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Quaternary Displacement Rates on the Meeman-Shelby Fault and Joiner Ridge: Collaborative Research between the University of Memphis and United States Geological Survey

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Abstract

The principal objective of this research was to determine late Quaternary displacement rates for the subsurface Meeman-Shelby and Joiner ridge horsts in northeastern Arkansas near Memphis, Tennessee by coring and dating the vertically displaced Quaternary Mississippi River alluvium that overlies each horst. We collected continuous cores of the entire Quaternary section at each location using a 2 ft (0.6 m) long split spoon sampler, made detailed core descriptions, and obtained three OSL ages from each core. The Meeman-Shelby horst core consists of 118 ft (36 m) of 4.28 ka to 5.20 ka Holocene alluvium overlying 16.5 ft (5 m) of 14.30 ka Kennett alluvium that in turn overlies Eocene Upper Claiborne Group sediment at 134.5 ft (41 m). The Kennett alluvium is displaced 92 ft (28 m) across the horst's east-bounding Meeman-Shelby fault and so the average displacement rate within the last 14.30 ka is 2 mm/yr. The Joiner ridge horst core consists in descending order of 36 ft (11 m) of 6.25 ka Holocene alluvium, 46 ft (14 m) of 11.53 ka Morehouse alluvium, a paleosol, 19.5 ft (6 m) of Kennett alluvium, and 13 ft (4 m) of 20.32 ka Sikeston alluvium that in turn overlies Eocene Upper Claiborne Group sediment at 115 ft (35 m). The Sikeston alluvium is displaced 66 ft (20 m) across the eastern bounding fault of the Joiner ridge horst and so the displacement rate is 1 mm/yr.

Introduction

Numerous sites in and adjacent to the New Madrid seismic zone have experienced Quaternary deformation (Fig. 1 and Table 1). Specifically, the Charleston uplift (Pryne et al., 2013), Lake County uplift (Russ, 1982; Kelson et al., 1996; Purser and Van Arsdale, 1998; Champion et al., 2001; Carlson and Guccione, 2010), Blytheville arch (Guccione et al., 2000; Pratt et al., 2012), Joiner ridge horst (Csontos et al., 2008; Odum et al., 2010), and the Meeman-Shelby fault zone (Hao et al., 2013) have folded or faulted a base-of-alluvium sand and gravel unit that is believed to be Quaternary in age (Csontos et al., 2008; Van Arsdale and Cupples, 2013). The displacement of this basal alluvium, inferred to be Quaternary in age, has been

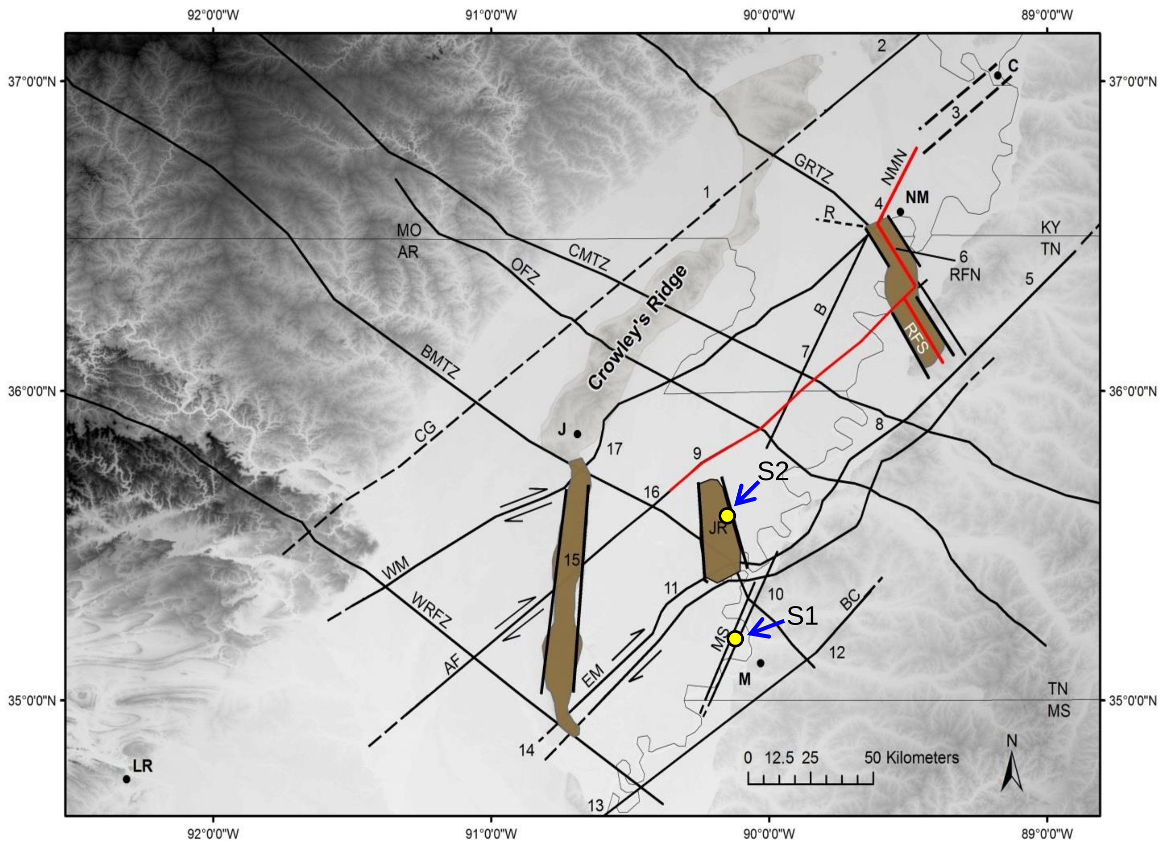

Figure 1. Reelfoot rift faults and numbered locations of documented Quaternary faulting and liquefaction (from Van Arsdale and Cupples, 2013). Numbers correspond to numbers in Table 1. Right-lateral shear across the Reelfoot rift is responsible for the New Madrid seismic zone earthquakes, which occur along the faults colored red. Quaternary right-lateral shear on the rift faults is also causing uplift of the Lake County uplift/Reelfoot North fault (RFN), Joiner Ridge (JR), and the southern portion of Crowley's Ridge. WRFZ = White River fault zone, BMTZ = Bolivar Mansfield tectonic zone, OFZ = Osceola fault zone, CMTZ = Central Missouri tectonic zone, GRTZ = Grand River tectonic zone, EM = Southeastern Reelfoot Rift margin faults, WM = Northwestern Reelfoot Rift margin fault, AF = Axial fault, NMN = New Madrid North fault, RFS = Reelfoot South fault, MS = Meeman-Shelby fault zone, CG = Commerce Geophysical lineament/fault, BC = Big Creek/Ellendale fault, B = Bootheel fault, R = Risco fault (defined by seismicity), M = Memphis, LR = Little Rock, NM = New Madrid, C = Cairo.

documented through the analysis of 3374, 300 ft (91.4 m) deep lignite exploration wells and other core data provided by the U.S. Army Corps of Engineers (Csontos, 2007; Csontos et al., 2008; Van Arsdale and Cupples, 2013, Van Arsdale et al., 2014).

Although the Lake County uplift and bounding Reelfoot fault have been seismically assessed (e.g. Kelson et al., 1996; Champion et al., 2001; Holbrook et al., 2006; Carlson and Guccione, 2010) a significant shortcoming in the quest to evaluate the seismic hazard of other known Mississippi Valley structures is that we do not know their respective Quaternary fault histories. When blind faults displace Quaternary alluvium it is necessary to know the age of the displaced alluvium to calculate a vertical slip rate. We do not know the absolute age(s) of the

Table 1. Reelfoot rift Quaternary faulting and liquefaction locations designated with numbers in Figure 1 (from Van Arsdale and Cupples, 2013).

Location/name	Structure	Deformation age	Source
1 Western Lowlands	Faulting & Liquefaction	23,000-17,000 & 13,430-9000 yr BP, A.D. 240-1020 & 1440-1540	Shoemaker et al., 1997; Vaughn, 1994
2 Commerce fault	Faulting	60-50 ka, 35-25 ka, 5 ka, & 3660 yr BP	Harrison et al., 1999
3 Charleston Uplift	Faulting	< 12 ka	Pryne et al., 2013
4 New Madrid North fault	Faulting	Wisconsin	Baldwin et al., 2005
5 Southeastern Reelfoot rift margin	Faulting	Pleistocene	Cox et al., 2006
6 New Madrid seismic zone	Faulting & Liquefaction	2350 BC, A.D. 300, 900, 1450, & 1811	Kelson et al., 1996; Tuttle et al., 2002, 2005
7 Bootheel fault	Faulting	12.5-10.2 ka, 2.7–1.0 ka, & A.D. 1450	Guccione et al., 2005
8 Southeastern Reelfoot rift margin	Faulting	< 20 ka	Cox et al., 2006
9 Manila high	Faulting	11,500-5400 BP, A.D. 1450 & 1811	Guccione et al., 2000; Odum et al., 2010
10 Southeastern Reelfoot rift margin	Faulting	4000-2000 yr. BP (2 events); <2000 yr. B.P.	Cox et al., 2013
11 Southeastern Reelfoot rift margin	Faulting	Quaternary	Howe, 1985
12 Ellendale	Faulting	~A.D. 400	Velasco et al., 2005
13 Big Creek	Faulting	< 27 ka	Harris & Sorrells, 2006
14 Marianna	Liquefaction	7000-5000 BP	Tuttle et al., 2006
15 Crowley's Ridge	Faulting	Wisconsin	Van Arsdale et al., 1995
16 Marked Tree high	Faulting	4440-3350 BP	Guccione, 2005
17 Northwestern Reelfoot rift margin	Faulting	< 19 ka	Van Arsdale et al., 1995
18 Meeman-Shelby fault	Faulting	Quaternary	Hao et al., 2013

displaced alluvium deeply buried beneath the terraces and floodplains in the central Mississippi River valley. In this study we identify the stratigraphy and age of the displaced alluvial section overlying the subsurface Joiner ridge horst (Csontos et al., 2008; Odum et al., 2010) located 32 miles (52 km) NNW of Memphis, Tennessee and the Meeman-Shelby fault (Hao et al., 2013), located beneath the Mississippi River floodplain 5 miles (8 km) west of Memphis (Fig. 1).

Seismic reflection (Odum et al., 2010) shows that Joiner ridge is a N10°W trending subsurface horst with 66 ft (20 m) of apparent fault displacement on the Eocene-Quaternary disconformity (Csontos et al., 2008) (Figs. 1 and 2). The Meeman-Shelby fault is the east-bounding fault of the Meeman-Shelby horst and has 92 ft (28 m) of displacement on the Eocene-Quaternary disconformity (Fig. 1, 3-5) also imaged with seismic reflection (Hao et al., 2013).

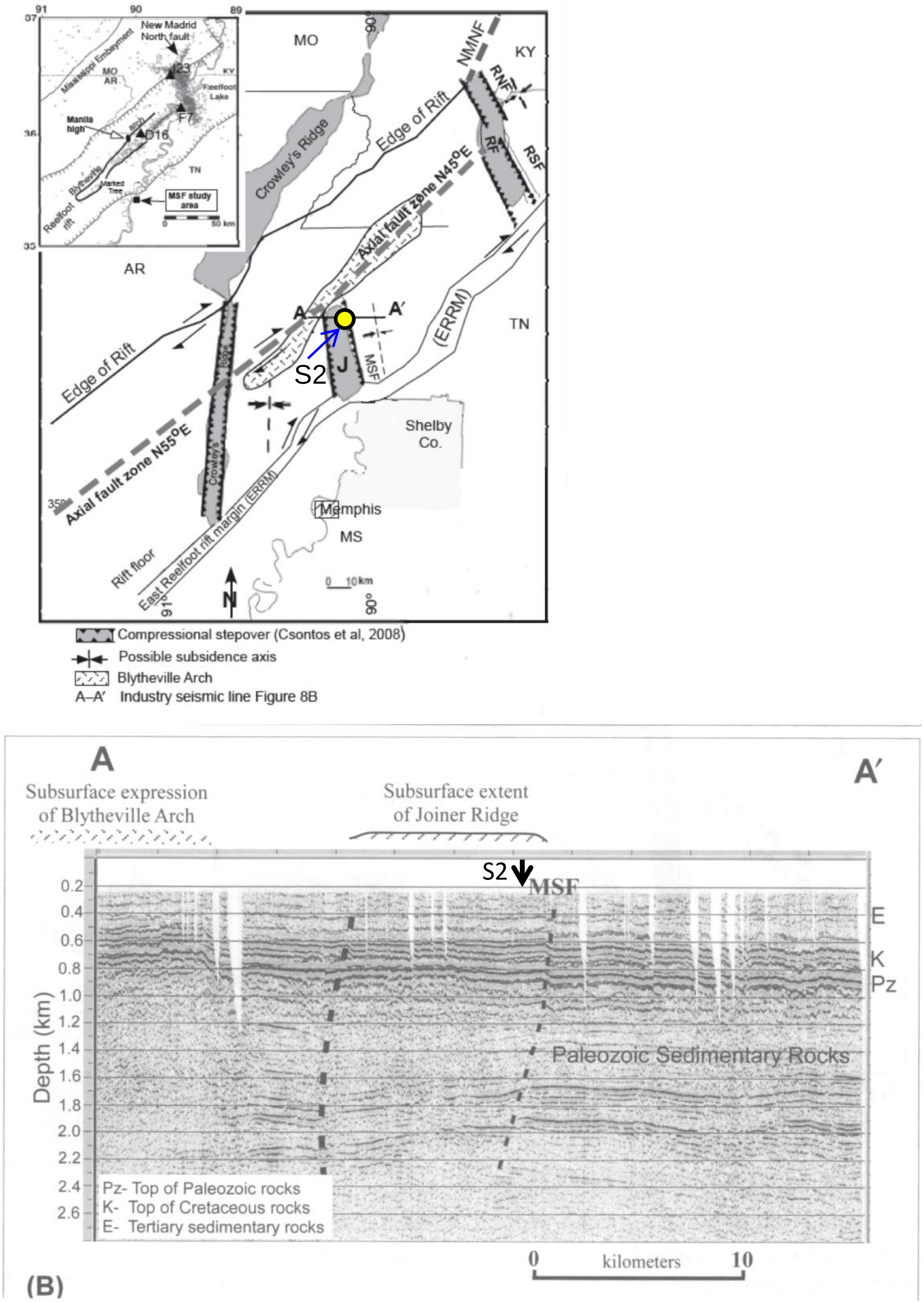

Figure 2. Joiner Ridge (A) and seismic reflection profile (B) illustrating displacement (from Odum et al., 2010). Joiner Ridge horst well drilled at location S2.

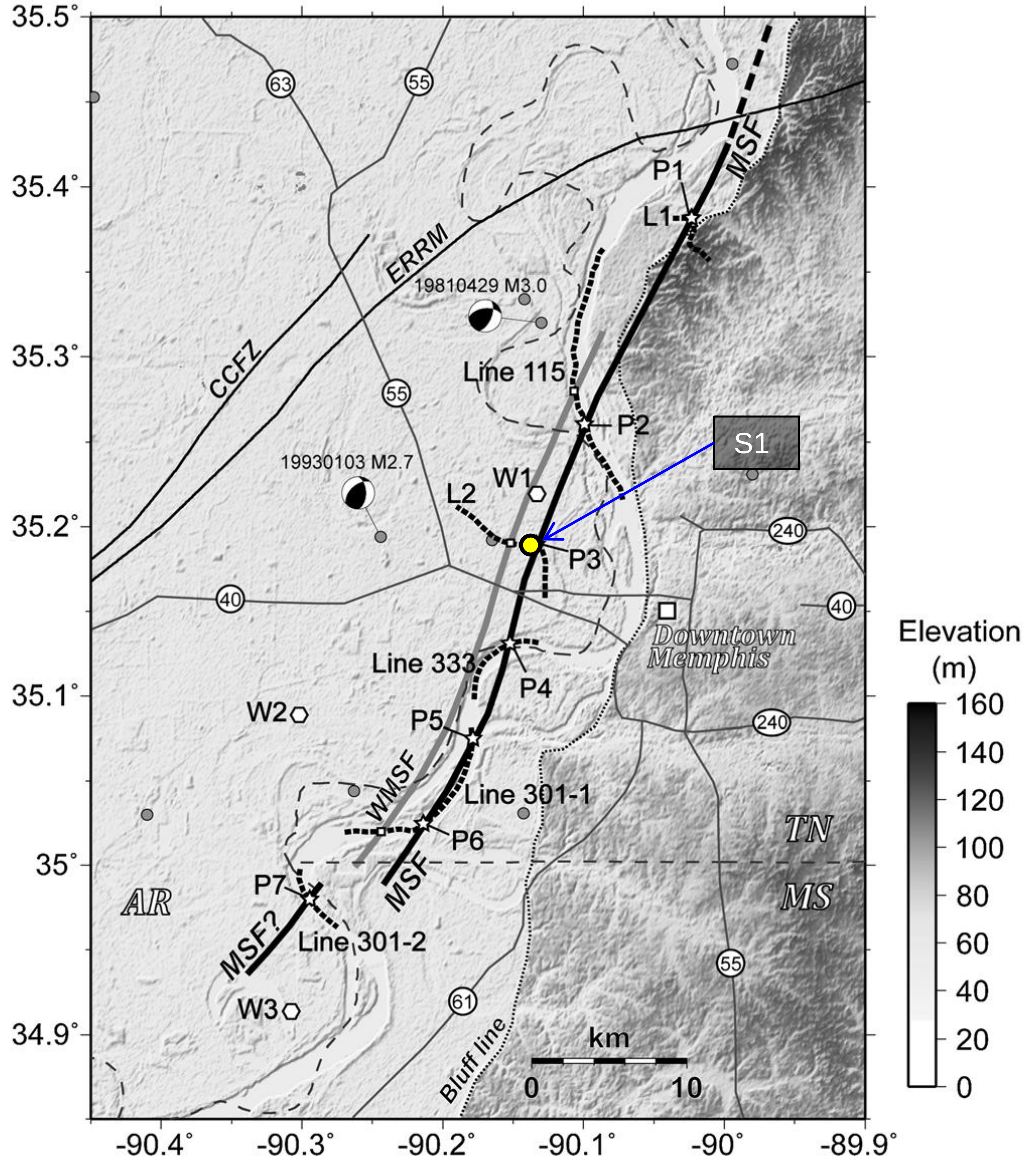

Figure 3. Meeman-Shelby fault (MSF - heavy black line) as interpreted from seismic profiles (from Hao et al., 2013). CCFZ - Crittenden County fault zone; ERRM - Eastern Reelfoot rift margin (Hildenbrand and Hendricks, 1995). Heavy dashed lines indicate land and marine multichannel seismic reflection lines. Colored dots show seismicity in the area (CERI New Madrid Earthquake Catalog 1974-2012). Focal mechanism solutions by Chiu et al. (1997): event 1981/04/29 (strike N83°E, dip N51°W, rake 137°, right-lateral strike-slip fault with thrust component, 6.3 km depth, M 3.0); event 1993/01/03 (strike N49°E, dip N51°W, rake 126°, right-lateral strike-slip fault with thrust component, 17.3 km depth, M 2.7). Hollow hexagons show boreholes (W1-3). Stars show surface projections (P1-7) of the Meeman-Shelby fault. Squares represent surface projections of the secondary eastward dipping fault (gray line), the West Meeman-Shelby Fault (WMSF). Meeman-Shelby fault well was drilled at S1.

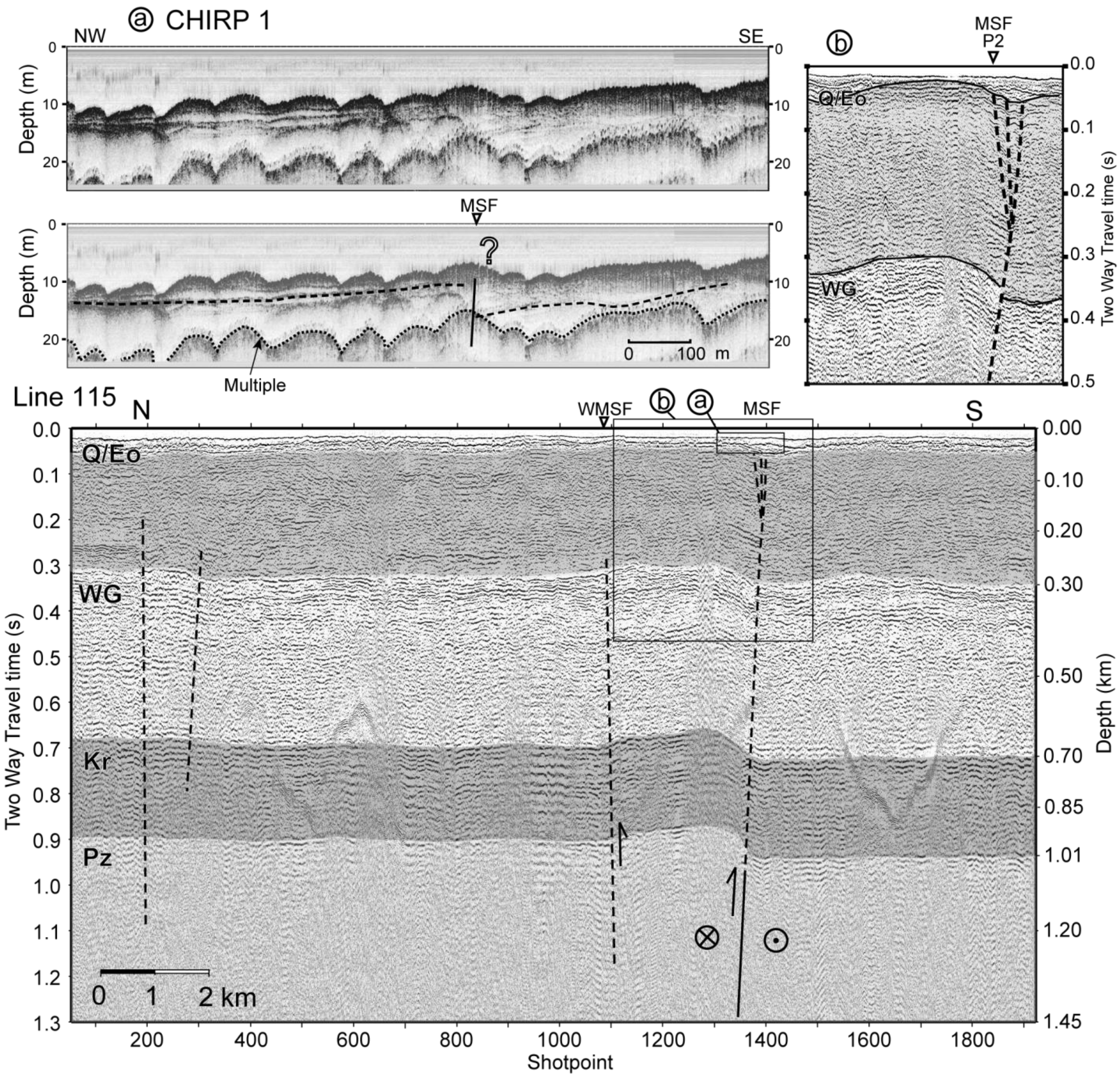

Figure 4. Multichannel seismic reflection line 115 located in Figure 3 and CHIRP profile CHIRP 1 (from Hao et al., 2013). Black solid and dashed lines indicate interpreted faults. Line 115 is a two-way travel time profile with estimated values of depth based on time-to-depth conversion. Pz - Paleozoic; Kr - Cretaceous; WG - Paleocene-Eocene Wilcox Group; Q/Eo, - Quaternary-Eocene unconformity. P2 and a triangle indicate the surface projection of the MSF and a triangle indicates the surface projection of the WMSF. (a) CHIRP profile above the MSF showing a clear reflector offset ~ 20 ft (~ 6 m). (b) Close-up of line 115 showing the deformed WG and Q/Eo boundaries. Our well was drilled on Line L2 at S1 of Figure 3. Our well location is structurally equivalent to location "a" in this lower diagram (Line 115).

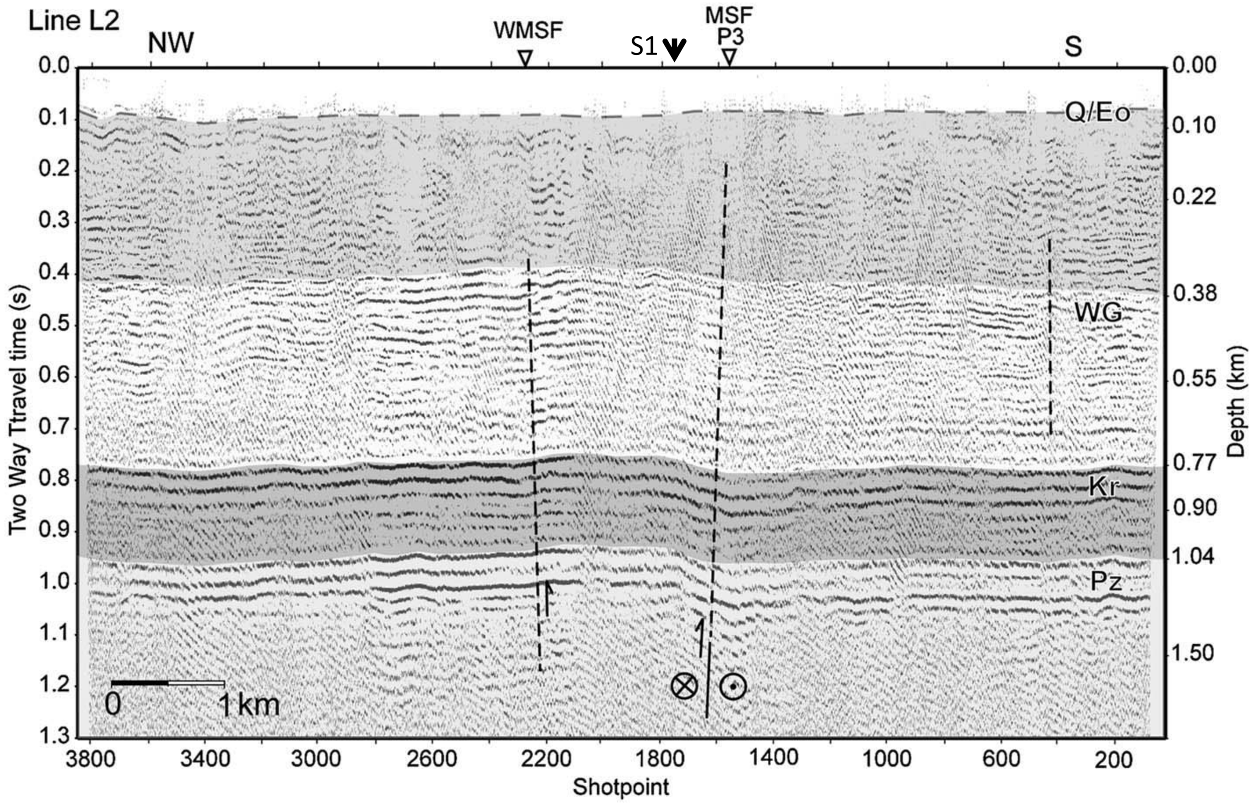

Figure 5. Land seismic profile Line L2 and interpretation (see Figure 3 for location). Labels of stratigraphy are the same as Line 115 in Figure 4. Triangles and labels show the surface projections of the MSF and the WMSF. The Q/Eo boundary is estimated according to local stratigraphy. From Hao et al. (2013).

Furthermore, Hao et al. (2013) concluded that alluvium 3 m below the bottom of the Mississippi River has 6 m of vertical displacement (Fig. 4). Neither the Meeman-Shelby horst nor Joiner ridge horst has any surface manifestation so there is no evidence of late Holocene fault displacement. Considering that both structures lie within the Mississippi River valley, it is likely that any surface manifestations would be transient features. However, the absolute ages of the "Quaternary" alluvium that is displaced by these two structures has never been determined. This research addresses these questions by acquiring, describing, and dating continuous alluvial cores from the crest of each of these two horsts into the underlying Eocene Upper Claiborne Group.

The age of deeper alluvial sections underlying surficial Pleistocene terraces and Holocene floodplains is essentially unknown in the central Mississippi River valley. Van Arsdale et al. (2014) argue that the alluvial terraces and floodplains shown in Figure 6 may be the same age from the surface to the Eocene-Quaternary disconformity. Alternatively, Van Arsdale et al. (2014) hypothesize that the basal Quaternary alluvium on the Meeman-Shelby horst is the ~12 ka Morehouse outwash described by Rittenour (2007). If the alluvium is the same age from the surface to the base of the Quaternary section, the 20 m of basal alluvium displacement along northern Joiner ridge is younger than the 12 ka Morehouse terrace alluvium. Similarly, the faulting that displaces basal alluvium over the Meeman-Shelby horst may be younger than 10 ka.

Vertical displacement of the base of alluvium at the Joiner ridge horst is 66 ft (20 m) and is 92 ft (28 m) across the Meeman-Shelby fault zone. If the displaced basal alluvium at Joiner

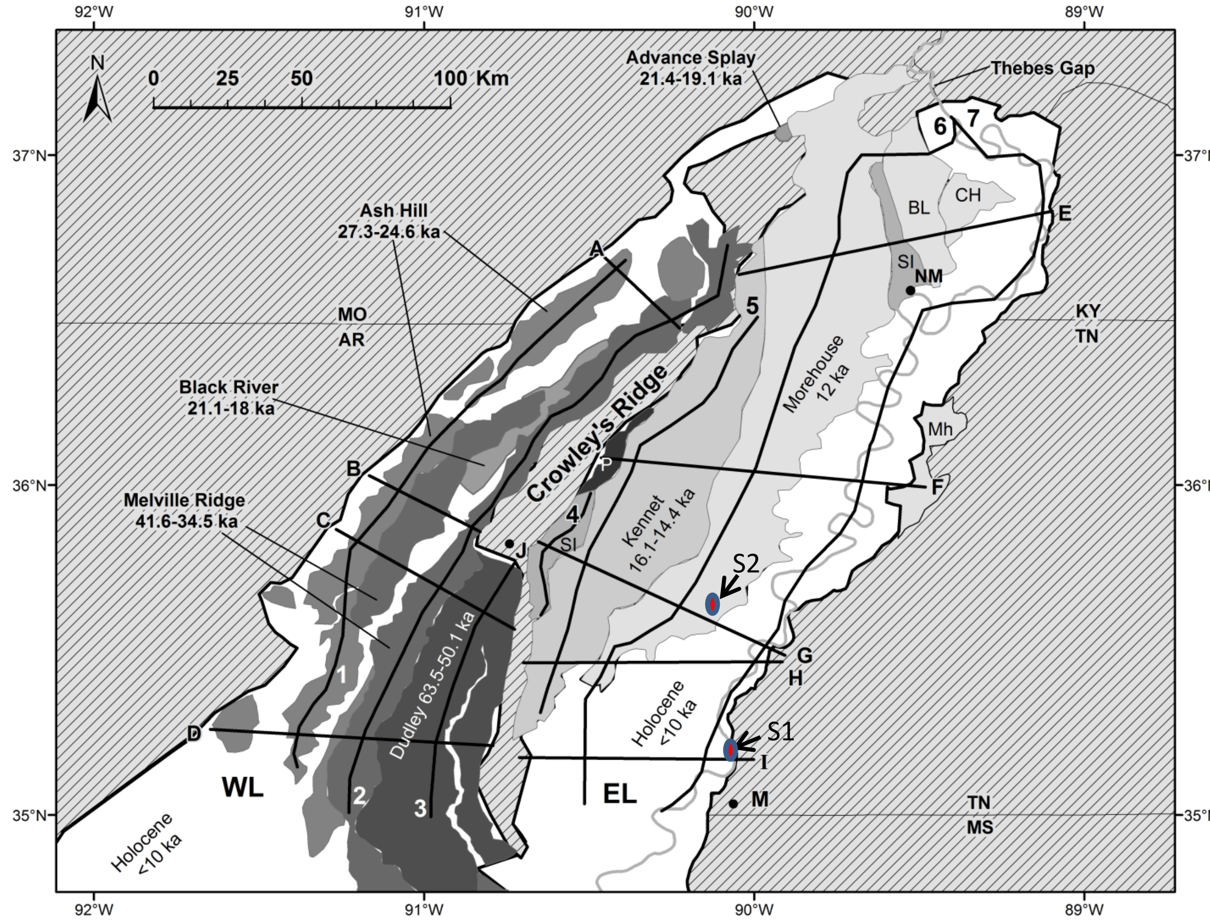

Figure 6. Pleistocene Mississippi River terraces and Holocene floodplain of the Mississippi River (from Van Arsdale et al., 2014). Lines labeled with letters are cross sections not shown here. J = Jonesboro, NM = New Madrid, M = Memphis, P = Paragould terrace (85 ka), SI = Sikeston terrace (17-19 ka), Mh = Morehouse terrace (12 ka), BL = Blodgett terrace (13 ka), CH = Charleston terrace (14 ka), WL = Western Lowlands, EL = Eastern Lowlands. The Ash Hill terrace is 24–27 ka and Melville Ridge terrace is 34-41 ka. Drill sites S1 and S2 are designated.

ridge is 12 ka Morehouse alluvium the vertical slip rate across Joiner ridge for the past 12 ka is 1.7 mm/yr. If the displaced basal alluvium across the Meeman-Shelby fault is 10 ka Holocene alluvium the vertical slip rate is 2.8 mm/yr over the last 10 ka. Obviously, these are very high fault slip rates that require confirmation.

Methodology

The research methodology, sedimentologic analyses, and core photographs are presented in detail in Ward (2016) and summarized herein. The first objective of this research was to determine the stratigraphy and OSL ages of the alluvium beneath the Morehouse terrace at the Joiner Ridge horst site and beneath the Holocene Mississippi River floodplain at the Meeman-Shelby horst site (Fig. 1). The second objective was to calculate late Quaternary slip rates for the

Meeman-Shelby fault and Joiner Ridge horst based on the ages of the displaced basal alluvium. These objectives were pursued by obtaining two continuous cores through the Quaternary alluvium and into the underlying Eocene Claiborne Group sediment (Figs. 1, 7, and 8). McCray Drilling LLC of Memphis, Tennessee, used mud rotary drilling and split spoon sampling, coring in 2 ft (0.6 m) intervals. They hammered the split spoon into the ground and recorded blow count data for both cores (Ward, 2016). After collecting a split spoon sample, the cored interval was drilled with a rotary drill bit to circulate drilling mud through the formation and prevent borehole collapse and ensuring sample integrity. Split spoon sediment samples were recovered in 2 ft (0.6 m) long by 2.5 inch (6.35 cm) diameter plastic liners inside the steel opaque split spoon core barrel. We removed the plastic core liners from the split spoon sampler inside a Ford E450 that was converted to a light-tight darkroom (field lab vehicle supplied by the USGS Tennessee Water Science Center). We split the sediment tubes longitudinally using box cutters and nickel guitar wire inside the mobile dark lab and placed one half of the split core in three layers of light-tight, opaque bags and transported them to the University of Southern Indiana, where samples were extracted from the cores in a darkroom and sent to the U.S. Geological Survey luminescence dating lab in Lakewood, Colorado. The other half of the split core was photographed on site and transported to a geology lab at the University of Memphis for additional analyses.

Immediately upon completion of the drilling, plastic pvc casing was placed in each borehole. The borehole casings were filled with water and were subsequently electrically logged by USGS personnel using a down-hole logging system. Logs collected include gamma ray, induction resistivity, and electromagnetic conductivity (Figs. 7 and 8).

We logged volume magnetic susceptibility on the non-OSL split cores in one-centimeter increments at the Kentucky Geological Survey sediment lab in Henderson, Kentucky (Figs. 7 and 8). This was done to search for magnetic susceptibility highs that could indicate the presence of paleosols and/or changes in provenance. Upon completion of these magnetic measurements the cores were returned to the University of Memphis.

We described each split core sample at the University of Memphis with respect to sedimentological and stratigraphic properties. Observed parameters included, but were not limited to, visual interpretation of bed contacts, bed forms, mineralogy, texture, and soil structure. From these physical core descriptions we constructed stratigraphic interpretations. Grain size analyses were conducted on ten samples from each core to quantify the stratigraphic interpretations, which required wet and dry sieving, pipet analyses, and hydrometer analyses (Ward, 2016). These cores are currently located at the University of Memphis.

Optically stimulated luminescence (OSL) dating is used to determine the time that has elapsed since quartz or feldspar grains were exposed to daylight (Aitken, 1998; Murray and Olley, 2002; Duller, 2004; Rhodes, 2011) and the technique has been used successfully to date glacial outwash deposits worldwide. Rittenour et al. (2005; 2007) mapped the near-surface extent of Pleistocene Mississippi River terraces, as well as the Holocene Mississippi River floodplain, and determined the near-surface ages of these alluvial packages using OSL dating (Fig. 6).

We collected three samples for OSL dating from each of the two cores kept in the light-tight containers. Samples were taken from near the top, the midsection, and right above the Quaternary-Eocene contact near the bottom of the cores. These samples were then sent to the USGS Luminescence Lab for dating (Figs. 7 and 8). The halves of the cores in light-tight storage are currently stored at the University of Southern Indiana, but they will be permanently archived at the USGS core facility in Reston, Virginia.

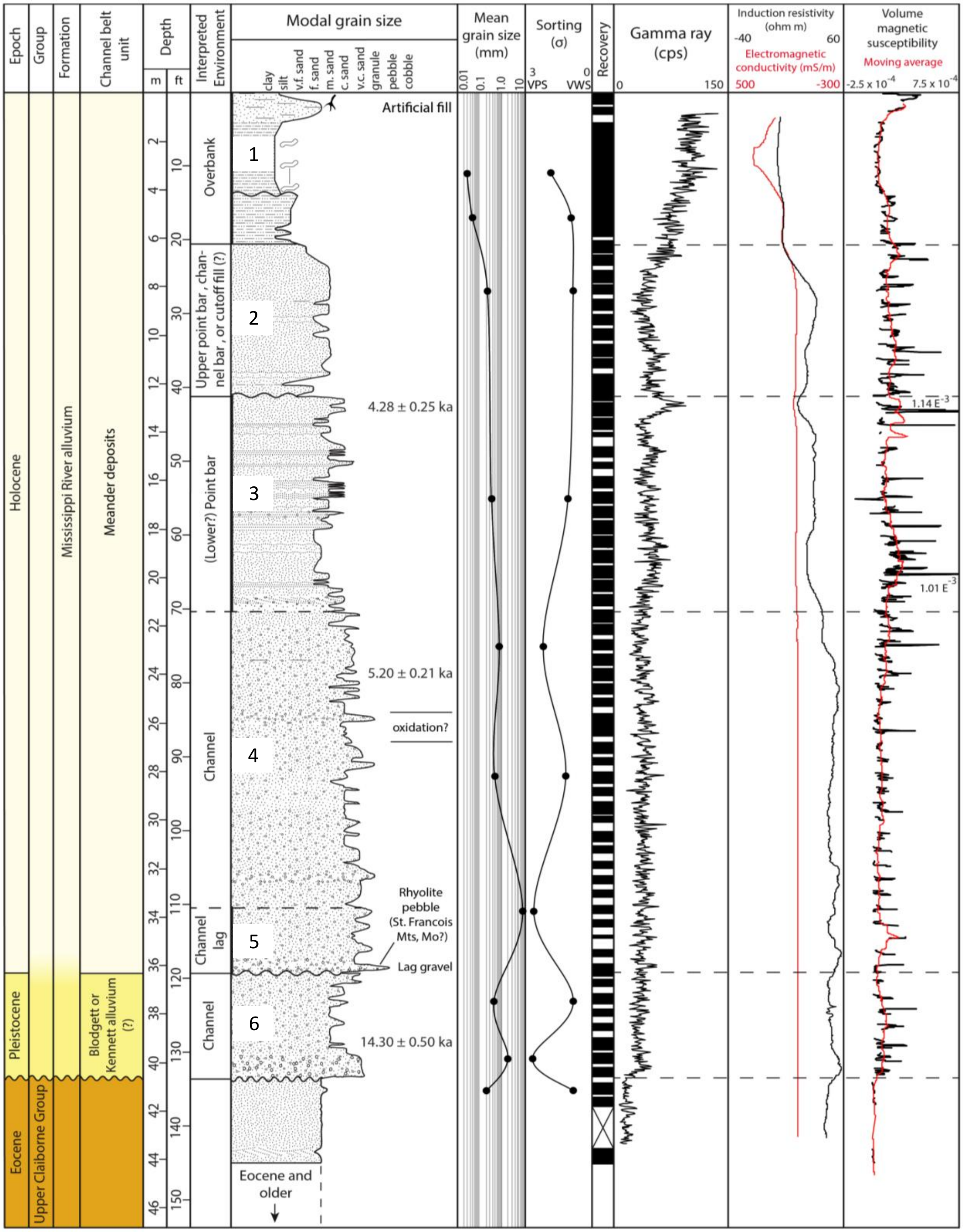

Figure 7. Geologic log of the Meeman-Shelby fault core located at S1 in Figures 1, 3, and 5. Vertical line width and adjacent number corresponds to unit extent and designation.

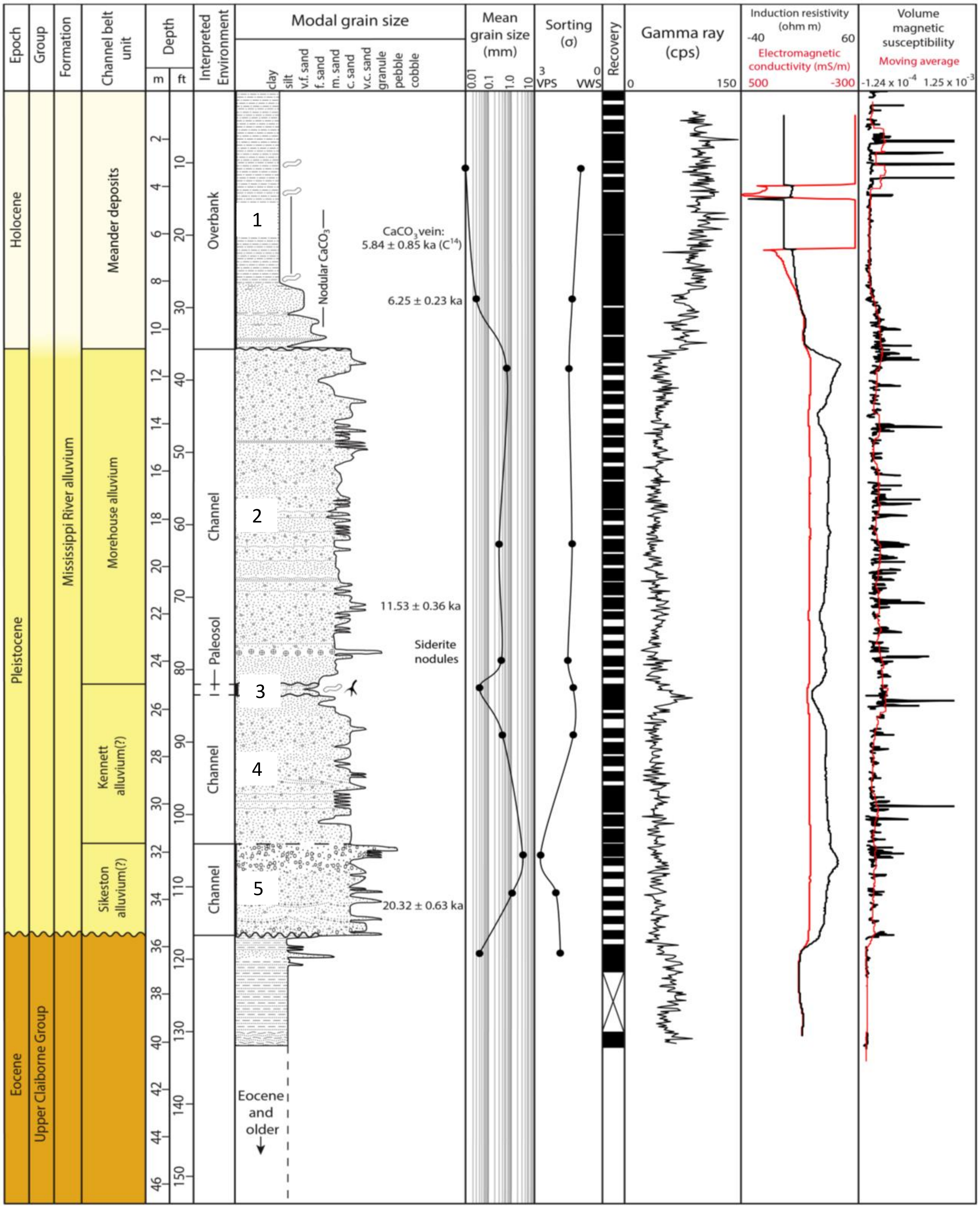

Figure 8. Geologic log of the Joiner ridge core located at S2 in Figures 1 and 2. Vertical line width and adjacent number corresponds to unit extent and designation.

Results

Stratigraphy of the Meeman-Shelby Core

The Meeman-Shelby core, acquired on the Mississippi River floodplain (Figs. 1 and 3), is 145 ft (44.2 m) deep and includes 11 ft (3.4 m) of Eocene Upper Claiborne Group sediment in the bottom of the core (Fig. 7). Within the upper 134 ft (40.8 m) of this core there are five Holocene meandering river stratigraphic units underlain by one Pleistocene channel unit.

Unit 1 is the uppermost 21 ft (6.4 m) of the core and is interpreted as overbank alluvium. Unit 1 consists of silty clay that coarsens downward to silt-to-very-fine sand. There is an abrupt contact with underlying medium sand between unit 1 and unit 2. Unit 2 spans from 21 to 42 ft (6.4-12.5 m) and is probably a chute fill deposit or possibly the uppermost portion of a point bar deposit. Between the depths of 41 to 68.5 ft (12.5-20.9 m) is unit 3, which consists of coarse cross and parallel laminated sand that is consistent with a point bar deposit. OSL dating indicates unit 3 is 4.28 ± 0.25 ka at 44 ft (13.4 m). The contact at the base of unit 3 is gradational with the underlying channel deposits. Unit 4 was from 68.5 to 111 ft (20.9-33.8 m) in the core and is interpreted as a channel deposit that exhibits a gradual mean grain size increase with increasing depth. An OSL age of 5.20 ± 0.21 ka was obtained at 80 ft (24.4 m) where gravel becomes abundant near the base of this unit. Although no bed forms were observed in this unit, any such bed forms are likely too large to be identified within the relatively narrow core diameter. The base of this Holocene section, unit 5, was from 111 to 119 ft (33.8-36.3 m) in the core and is interpreted as a channel lag deposit of gravel in a coarse-to-very-coarse sand matrix. As evident from grain size analyses and physical core description, unit 5 has been significantly winnowed of fines. One gravel clast of porphyritic rhyolite was found at 118.5 ft (36.1 m) and likely originated from the St. Francis Mountains of southeast Missouri, suggesting Mississippi River instead of Ohio River deposition. Unit 6, from 119 to 133.5 ft (36.3-40.7 m) in the core, is a late Pleistocene, medium-to-coarse channel sand. An OSL sample obtained at 130 ft (39.6 m) indicates it is 14.30 ± 0.50 ka. Gravel becomes common near the base of unit 6. Below this Pleistocene alluvium, Eocene Upper Claiborne Group, a medium gray, very well sorted quartz sand, comprises the remaining depth of the core from 133.5 to 145 ft (40.7-44.2 m).

Stratigraphy of the Joiner Ridge Core

The Joiner ridge core is mapped as part of the surficial extent of the 12 ka Morehouse terrace alluvium (Rittenour et al., 2007) (Figs. 1, 2, and 6), although our drilling revealed Holocene alluvium at the surface. This core is 132 ft (40.3 m) deep with the bottom 15 ft (4.7 m) being Eocene Upper Claiborne Group sediment (Fig. 8). There are three texturally distinct Pleistocene outwash units with one paleosol overlain by Holocene floodplain alluvium within the upper 117 ft (35.7 m) of the Joiner ridge core. The uppermost 35.5 ft (10.8 m), unit 1, consists of very fine sand, silt, and clay interpreted as Mississippi River overbank sediment. An OSL age of 6.25 ± 0.23 ka was obtained from the overbank sediment at a depth of 29 ft (8.8 m). Calcite nodules are common within the overbank unit and a calcite vein is present at a depth of 21 ft (6.4 m). A ^{14}C date of 5.84 ± 0.85 ka was obtained from the calcite vein. The base of the overbank unit is characterized by a rapid fining downward sequence to interlaminated clay and silt and an abrupt irregular contact with the underlying medium-to-coarse sand of unit 2. Unit 2, spanning from 35.5 to 82 ft (10.8-25 m) in the core is texturally homogenous medium-to-coarse fluvial channel sand with some gravel and minor cross and parallel laminations. An OSL age of 11.53 ± 0.36 ka was obtained from unit 2 at a depth of 71 ft (21.7 m). From 82 to 83.5 ft (25-25.5 m) is unit 3, a bioturbated coarse silt to very-fine sand that is interpreted as a paleosol due to the presence of burrows, root traces, and elevated magnetism in the volume magnetic susceptibility curve (Fig. 8). This paleosol exhibits somewhat abrupt contacts with the underlying and overlying sand. Unit 4, from 83.5 to 104 ft (25.5-31.7 m) in the core, is a discrete alluvial channel unit composed of medium-to-coarse sand and gravel with better developed cross-stratification than observed in the overlying sand and gravel unit. The contact between unit 4 and the underlying unit 5 is characterized by an abrupt increase in modal grain size at 104 ft (31.7 m). Unit 5 is the basal unit ranging from 104 to 117 ft (31.7-35 m) in the core, and is a coarse-to-very-coarse sand and gravel deposit. Cross-beds with abrupt contacts between gravel rich beds and coarse sand beds are clearly evident within unit 5. The OSL age of this basal channel sand is 20.32 ± 0.63 ka at a depth of 112 ft (34.2 m). The scoured and irregular contact with the underlying Eocene Upper Claiborne Group is captured in a sample tube at 117 ft (35.6 m). Beneath unit 5, from 117 to 132 ft (31.7-40.3 m) is dense, Eocene lignite.

Discussion of the Meeman-Shelby Fault and Joiner Ridge Horst Cores

Stratigraphic Interpretation of the Meeman-Shelby Core

The uppermost 119 ft (36.3 m) (units 1-5) of the Meeman-Shelby core constitute an upward fining point-bar and overbank floodplain alluvial section typical of meandering rivers (e.g. Reineck and Singh, 1975; Smith, 1983; Miall, 1996; Bierman and Montgomery, 2014). The age of this alluvial section is 4.28 ± 0.25 ka at a depth of 43 ft (13.1 m) and 5.20 ± 0.21 ka at a depth of 79 ft (24.1 m). Because the Mississippi River has been meandering since 11.3 ka (Rittenour et al., 2007), these ages corroborate our Holocene Mississippi River point bar and overbank stratigraphic interpretation (Fig. 7). A Pleistocene alluvial channel deposit that consists of coarse sand with a sandy gravel interval near the base are preserved from 119 to 133.5 ft (36.3-40.7 m) (unit 6). This sandy gravel interval between 119 and 133.5 ft (36.3-40.7 m) appears to be a channel facies of 14.30 ± 0.50 ka Blodgett (13 ka) or Kennett(16-14 ka) alluvium (Rittenour et al., 2005; 2007).

We believe that this core stratigraphy reflects a late Pleistocene and Holocene depositional and erosional history. Our interpretation is a Kennett sequence existed at this location 14.30 ka. The original thickness of the Kennett floodplain sequence is unknown but was probably as thick as the overlying Holocene floodplain alluvium since northwest of the Meeman-Shelby S1 core site the alluvium beneath the Kennett terrace may be 180 ft (54.9 m) thick (Van Arsdale et al., 2014). During the early Holocene, the Mississippi River eroded the upper portion of the Kennett alluvium and deposited the 119 ft (36.3 m) of 5.2 ka and younger Holocene point bar and overbank alluvium. It is possible that the Holocene erosion of the Kennett floodplain alluvium occurred earlier than 5.20 ka because the 5.20 ka alluvium age was obtained 40 ft (12.2 m) above the base of the Holocene alluvium. It is also possible that the lower portion of our interpreted Holocene alluvium (lowermost unit 4 and unit 5) is actually 12 ka Morehouse alluvium. It would be necessary to OSL date the alluvium near 110 ft (33.5 m) in depth to test these possibilities.

Stratigraphic Interpretation of the Joiner Ridge Core

The stratigraphy of the Joiner Ridge core consists of 6.25 ka Mississippi River overbank sediment from the ground surface to a depth of 35.5 ft (10.8 m) (unit 1), which overlies late Wisconsin deposits that are probably braided river glacial outwash sediments (Fig. 8). The calcite nodules and 5.84 ka calcite vein are of unknown origin but probably precipitated during the mid-Holocene drought described by Ohring (2014). The fact that the vein cross-cuts the 6.25 ka alluvium supports both the ^{14}C and OSL dates. From 35.5 to 82 feet (10.8-25 m) (unit 2) lies 11.53 ka Morehouse channel alluvium. A paleosol lies immediately beneath the Morehouse alluvium (unit 3), thus revealing a period of subaerial exposure of the top of the underlying and undated "Kennett channel" alluvium (unit 4). The undated unit from 83.5 to 104 ft (25.5-31.7 m) (unit 4) is interpreted to be Kennett channel alluvium because it is texturally distinct from the dated overlying and underlying alluvial units. Between the depths of 104 and 117 ft (31.7-35.6 m) (unit 5) is 20.32 ka Sikeston outwash alluvium that is cross-bedded, very coarse sand and gravel (Rittenour et al., 2007).

Conclusions

Two continuous cores were drilled, described, analyzed, and radiometrically dated in the Eastern Lowlands of the Mississippi River valley near Memphis, Tennessee (Fig. 1). At both sites the cores were collected on subsurface structural horsts with reported Quaternary vertical displacement. Drilling site S1 located 5 miles (8 km) west of Memphis, cored through Quaternary alluvium in the Meeman-Shelby horst, which is bounded on its east by the Meeman-Shelby fault and on its west by the West Meeman-Shelby fault (Figs. 1, 3, and 5). Drilling site S2, located 32 miles (52 km) northwest of Memphis, cored through Quaternary alluvium in the Joiner Ridge horst (Figs. 1 and 2). Both cores penetrated Eocene Upper Claiborne strata at their base and so the entire Quaternary alluvial (floodplain) section was captured at both locations (Fig. 7 and 8). Although both cores reveal Quaternary alluvium, the age chronology and stratigraphy of the deposits are quite different. Based on the ages of the terrace and floodplain sediments revealed in this study, the age of the surface sediment is not the same age as the entire underlying alluvial section.

The general late Quaternary erosional and depositional history of the two core sites can be assessed; however, we do not consider possible contemporaneous uplift on the two horsts because we do not have sufficient information to do so. The Meeman-Shelby core reveals 119 ft (36.3 m) of Holocene Mississippi River alluvium overlying the remnant of a 14.30 ka probable Kennett river (ancestral Ohio River) alluvial section. Thus, it appears that an unknown thickness of the uppermost Kennett floodplain was eroded by the laterally migrating Holocene Mississippi River. This Kennett basal floodplain remnant was subsequently buried as a Holocene Mississippi River meander channel and point bar sequence was deposited over the site. We propose that the S1 core represents a "type section" of the Holocene Mississippi River alluvium that may be applicable as a model for big rivers elsewhere in the world.

The Joiner ridge core reveals 35.5 ft (10.8 m) of Holocene Mississippi River overbank sediment overlying 11.53 ka Morehouse alluvium, which in turn overlies probable Kennett alluvium. Kennett alluvium overlies 20.32 ka Sikeston alluvium, which in turn extends to the base of the Quaternary. The history at this site is interpreted to be: 1) deposition of the Sikeston floodplain possibly to the height of the modern Mississippi River floodplain, 2) erosion of most of the Sikeston floodplain and deposition of the Kennett alluvium to a current depth of 82 ft (25 m), 3) formation of a soil on the Kennett alluvium, 4) deposition of the Morehouse alluvium, and 5) deposition of the Holocene overbank alluvium.

Previous research has documented that the alluvial section is vertically displaced by faulting near both S1 and S2 core sites (Odum et al., 2010; Hao et al., 2013; Van Arsdale and

Cupples, 2013). At site S1 our data reveal that the base of the alluvium is 14.30 ka and the displacement is 92 ft (28 m). This results in a displacement rate of 2 mm/yr for the Meeman-Shelby fault over the past 14.3 ka. At the Joiner Ridge S2 site the base of the alluvium is 20.32 ka and the displacement is 66 ft (20 m) resulting in a displacement rate of 1 mm/yr. Both of these estimates are likely minimum slip rates because these determinations are for vertical slip only and both faults have been reported to be transpressive structures and thus may also have late Quaternary strike slip displacement (Hao et al., 2013; Van Arsdale and Cupples, 2013).

This report and its more detailed companion study by Ward (2016) have documented a rather novel approach to studying active tectonics in the Mississippi River Valley. Our study is also a proof-of-concept to test whether reliable continuous cores (good recovery) could be collected through the entire section of unconsolidated Mississippi River alluvium. A parallel test was to ascertain whether the continuous cores could be collected so that light-sensitive OSL sediment samples could be later extracted from the cores for dating of the alluvium. Both of these tests were successfully completed, and therefore we have developed a protocol for conducting this type of active tectonic, stratigraphic, and geomorphic analyses that can be applied throughout the Mississippi River Valley and used globally in other large river valleys.

We close by stating that to fully accept the slip rates determined for the Meeman-Shelby and Joiner ridge structures herein reported it will be necessary to continuously core on the downthrown sides of these faults to confirm that the displaced basal alluvium is the same age on both sides of the respective faults. This proposed second coring program may also reveal a detailed slip history through identification of a number of displaced identical units on opposite sides of the faults.

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