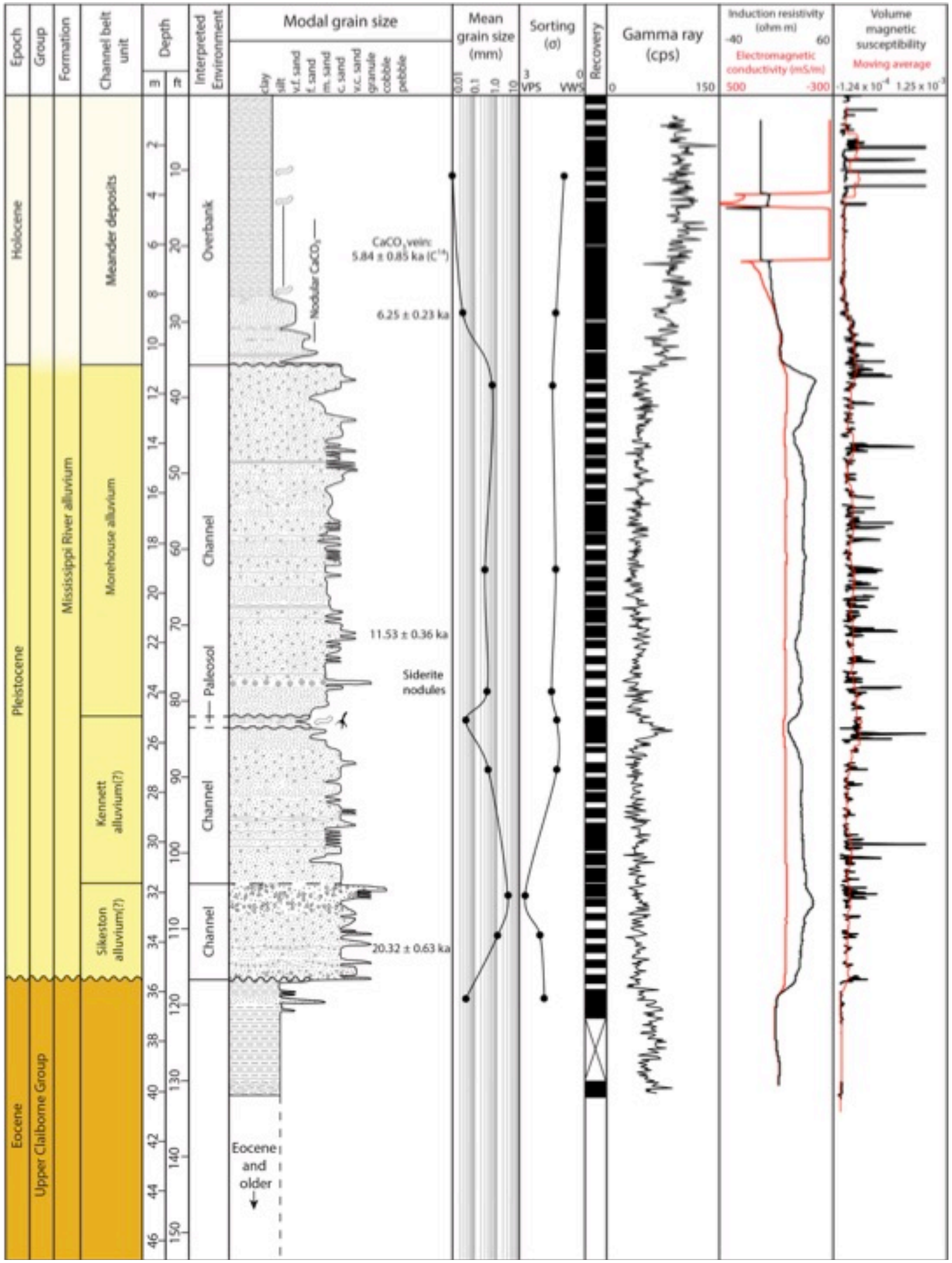


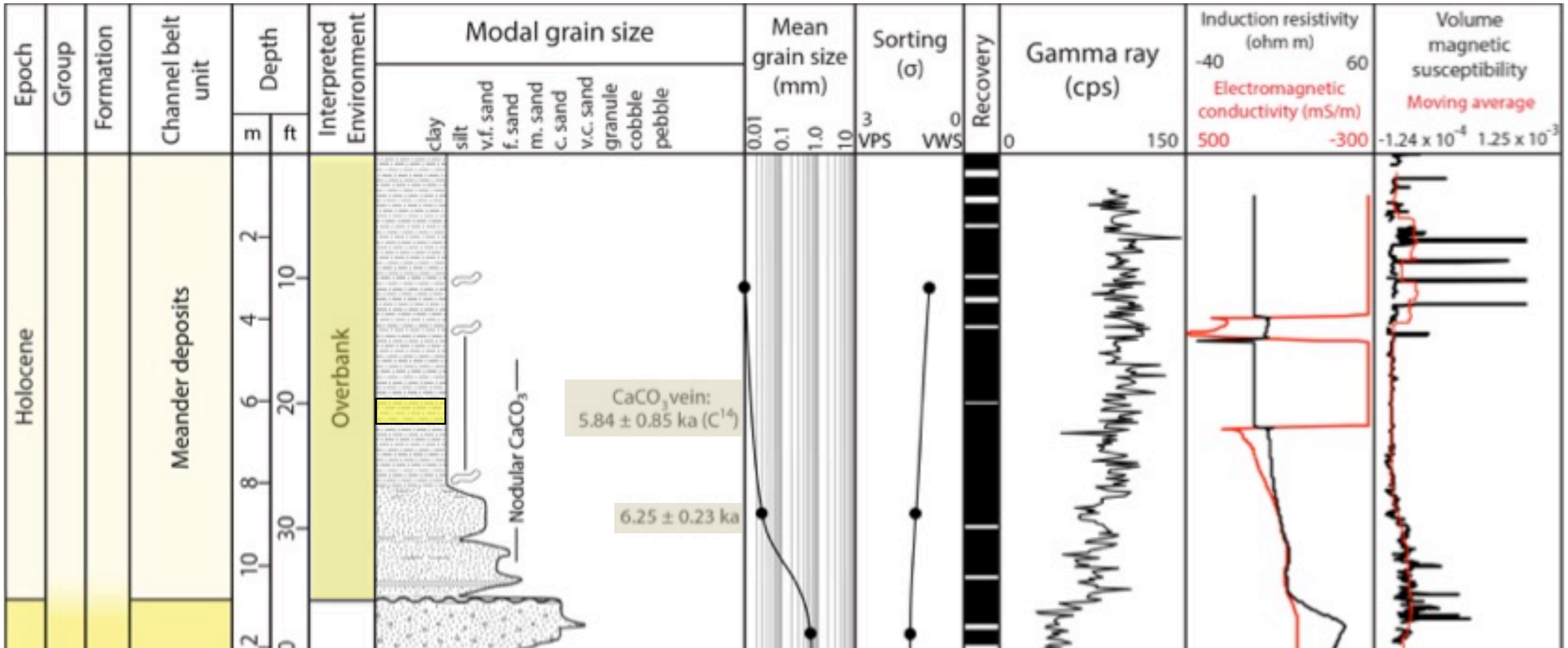
<u>Medium quartz sand, 133.5- 145 ft (40.69- 44.2 m)</u>

- *Moderately to well sorted subangular to subrounded sand*
- *Gray to light gray quartz sand with some clay rich cross beds*
- *Dominantly quartz (>90%) with trace chert*
- *Abrupt increase in blow count*

Interpretation: Eocene Upper Claiborne Group

Joiner Ridge horst core stratigraphy



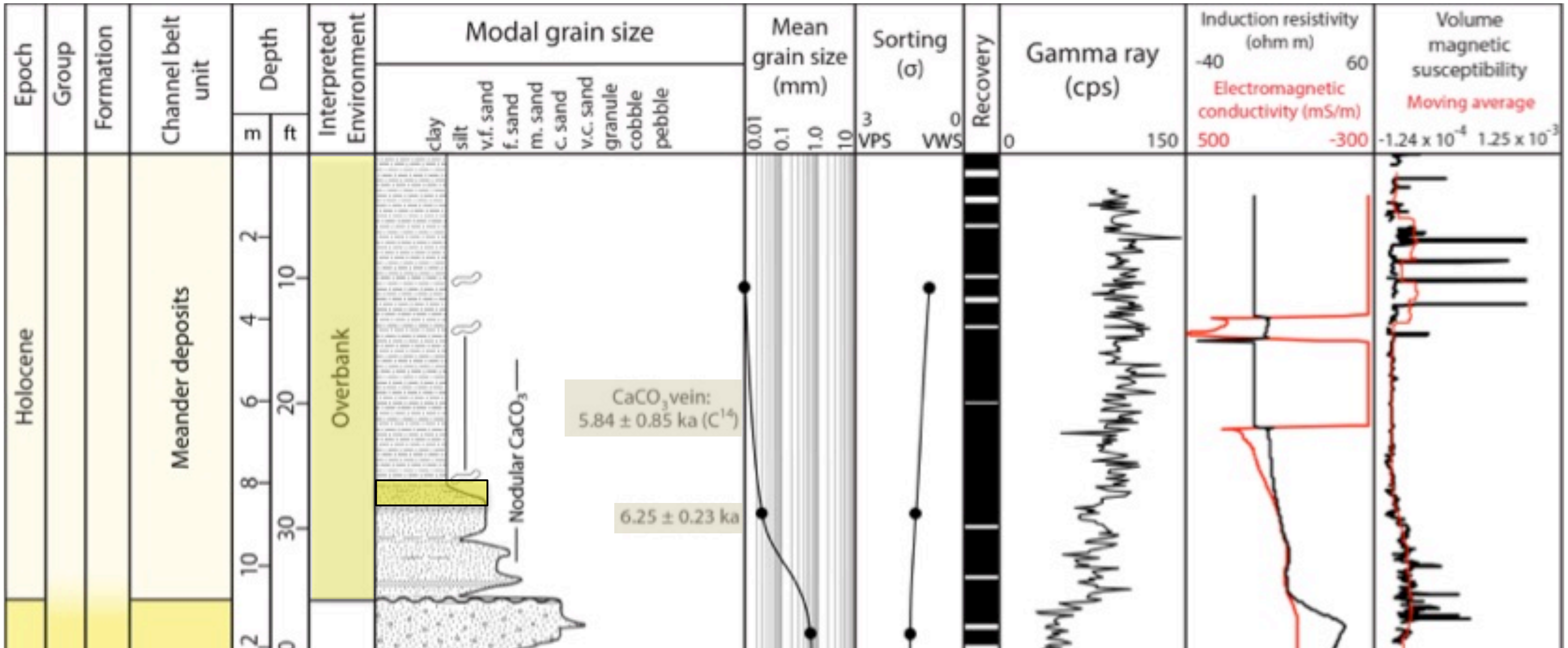


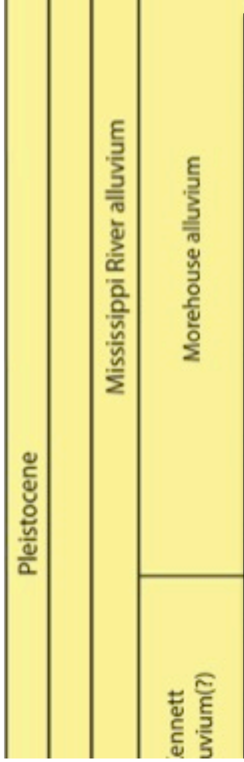
Silty clay, 4- 27 ft (0- 8.2 m)

- *Brown gray mottled silty clay with orange very fine sand pods*
- *Burrows and calcite nodules, vein at 21 ft*

Interpretation: Distal overbank floodplain deposit

Vertically accreted overbank sediment deposited during Holocene flooding of Miss. River

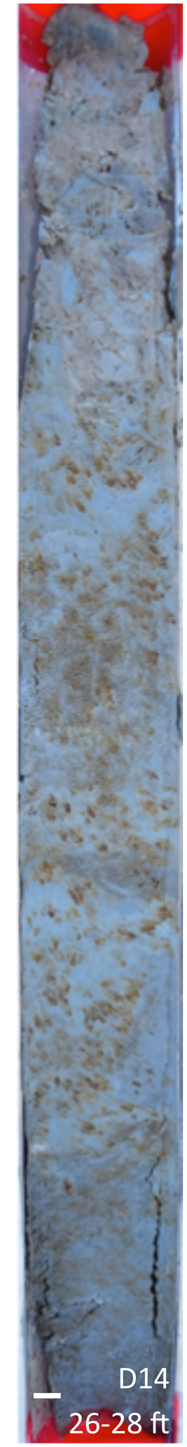


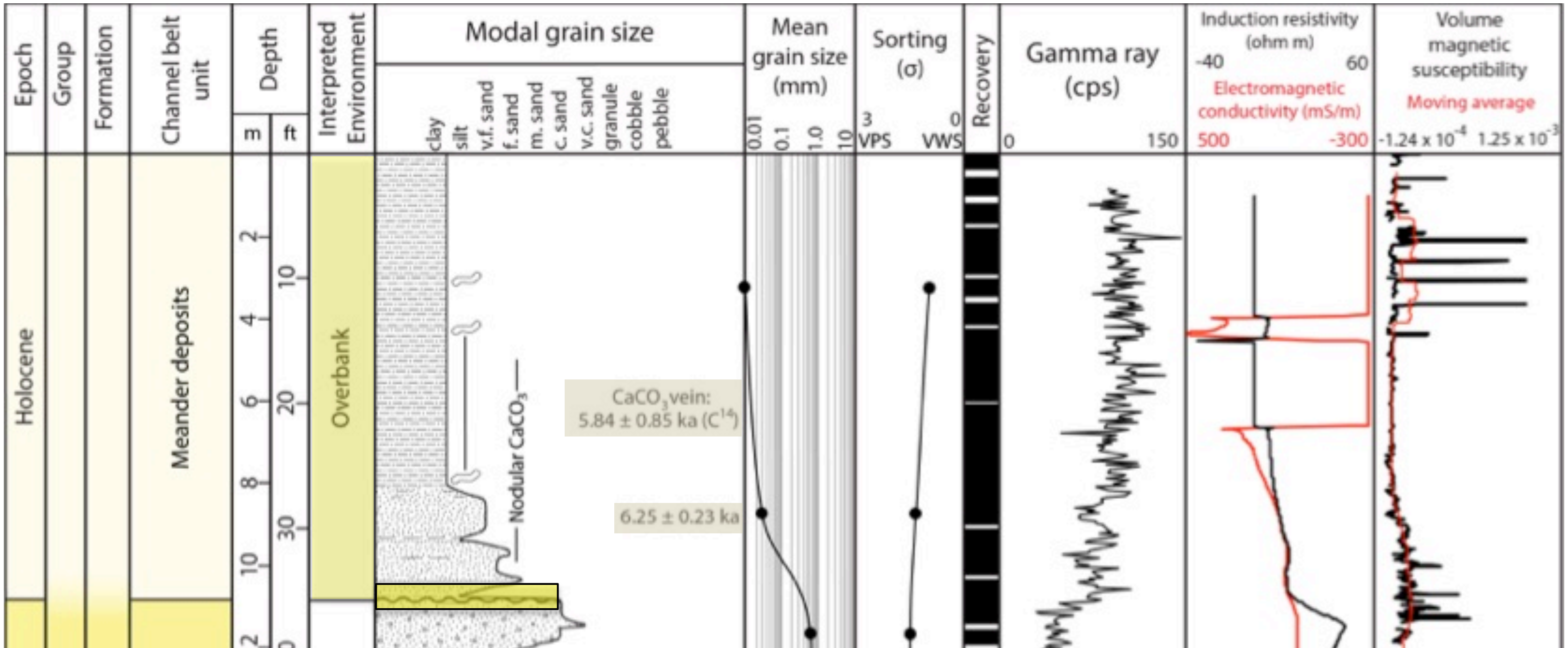


Silt to very fine sand, 27- 35.5 ft (8.2- 10.8 m)

- *Brown to gray brown quartz, chert, muscovite silt to sand with orange brown mottles*

Interpretation: Proximal overbank floodplain deposit Vertically accreted overbank sediment deposited during Holocene flooding of Miss. River

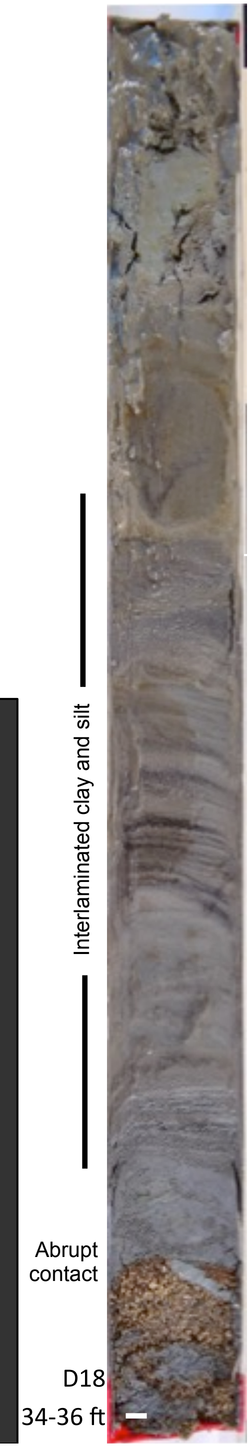


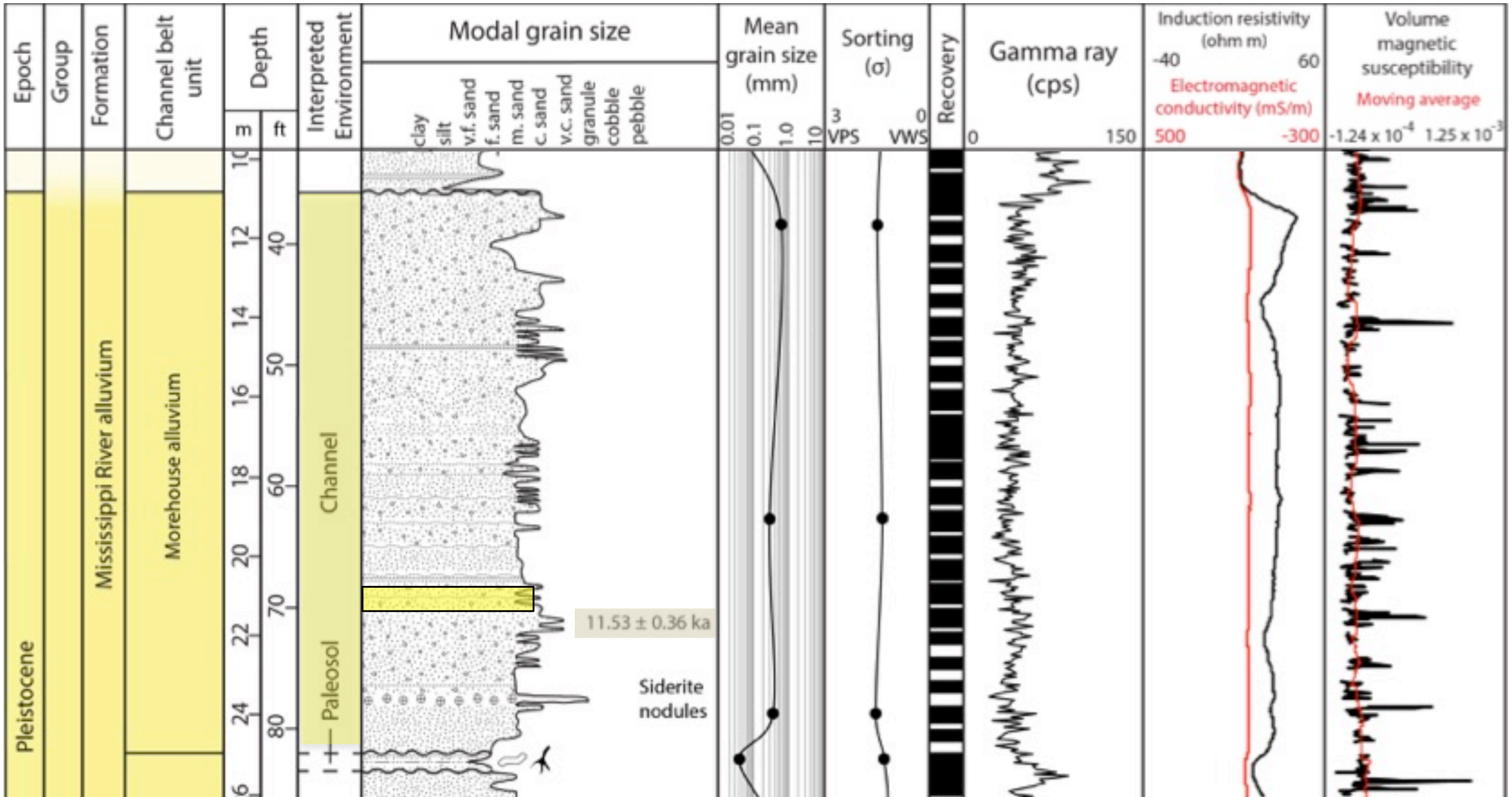


Silt to very fine sand, 27- 35.5 ft (8.2- 10.8 m)

- *Grain size fines to interlaminated clay and silt toward base of unit*
- *Abrupt planar contact at base*

Interpretation: Base of Holocene floodplain overlying Morehouse terrace alluvium

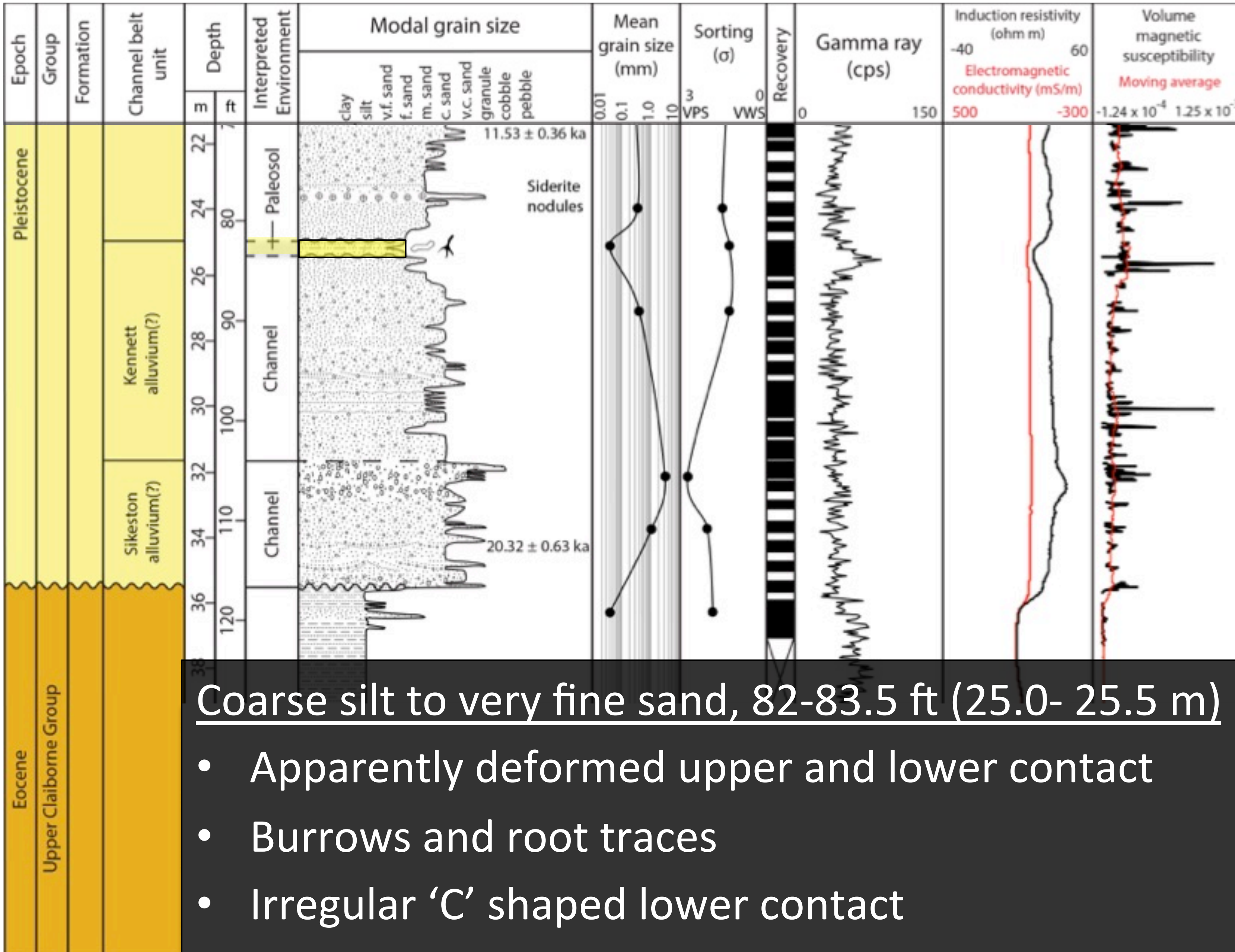




Medium-to-coarse sand and gravel, 35.5- 82 ft (10.8- 25.0 m)

- Parallel and cross laminations common
- Bedded detrital lignite

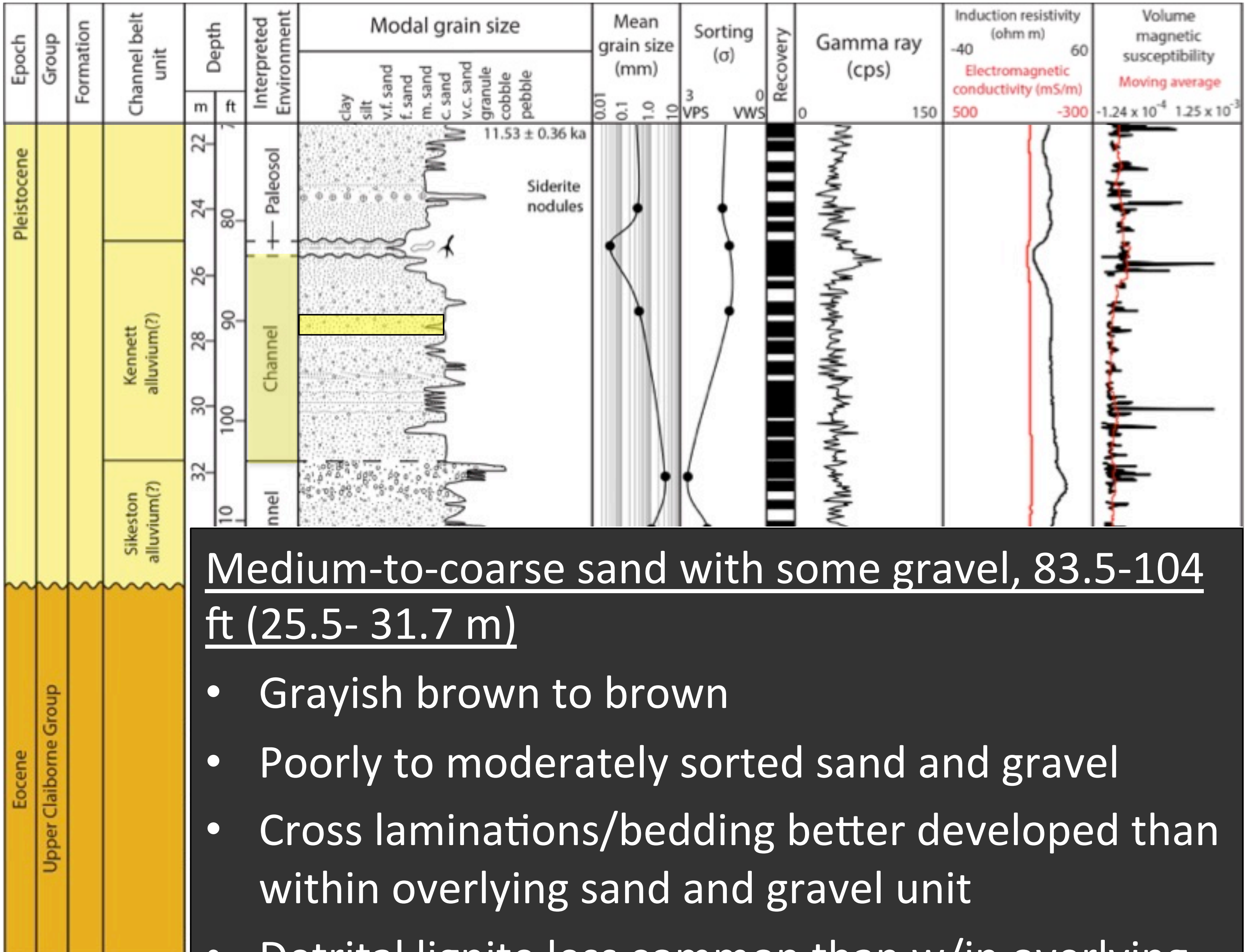
Interpretation: 12 ka Morehouse channel alluvium



Coarse silt to very fine sand, 82-83.5 ft (25.0- 25.5 m)

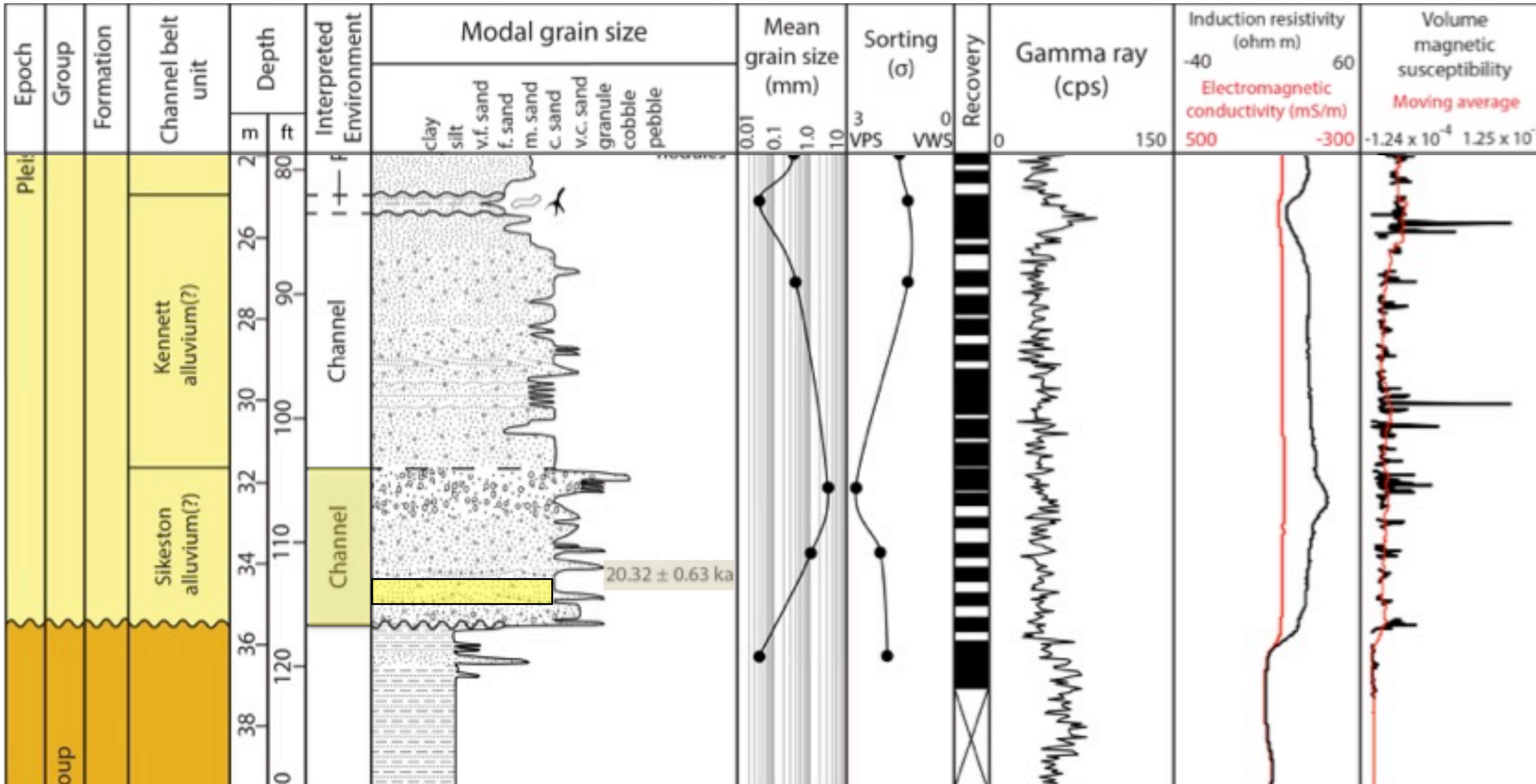
- Apparently deformed upper and lower contact
- Burrows and root traces
- Irregular 'C' shaped lower contact
- **Interpretation**: Paleosol; lower contact due to recovery or soft sed. deformation

Irregular backwards 'C' shaped contact



Medium-to-coarse sand with some gravel, 83.5-104 ft (25.5- 31.7 m)

- Grayish brown to brown
- Poorly to moderately sorted sand and gravel
- Cross laminations/bedding better developed than within overlying sand and gravel unit
- Detrital lignite less common than w/in overlying sand and gravel unit

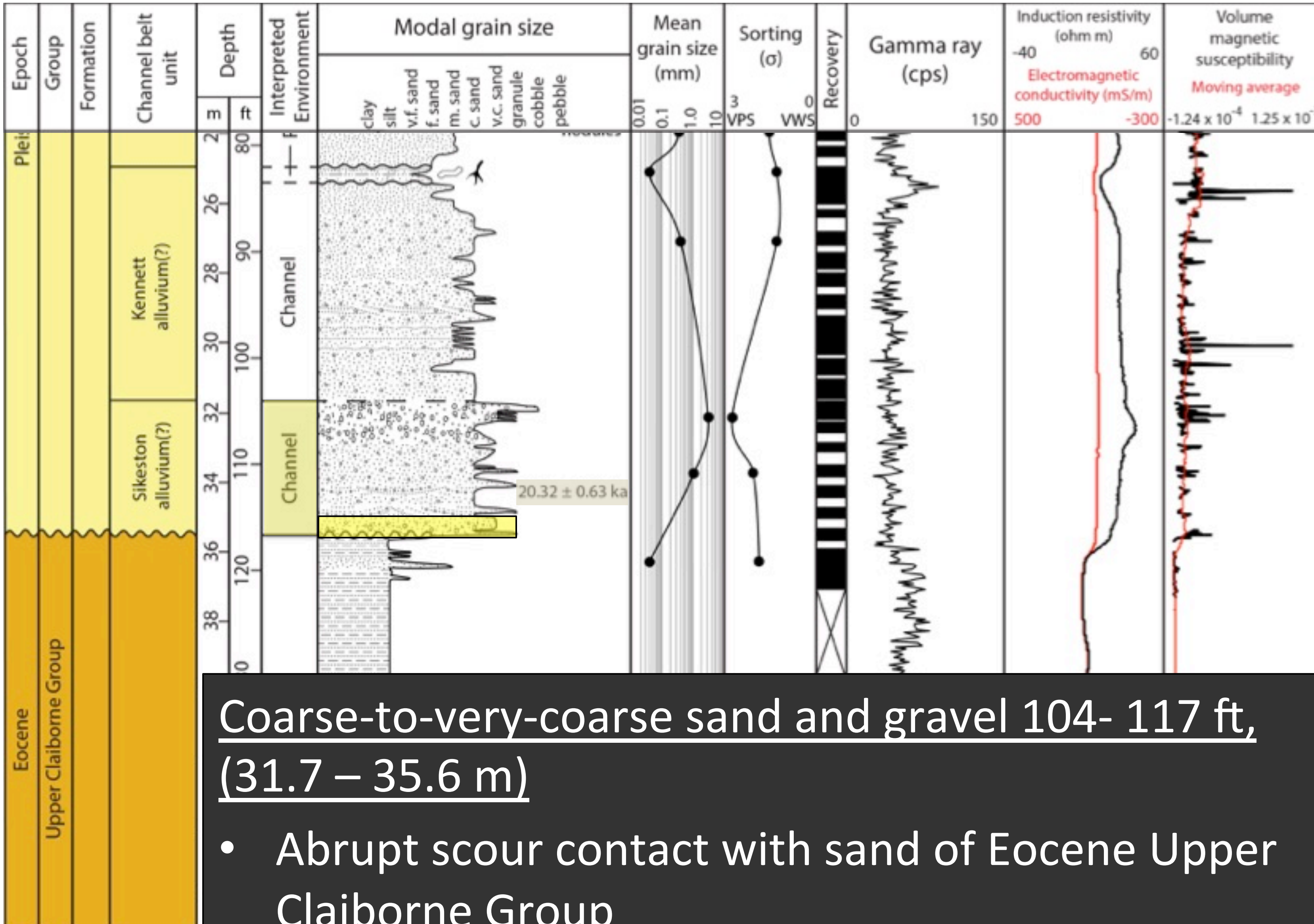


Coarse-to-very-coarse sand and gravel 104- 117 ft, (31.7 – 35.6 m)

- Relatively thick cross beds w/ well segregated sand and gravel beds
- Tallest cross bed is ~5 in thick

D57

112- 114 ft



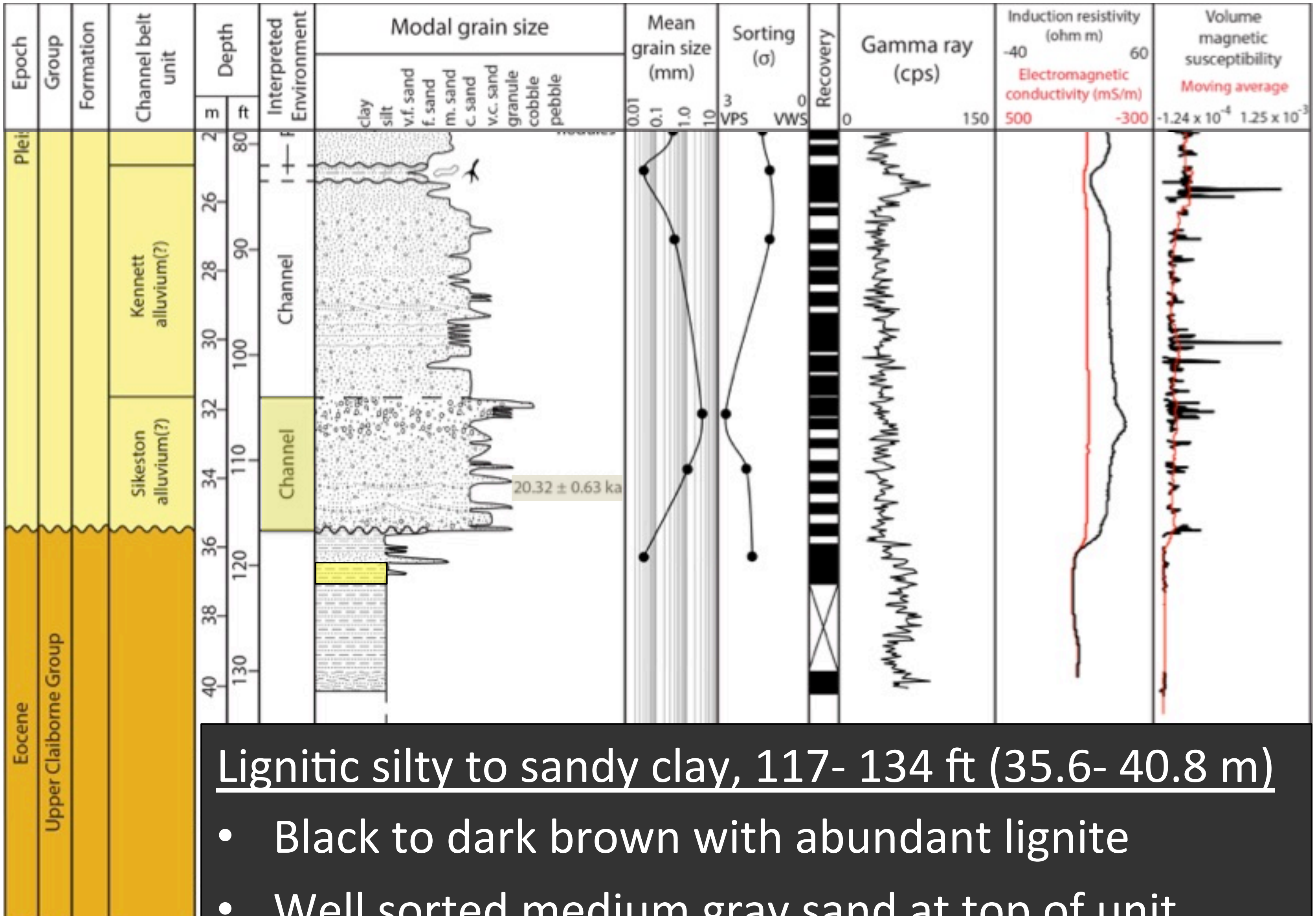
D57

112- 114 ft

Coarse-to-very-coarse sand and gravel 104- 117 ft, (31.7 – 35.6 m)

- Abrupt scour contact with sand of Eocene Upper Claiborne Group

Interpretation: Sikeston (?) terrace channel alluvium over scoured base of alluvial valley



<u>Lignitic silty to sandy clay, 117- 134 ft (35.6- 40.8 m)</u>

- Black to dark brown with abundant lignite
- Well sorted medium gray sand at top of unit

Interpretation: Eocene Upper Claiborne Group; potentially near contact between formations/units

Vertical displacement rates

Meeman-Shelby fault

$$\frac{28\ meters}{14.30\ ka} \approx 2.0\ mm/yr$$

Joiner Ridge horst

$$\frac{20\ meters}{20.32\ ka} \approx 1.0\ mm/yr$$

- These rates assume that the dated basal strata are continuous across the fault
- By comparison, the Reelfoot fault has a Holocene slip rate of 1.8 mm/yr since 9 ka and 6.2 mm/yr since 950 AD
- Calculated vertical slip rate for the MSF is a minimum net slip rate as it is interpreted to have experienced right lateral offset

Conclusions

- We have developed a type section of the modern Mississippi River and identified Pleistocene alluvial packages at depth
- Slip rates confirm possibility of two active and extensive faults with recent displacement near Memphis, Tennessee
- Significance of understanding these structures:
  - Meeman-Shelby fault capable of producing M 6.9 EQ and is less than 10 km from downtown Memphis
  - Joiner Ridge horst may be important for understanding strain accommodation in the Reelfoot Rift

Conclusions

- This research demonstrates that Mississippi River alluvium can provide late Quaternary deformation history
- These methods provide the necessary stratigraphic and temporal resolution to developed well constrained deformation chronologies
- Methods should be applicable to any region in which late Quaternary alluvium is deformed in the subsurface by blind faults
- Proposed future work:
  - Obtain continuous cores on the downthrown blocks of each structure and determine basal age by radiometric dating
  - Shallow seismic reflection or ground penetrating radar profiles of Joiner Ridge horst and Meeman-Shelby fault

Acknowledgements

Award number: G15AP00014

- National Earthquake Hazards Reduction Program
- Kentucky Geological Survey
- USGS Geochronological laboratory
- USGS Water Division
- All University of Memphis faculty and staff involved

Questions?