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

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Modified from Vigil et al., 2000
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
• Low recent seismicity
• Minimum of 10 km from downtown Memphis
• Strike: N25°E for 45 km
• Dip: 83° NW
• Interpreted as positive flower structure
<table>
<thead>
<tr>
<th>Reflector</th>
<th>Mean cumulative deformation (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Holocene?</td>
<td>6 ?</td>
</tr>
<tr>
<td>Eocene-Quaternary</td>
<td>28</td>
</tr>
<tr>
<td>Paleocene-Eocene</td>
<td>47</td>
</tr>
<tr>
<td>Cretaceous-Paleocene</td>
<td>61</td>
</tr>
<tr>
<td>Paleozoic-Cretaceous</td>
<td>127</td>
</tr>
</tbody>
</table>

From Hao et al., 2013
• 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
• 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
• 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
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
<table>
<thead>
<tr>
<th>Site</th>
<th>Structure</th>
<th>Surface elevation (m)</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Thickness of alluvium</th>
<th>Age of surface alluvium</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>MSF</td>
<td>65.53</td>
<td>35.19032806</td>
<td>-90.12998141</td>
<td>45 meters</td>
<td>~10 ka</td>
</tr>
<tr>
<td>S2</td>
<td>Joiner Ridge horst</td>
<td>69.5</td>
<td>35.61070792</td>
<td>-90.14998943</td>
<td>40 meters</td>
<td>~12 ka</td>
</tr>
</tbody>
</table>
Meeman-Shelby fault site

Credit: Ronald Counts
Continuous core mud rotary drilling by McCray Drilling LLC

Drilled through entire thickness of alluvium collecting split spoon samples in two foot intervals
Utilized mobile dark lab to preserve OSL samples
Utilized mobile dark lab to preserve OSL samples
Split sample tubes in mobile dark lab to produce an OSL-split and physical core description split.
Photography tent to obtain images of split core samples upon recovery
Photography tent to obtain images of split core samples upon recovery. Split sample tubes in mobile dark lab to produce an OSL-split and physical core description split.
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

<table>
<thead>
<tr>
<th>Site</th>
<th>Structure</th>
<th>Surface elevation</th>
<th>Bottom hole depth (elev. ASL)</th>
<th>Q-Eo disconformity depth (elev. ASL)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>ft</td>
<td>m</td>
<td>ft</td>
</tr>
<tr>
<td>S1</td>
<td>MSF</td>
<td>215.0</td>
<td>65.5</td>
<td>144.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(70.2)</td>
</tr>
<tr>
<td>S2</td>
<td>Joiner Ridge horst</td>
<td>228.0</td>
<td>69.5</td>
<td>132.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(95.9)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Site</th>
<th>Total Core Recovery (%)</th>
<th>Quaternary alluvium</th>
<th>Eocene sediment recovery (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Silty clay to vf sand recovery (%)</td>
<td>Sand and gravel recovery (%)</td>
</tr>
<tr>
<td>S1</td>
<td>65.2</td>
<td>80.5</td>
<td>62.2</td>
</tr>
<tr>
<td>S2</td>
<td>76.1</td>
<td>88.5</td>
<td>69.8</td>
</tr>
</tbody>
</table>
Meeman-Shelby fault core stratigraphy

Ideal Facies Sequence
- Clay
- Silt
- Sand
- Gravel

Copyright: Kenneth Davis, 2014
Silty clay, 4-14 ft (1.2-4.3 m)

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

**Interpretation:** Distal overbank floodplain deposit
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)

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- 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)

**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.)
Medium quartz sand, 133.5- 145 ft (40.69- 44.2 m)
- 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
<table>
<thead>
<tr>
<th>Epoch</th>
<th>Group</th>
<th>Formation</th>
<th>Channel belt unit</th>
<th>Depth</th>
<th>Interpreted Environment</th>
<th>Modal grain size</th>
<th>Mean grain size (mm)</th>
<th>Sorting (σ)</th>
<th>Gamma ray (cps)</th>
<th>Induction resistivity (ohm m)</th>
<th>Induction conductivity (mS/m)</th>
<th>Volume magnetic susceptibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Holocene</td>
<td></td>
<td>Meander deposits</td>
<td>Overbank</td>
<td>D21</td>
<td>Silt to very fine sand, 27- 35.5 ft (8.2- 10.8 m)</td>
<td>Clay, v.f. sand</td>
<td>0.01 - 0.25</td>
<td>3 VPS</td>
<td>0</td>
<td>-40 - 60</td>
<td>500</td>
<td>-1.24 x 10^-4 - 1.25 x 10^-3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Gravel, cobble</td>
<td>0.25 - 0.35</td>
<td>0 VWS</td>
<td>150</td>
<td>-300</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Grain size fines to interlaminated clay and silt toward base of unit</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td>Abrupt planar contact at base</td>
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</tr>
</tbody>
</table>

**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
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
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
Lignitic silty to sandy clay, 117-134 ft (35.6-40.8 m)

- 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

<table>
<thead>
<tr>
<th>Fault/Feature</th>
<th>Vertical Displacement Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meeman-Shelby fault</td>
<td>$\frac{28 \text{ meters}}{14.30 \text{ ka}} \approx 2.0 \text{ mm/yr}$</td>
</tr>
<tr>
<td>Joiner Ridge horst</td>
<td>$\frac{20 \text{ meters}}{20.32 \text{ ka}} \approx 1.0 \text{ mm/yr}$</td>
</tr>
</tbody>
</table>

- 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

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

Questions?