10-23-2015

Investigation of the Reelfoot South Fault in Northwestern Tennessee

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INVESTIGATION OF THE REELFOOT SOUTH FAULT IN NORTHWESTERN TENNESSEE

by

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A Thesis

Submitted in Partial Fulfillment of the

Requirements for the Degree of

Master of Science

Major: Earth Sciences

The University of Memphis

December 2015

ACKNOWLEDGMENTS

Completion of this thesis would not have been possible without the support from numerous people. First and foremost I would like to thank my loving wife, Emily, who without her none of this would have been possible. Her encouragement and patience with me was my anchor. My advisor, Dr. Van Arsdale, was instrumental in this project by providing me with the tools needed to undertake this task. Dr. Van Arsdale provided invaluable insight for this project and taught me how to conduct research and to never leave any stone unturned.

My other committee members, Dr. Lumsden and Dr. Cox, also supported with their suggestions and edits. The faculty and other graduate students here at the University of Memphis, also supported me through their comments and encouragement.

Dr. Woolery from the University of Kentucky acquired and processed the seismic reflection data, without which this project would not have been completed. I would also like to acknowledge William Stephenson from the U.S. Geological Survey for his input and contributions to this project. I would also like to acknowledge the U.S. Geological Survey who provided funding for this project under the NEHRP grant number G14AP00013.

Finally, I would also like to thank my family, without them I would not be here accomplishing my dreams. My parents, Martha and Stuart Greenwood, gave me moral support when I needed it the most, allowing me never to settle in life. My brother and his wife, Andrew and Mandy Greenwood, also supported me in this endeavor through always reminding me not to sweat the little things and to laugh once and a while.

ABSTRACT

Greenwood, Matthew Lewis. M.S. Earth Sciences. The University of Memphis. December 2015. Investigation of the Reelfoot South Fault in Northwestern Tennessee. Major Professor: Dr. Roy Van Arsdale.

The Reelfoot reverse fault, a major northwest-striking and southwest-dipping fault within the New Madrid seismic zone, is projected to cross from the Mississippi River floodplain into the loess-covered Mississippi River bluffs immediately southeast of Reelfoot Lake in northwestern Tennessee. A pressing problem is whether the Reelfoot fault (and its associated Tiptonville dome) crosses the northeast-striking Axial fault zone as one continuous fault or is segmented into two discreet faults (the Reelfoot North and the Reelfoot South faults). This investigation uses geologic mapping, geomorphic analysis, and seismic reflection to locate and determine the history of the Reelfoot (South) fault within the Mississippi River bluffs. A geologic profile of the ~3.1 Ma Upland Complex (Mississippi River terrace) within the Mississippi River bluffs reveals an apparent ~6 m of up-to-the-south displacement at the location of the projection of the Reelfoot (South) fault. Six meter high creek terraces within the bluffs are primarily confined to the Tiptonville dome thus indicating ~6 m of late Wisconsin or Holocene uplift on the Reelfoot fault and Tiptonville dome. Gravel pit distribution and anomalous stream orientations also support the Reelfoot (South) fault passing into the bluffs.

Seismic reflection profiles acquired for this investigation reveals the Reelfoot (South) fault displaces the tops of the Paleozoic section 65 m, Cretaceous 40 m, Paleocene Porters Creek Clay 31 m, Eocene Wilcox Group 20 m, and Eocene Memphis Sand 16 m within the bluffs. A previously uninterpreted reflection profile completed by the USGS in 2008 reveals an up-to-the-north reverse fault 4.3 km south of the Reelfoot

fault that displaces the top of the Paleozoic section 20 m and top of the Memphis Sand 6 m. This fault, or backthrust, of the Reelfoot South fault appears to be the southwest margin of the Tiptonville dome.

Comparison of previous seismic reflection lines completed both northwest and southeast of the seismic reflection lines acquired for this project, reveals similar displacement histories on common stratigraphic reflectors suggesting that the Reelfoot fault has been one continuous fault zone across the Axial fault zone. The Reelfoot fault is also not laterally offset across the Axial fault zone further supporting that the Reelfoot fault is one continuous fault.

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INTRODUCTION

1.1 The New Madrid Seismic Zone

The New Madrid seismic zone (NMSZ) in the central United States is an area of continued research due to its seismicity and in particular because it was the site of three large earthquakes during the winter months of 1811-1812 (16 December 1811, 23 January 1812, and 7 February 1812) (Fig. 1) (Johnston, 1996; Johnston and Schweig, 1996; Cramer and Boyd, 2014). The NMSZ earthquakes are occurring along a northeast-trending, right-lateral strike-slip fault system with a left-stepover compressional zone (Fig. 2) (Purser and Van Arsdale, 1998; Van Arsdale, 2000) within the Mississippi embayment, a broad southwest-plunging erosional trough filled with poorly consolidated late Cretaceous and Paleogene shallow marine and fluvial sediments (Cox and Van Arsdale, 1997; Purser and Van Arsdale, 1998).

This embayment is underlain by the Reelfoot rift, which has been interpreted as a Cambrian aulacogen whose reactivated basement faults appear to be the source for this region's seismicity (Chiu et al., 1992; Hildenbrand and Hendricks, 1995; Csontos, 2007; Csontos et al., 2008; Csontos and Van Arsdale, 2008). The Reelfoot fault lies within the central segment of the NMSZ and is a northwest-striking and southwest-dipping reverse fault (stepover zone) (Fig. 2) (Csontos et al., 2008; Csontos and Van Arsdale, 2008). Johnston and Schweig (1996) argue that displacement on one segment of the New Madrid fault system loads the adjoining segments, resulting in three major faulting events occurring close together in time.

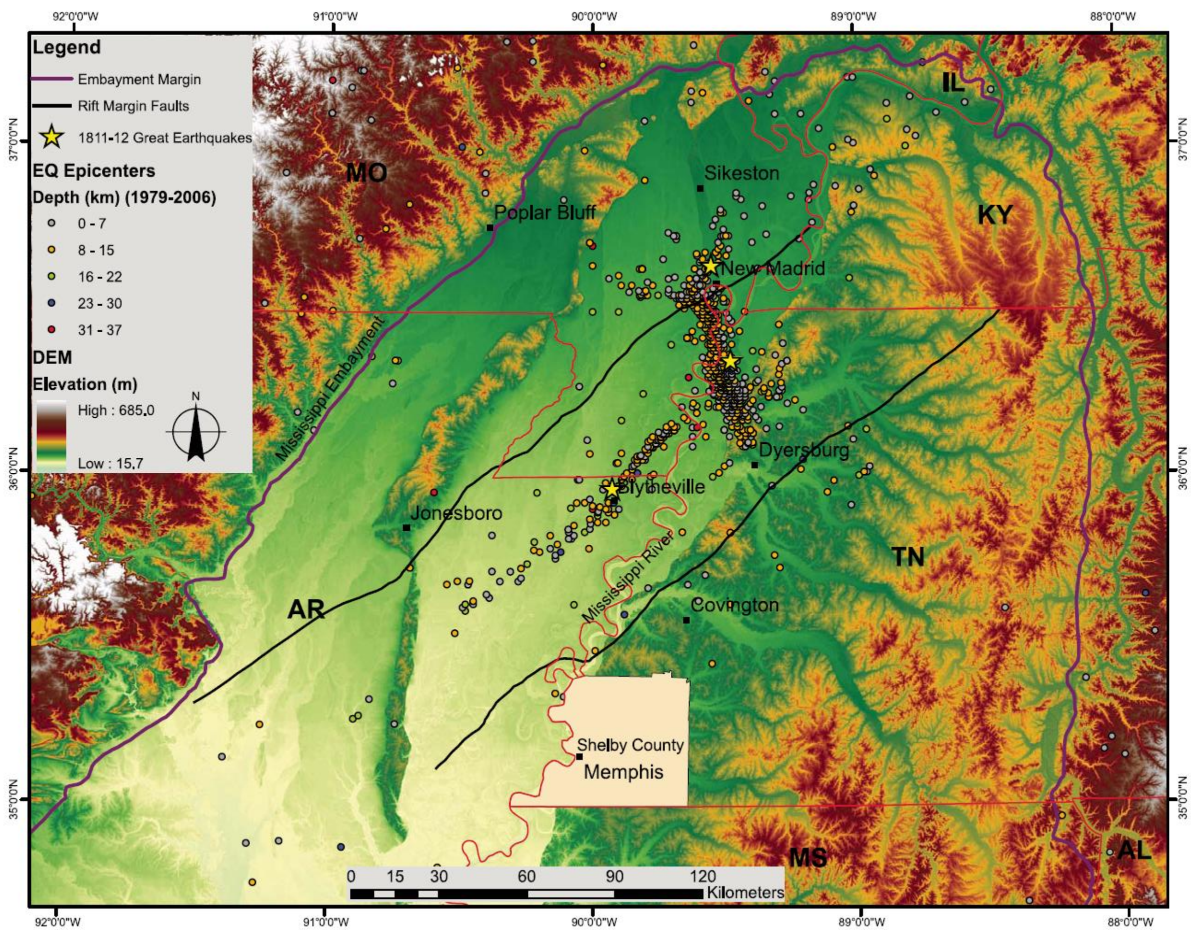

Figure 1. Location of the northern Mississippi embayment, Reelfoot rift, and New Madrid seismic zone earthquake epicenters shown as small circles (from Csontos and Van Arsdale, 2008). The southern star near Blytheville, Arkansas is an estimate of the epicenter of the 16 December 1811 **M** 7.5 earthquake, northern star the 23 January 1812 **M** 7.3 earthquake, and the middle star the 7 February 1812 **M** 7.7 earthquake (Johnston and Schweig, 1996; Cramer and Boyd, 2014).

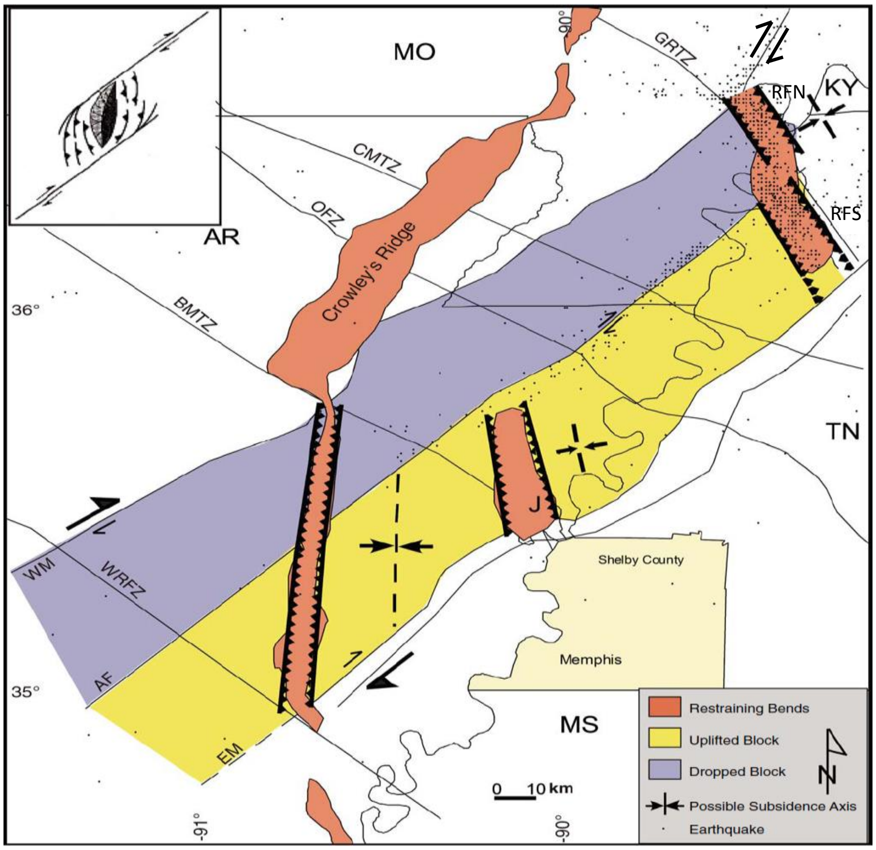

Figure 2. Orientation and extent of fault geometry within the New Madrid seismic zone region (from Csontos and Van Arsdale, 2008). Black lines—faults; Heavy lines with teeth—uplifted blocks. J—Joiner Ridge; GRTZ—Grand River Tectonic Zone; CMTZ—Central Missouri Tectonic Zone; OFZ—Osceola Fault Zone; BMTZ—Bolivar-Mansfield Tectonic Zone; WRFZ—White River Fault Zone; EM—Eastern Rift Margin faults; AF—Axial fault; WM—Western Margin fault; RFN—Reelfoot North fault; RFS—Reelfoot South fault. Inset map shows restraining bend model for stepovers.

The Reelfoot fault is responsible for much of the current seismicity in the area, and is believed to be the source for the largest of the three large New Madrid earthquakes of 1811-1812 (Johnston and Schweig, 1996; Cramer and Boyd, 2014). The Reelfoot fault has recently been interpreted to consist of two segments – the Reelfoot North and Reelfoot South segments (Csontos and Van Arsdale, 2008). The Reelfoot North fault connects two northeast striking right-lateral faults (WM and AF of Figure 2) and the Reelfoot South fault connects the other two northeast striking right-lateral faults (AF and EM of Figure 2) (Csontos and Van Arsdale, 2008).

1.2 Geology Near Reelfoot Lake, Tennessee

The surface geology and geomorphology changes along the Reelfoot fault southeast of Reelfoot Lake. Reelfoot Lake basin and its surrounding Mississippi River floodplain is underlain by about 50 meters of Holocene Mississippi River alluvium (Rittenour et al., 2007; Csontos et al., 2008). Moving southeast into the Mississippi River bluffs, which abruptly rise 50 m above the adjacent floodplain, are exposed Eocene, Pliocene, Pleistocene, and Holocene sediments. The oldest exposed stratum is the late Eocene Jackson Formation composed of sand, silt, lignite, and clay (Miller et al., 1966; Blythe et al., 1975), although a more recent study mapped this exposed stratum as the underlying late Eocene upper Claiborne Formation (Fig. 3) (Hart et al., 2008).

Eocene strata are overlain unconformably by a Pliocene sand and gravel unit called the Upland Complex (previously known as the Layfayette Formation), which is the remnant of a high-level terrace of the Pliocene Mississippi-Ohio River system (Van Arsdale et al., 2007). The Upland Complex has been dated at 3.1 Ma near Memphis, Tennessee (Van Arsdale et al., 2014). This is in turn overlain by at least three Pleistocene

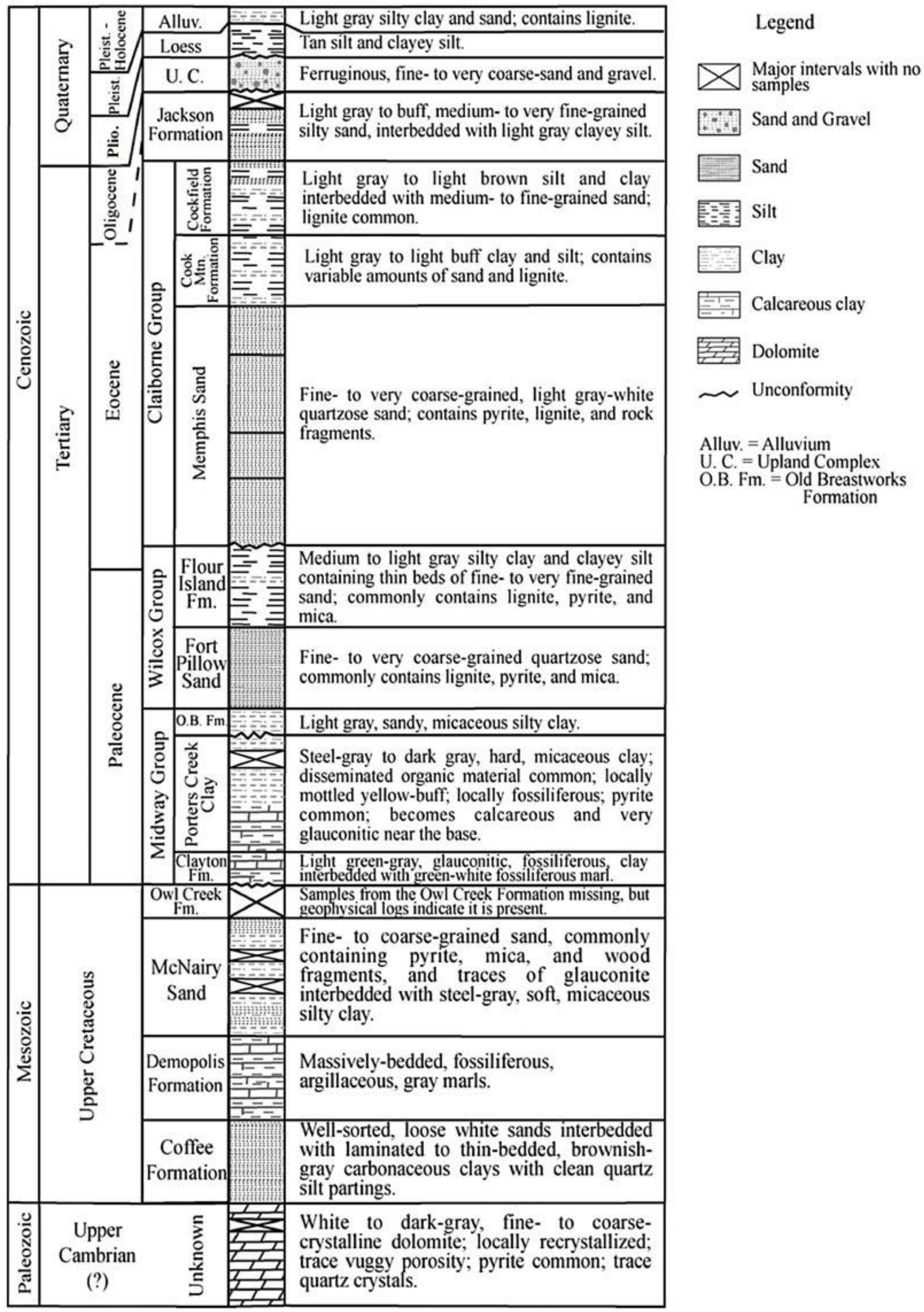

Figure 3. Stratigraphy of the New Madrid seismic zone region (modified from Crone,1981).

loess deposits, which collectively are as much as 30 m thick, and thin eastward (Rodbell et al., 1997; Markewich et al., 1998). These bluffs are highly dissected by small streams and its margin has been modified by landslides (Jibson and Keefer, 1988).

The subsurface geology within and around the Reelfoot Lake basin in descending order includes Eocene fluvial and marine sediments of the Claiborne Group, which is the thickest stratigraphic interval of Paleogene sediments in the northern Mississippi embayment. This Group is underlain unconformably by a series of Paleocene/Eocene near-shore marine and fluvial sands and silts, interbedded with silty micaceous clays known as the Wilcox Group (Crone, 1981).

Below the Wilcox Group lies the Midway Group, which primarily consists of an early Paleocene marine formation known as the Porters Creek Clay. The Porters Creek Clay consists of steel-gray to dark gray, hard, micaceous clay that becomes calcareous and very glauconitic near its base (Crone, 1981). Upper Cretaceous fluvial and marine sediments underlie the Midway Group and include fluvial sands and silty clays of the McNairy Sand. Fine to coarse-crystalline dolomite comprises the immediately underlying Paleozoic section (Fig. 3).

1.3 Reelfoot Fault

Stearns (1979) and Van Arsdale et al. (1995) mapped the northern portion of the Reelfoot fault from the southwest corner of Reelfoot Lake to New Madrid, Missouri, giving the surface rupture length of the Reelfoot fault to be approximately 32 km. A subsequent investigation by Van Arsdale et al. (2013) argues for an extension of the Reelfoot fault by another 14.5 km northwest of New Madrid, Missouri. Further attempts to document the length and continuity on the Reelfoot fault revealed that the fault extends to the southeast (Fig. 4) (Van Arsdale et al., 1999). Contemporary seismicity and subtle geomorphic evidence suggests that the Reelfoot fault extends southeast of the Mississippi River bluff line to near Dyersburg, Tennessee, giving a total length of 84.5 km (Fig. 4). This 84.5 km length of the Reelfoot fault also gives more validity to its role in producing the February 7, 1812 earthquake, the largest of the three New Madrid earthquakes most recently estimated to have been M 7.7 (Cramer and Boyd, 2014). However, it has been argued by some that the Reelfoot fault is not one continuous fault, but is composed of two discreet faults, the Reelfoot North and the Reelfoot South faults, that are separated by the northeast-striking right-lateral strike-slip Axial Fault zone just south of Reelfoot Lake (Fig. 2) (Csontos and Van Arsdale 2008).

Csontos and Van Arsdale (2008) proposed that the Reelfoot fault is actually composed of two left-stepping restraining bends and that the Reelfoot North and Reelfoot South faults together extend across the entire width of the Reelfoot rift. The evidence for two segments of the Reelfoot fault is based on differing fault dips and estimated displacement of the top of the Precambrian between the northern and southern segments of the Reelfoot fault. Determining the true geometry of the Reelfoot fault, namely its continuation or bisection by the Axial fault zone, is important since it would affect the potential earthquake magnitude and possibly its recurrence interval. Thus it is necessary to determine whether the 84.5 km long Reelfoot fault actually does consist of two discrete faults.

The Reelfoot fault has also been investigated with respect to its hanging wall deformation known as the Lake County uplift (Russ, 1979; 1982; Purser and Van Arsdale, 1998). The Lake County uplift, which includes the Tiptonville dome

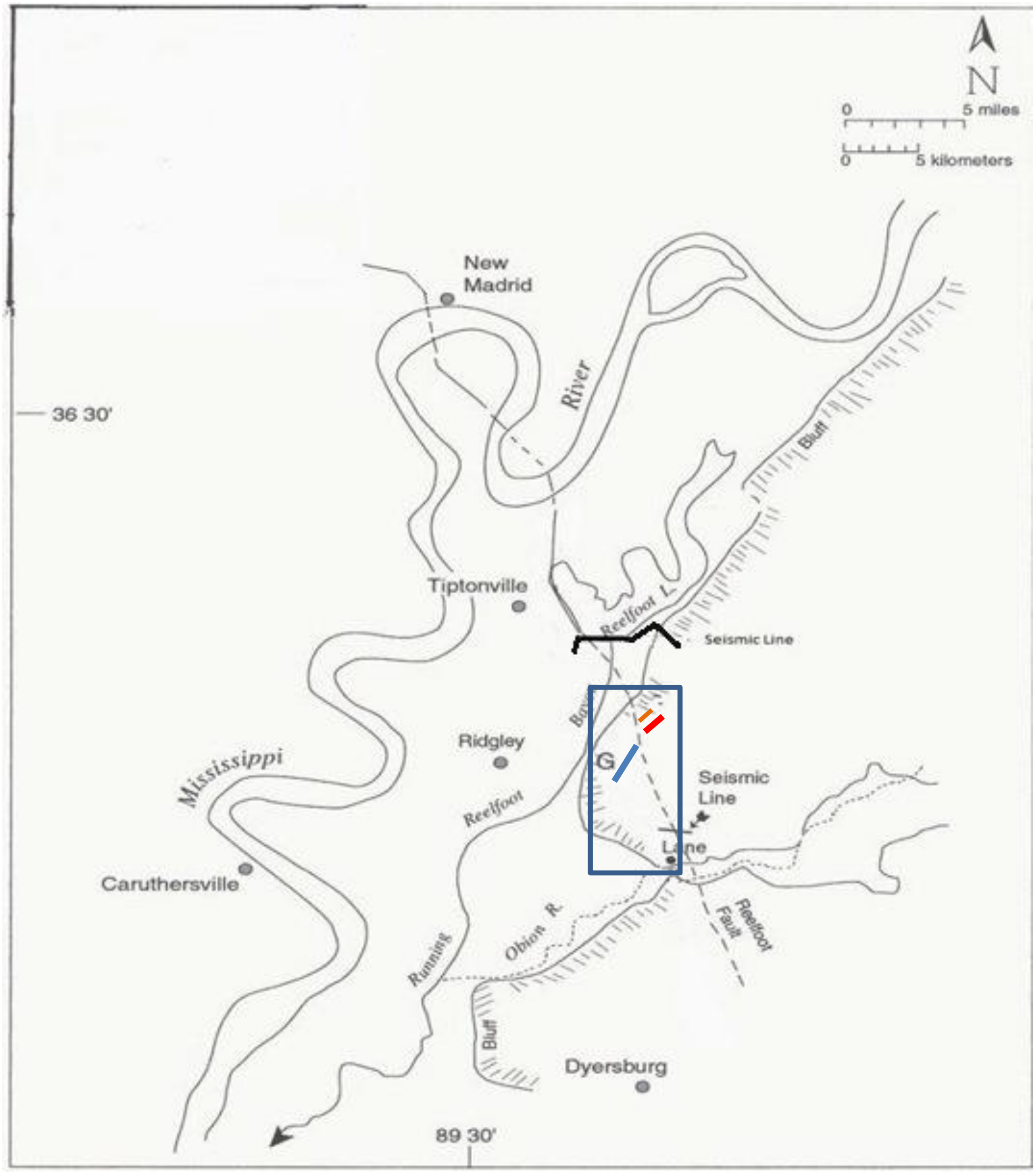

Figure 4. Proposed extent of the Reelfoot fault from New Madrid, Missouri to near Dyersburg, Tennessee. Solid lines are where there is control on the location of the fault, and dashed lines are projections based primarily on seismicity (modified from Van Arsdale et al., 1999). Box is study area of Figure 9. Blue line is an unpublished 2008 USGS seismic reflection line and the red (seismic line A) and orange (seismic line B) lines are seismic reflection lines acquired for this study.

culmination, occurs within the compressional step-over zone, and is bound on the northeast by the Reelfoot fault (Fig. 5A). Purser and Van Arsdale (1998) claim that these topographic and structural highs are the result of deformation in the hanging wall above the Reelfoot thrust fault. Specifically, it is believed that the structural geometry of the Lake County uplift and Tiptonville dome are related to the changing dip of the Reelfoot fault with depth (Fig. 5B). Through seismic reflection (Van Arsdale et al., 1998) as well as microearthquake studies (Pujol et al., 1997; Purser and Van Arsdale, 1998) it appears that the Reelfoot fault dips 73° in the near-surface to a depth of 4 km and then dips 32° to a depth of 12 km before flattening out (Fig. 5B).

This geometry coupled with the fault-bend model suggest that kink bands or back thrusts originate at these fault dip changes, producing the boundaries of the Lake County uplift and the Tiptonville dome (Fig. 5B). If the Reelfoot North and South faults are continuous, this deformation model suggests the Reelfoot South fault in the Mississippi River bluffs could also be accompanied by backthrusts, and thus define a southeastern continuation of the Lake County uplift and Tiptonville dome.

Seismic reflection studies were completed just northwest and southeast of the Mississippi River bluffs across the Reelfoot fault, one at the southern margin of Reelfoot Lake and the other just north of Lane, Tennessee (Figs. 4, 6, and 7) to better constrain the type and amount of fault displacement to a depth of approximately 900 m (Van Arsdale et al., 1998; Van Arsdale et al., 1999). The seismic reflection along the southern margin of Reelfoot Lake imaged 70 m of displacement at the top of the Paleozoic, 60 m at the top of the Cretaceous, 40 m at the top of the Porters Creek Clay Formation, 30 m at the top of the Wilcox Group, and 15 m at the top of the Eocene section/base of the

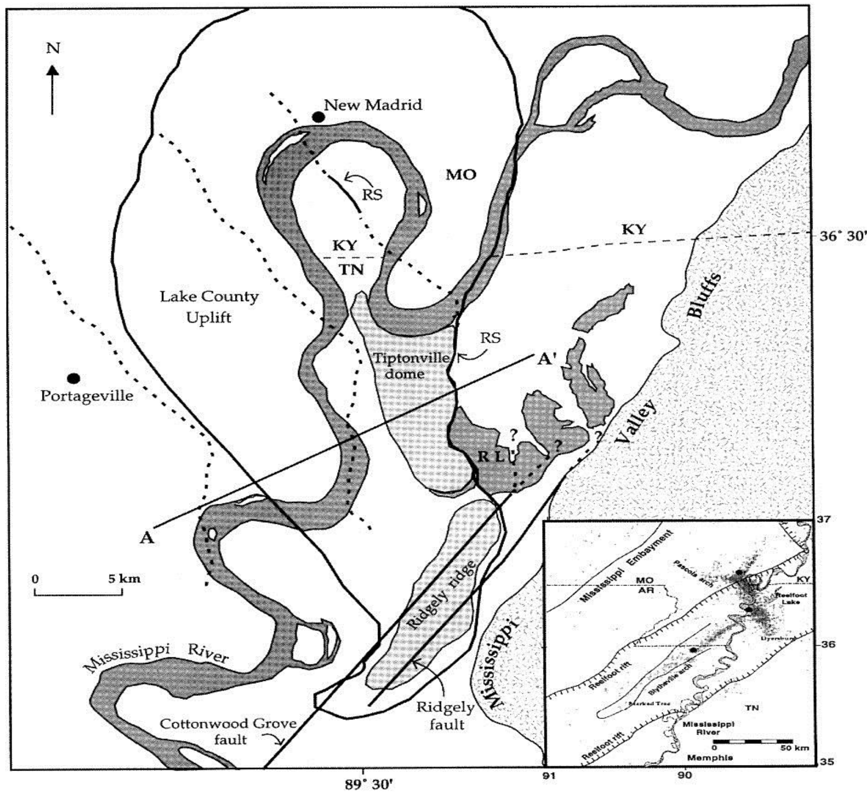

Figure 5A. The Lake County uplift and vicinity. Solid line marks boundary of the Lake County uplift, and dotted lines are proposed kink bands (backthrusts) (from Purser and Van Arsdale, 1998). Cross section A-A' is illustrated in Figure 5B.

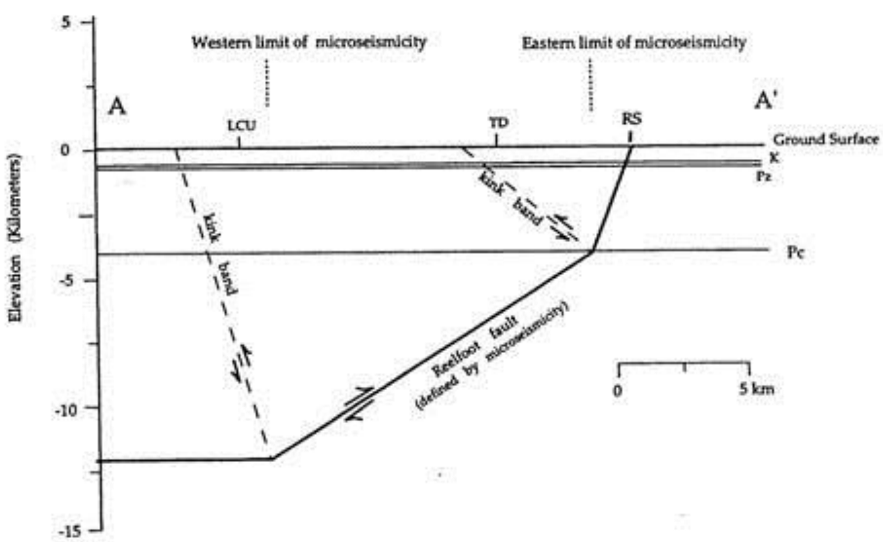

Figure 5B. Cross section of the Reelfoot fault using the fault-bend fold model. K = top of Cretaceous; Pz = top of Paleozoic; Pc = top of Precambrian; LCU = Lake County uplift western margin; TD = Tiptonville dome western margin; RS = Reelfoot scarp, which is the eastern margin of the Lake County uplift and Tiptonville dome (from Purser and Van Arsdale, 1998).

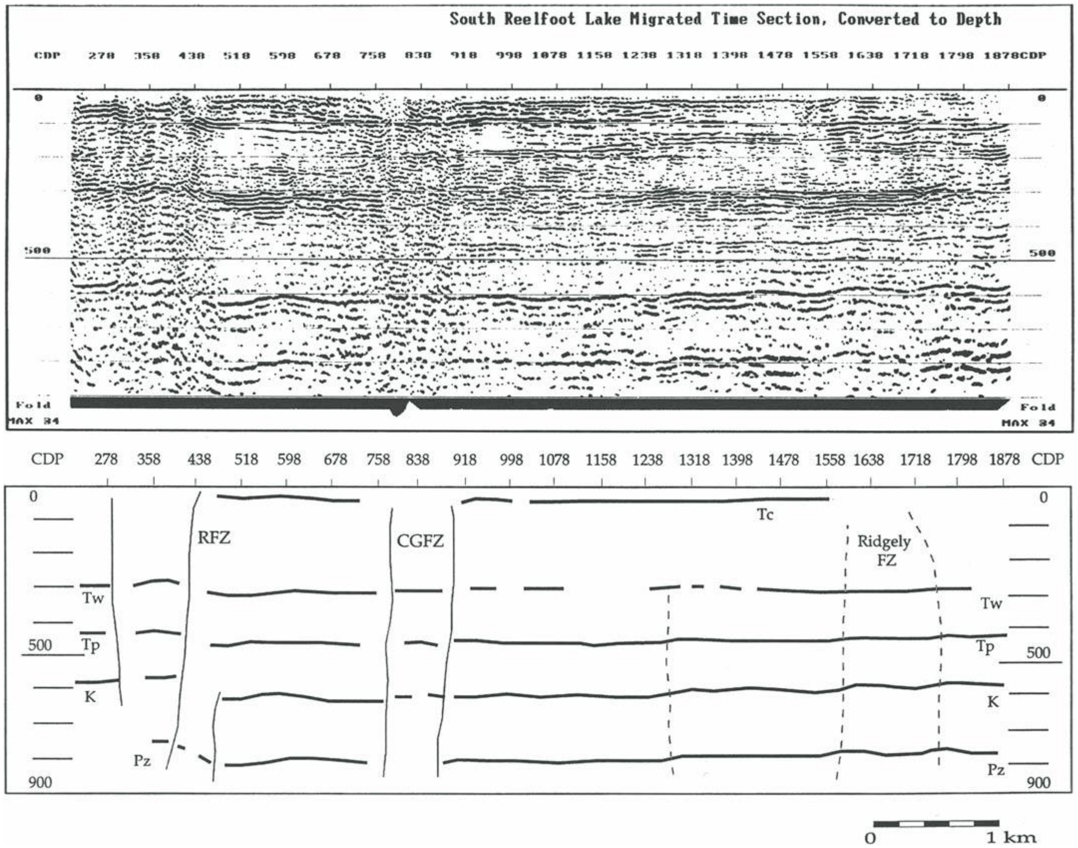

Figure 6. The 7.5-km-long Reelfoot Lake Mini-Sosie seismic reflection profile. Vertical exaggeration is 2.7. The vertical axis is in meters. RFZ = Reelfoot fault zone, CGF = Cottonwood Grove fault, Tc = Tertiary Claiborne, Tw = Tertiary Wilcox, Tp = Tertiary Porters Creek, K = Cretaceous, Pz = Paleozoic (from Van Arsdale et al., 1998).

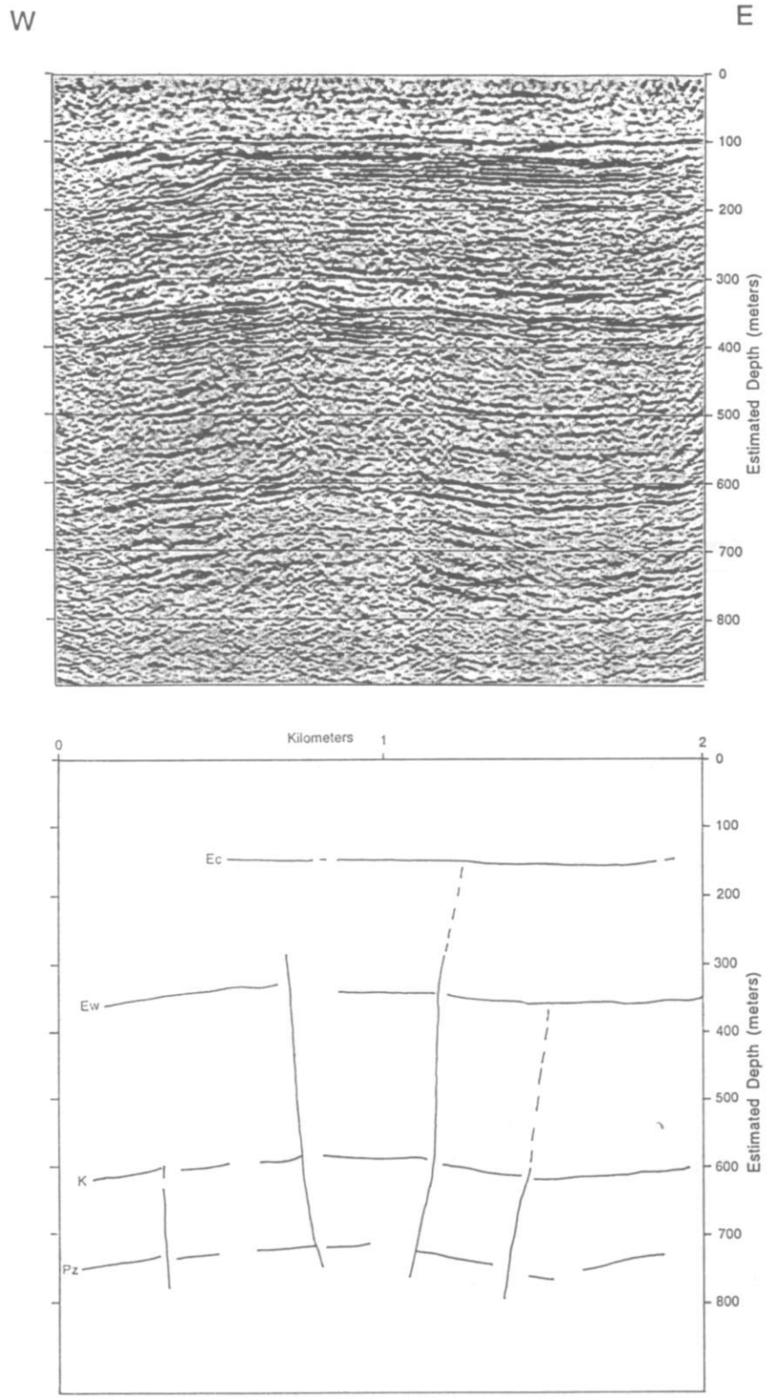

Figure 7. Top: 2 km-long Mini-Sosie seismic-reflection line near Lane, Tennessee located in Figure 4. Bottom: Geologic interpretation of the Lane seismic line. Ec = reflector in Eocene Claiborne Group, Ew = top of Eocene Wilcox Group, K = top of Cretaceous, Pz = top of Paleozoic. Vertical exaggeration is 2X (from Van Arsdale et al., 1999).

Quaternary section (Van Arsdale et al., 1998). In comparison, displacement seen on the Lane seismic line showed 40 m at the top of the Paleozoic with displacement diminishing up-section and no deformation being apparent at depths less than 120 m (Fig. 7) (Van Arsdale et al., 1999). This increasing displacement with depth also indicates that the fault has been reactivated through time (Sexton and Jones, 1986; Van Arsdale et al., 1998). An additional unpublished seismic reflection line, completed in 2008 by the USGS, was shot starting at Gratio, Tennessee and continued 4.08 km north along Bluff Line Road ending just south (approximately 1.0 km) of the seismic lines done for this project and is interpreted in this research.

1.4 Purpose of Study

Extension of the Reelfoot fault to the southeast of Reelfoot Lake, in northwestern Tennessee, was first investigated by Van Arsdale et al. (1999). Despite the absence of a fault scarp southeast of Reelfoot Lake, these researchers concluded that the Reelfoot fault does indeed extend southeast from the Mississippi River floodplain and into the river bluffs (Fig. 4). However, the location of where the fault extended into the bluffs was unknown due to a lack of surface deformation or displacement of near-surface strata and few seismic lines in the area. This apparent lack of Reelfoot fault deformation southeast of Reelfoot Lake was also discussed by Carlson and Guccione (2010). These authors noted substantial variability in the amount of relief along strike of the Reelfoot fault scarp, but found an overall decrease in apparent displacement from New Madrid, Missouri south in Tennessee (Fig. 8). However, Carlson and Guccione (2010) proposed that the Reelfoot fault trends south from Reelfoot Lake and does not trend southeast into the bluffs (Fig. 8A).

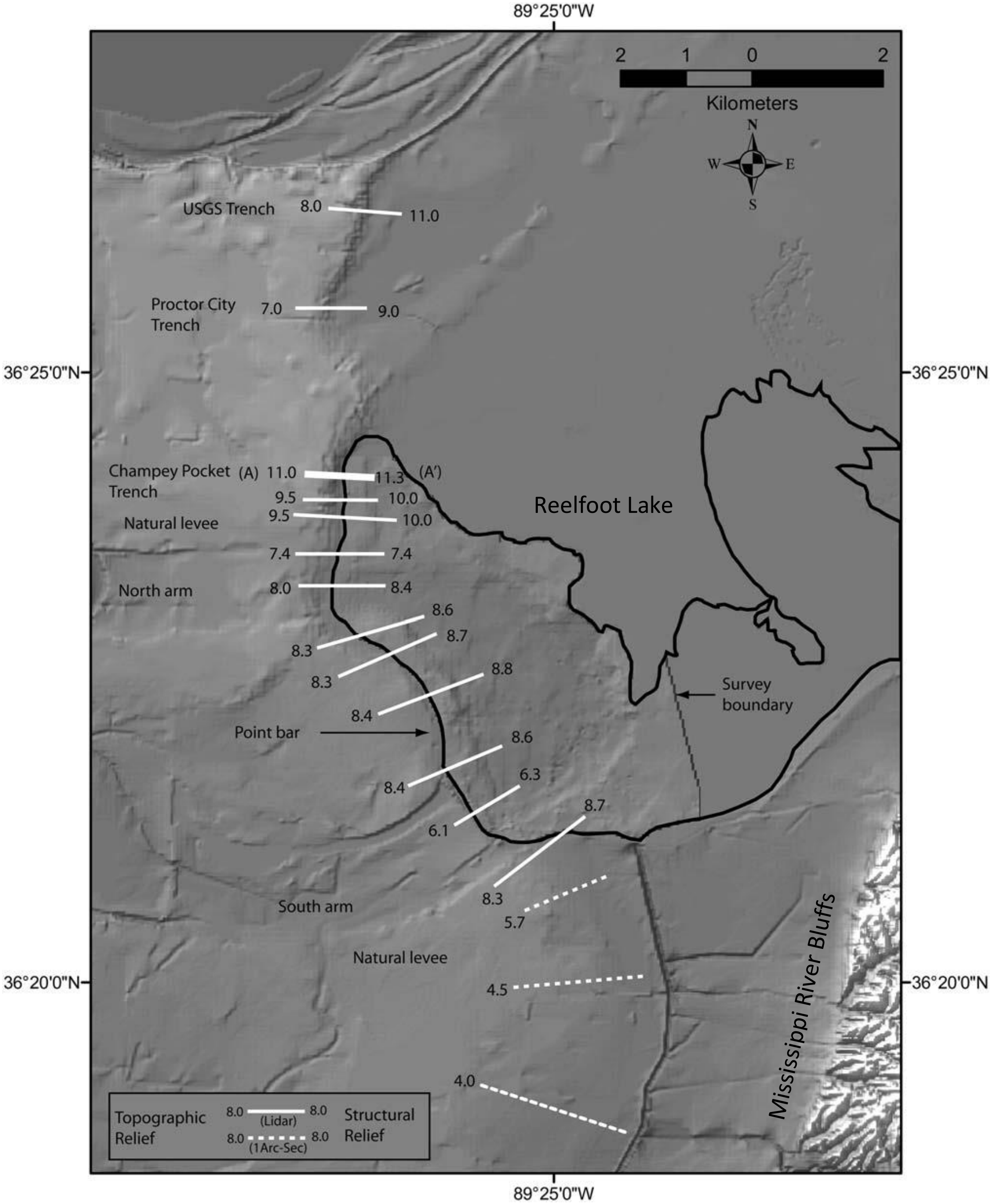

Figure 8A. Topographic and estimated structural relief map showing where measurements for Figure 8B were taken. These authors propose a south trend for the Reelfoot fault south of Reelfoot Lake (from Carlson and Guccione, 2010).

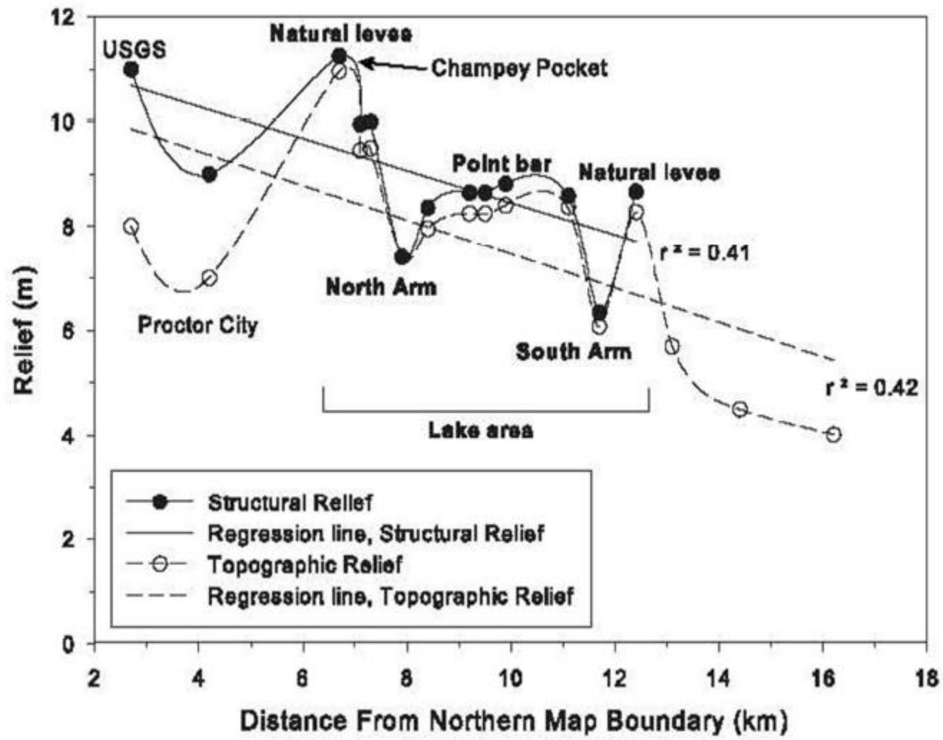

Figure 8B. Topographic and structural relief measurements along the Reelfoot scarp, showing an overall decrease in relief from northwest to southeast along the Reelfoot fault (from Carlson and Guccione, 2010).

It is the purpose of this study to determine if the Reelfoot fault extends southeast of Reelfoot Lake across the Axial fault as one continuous fault. To do this it was necessary to quantify the amount, timing, and type of displacement of any fault found within the Mississippi River bluffs and to compare its history with that previously reported at the southern margin of Reelfoot Lake and at Lane (Figs. 6 and 7) (Van Arsdale et al., 1998; 1999).

CHAPTER 2

METHODS

2.1 Geologic Mapping

To determine whether and where the Reelfoot fault extends into the Mississippi River bluffs, geologic mapping was conducted southeast of Reelfoot Lake from Lassiters Corner south to Cat Corner and east into the bluffs about 4 kilometers (Fig. 9). Specifically, all creeks within the 4 km by 17 km area in the bluffs were walked, with special attention being paid to the larger creeks that flow west out of the bluffs and onto the Mississippi River/Running Reelfoot Bayou floodplain. Within the creek valleys, exposure locations of top and bottom of the Upland Complex (UC) were determined using GPS in cellular phones to record the latitude and longitude.

Confidence was acquired in the accuracy of the GPS devices after multiple comparison tests were made of easily identifiable landmarks on the Ridgely 7.5 minute topographic map. UC contact locations were then plotted on Light Detection and Ranging (LiDAR) imagery to attain the outcrop's elevation with a LiDAR's vertical accuracy of +/- 9.25 cm. Due to the importance of elevation accuracy, these plotted measurements were cross-checked with physical measurements made in the field, from a readily identifiable stream bed location to the bottom/top of the Upland Complex exposure. Where exposed contacts of the UC did not exist, estimates were made in one of the following three ways: 1) where gravel pits were located the bottom of the pit was approximated to be the elevation of the bottom of the UC, 2) the UC could not exist in

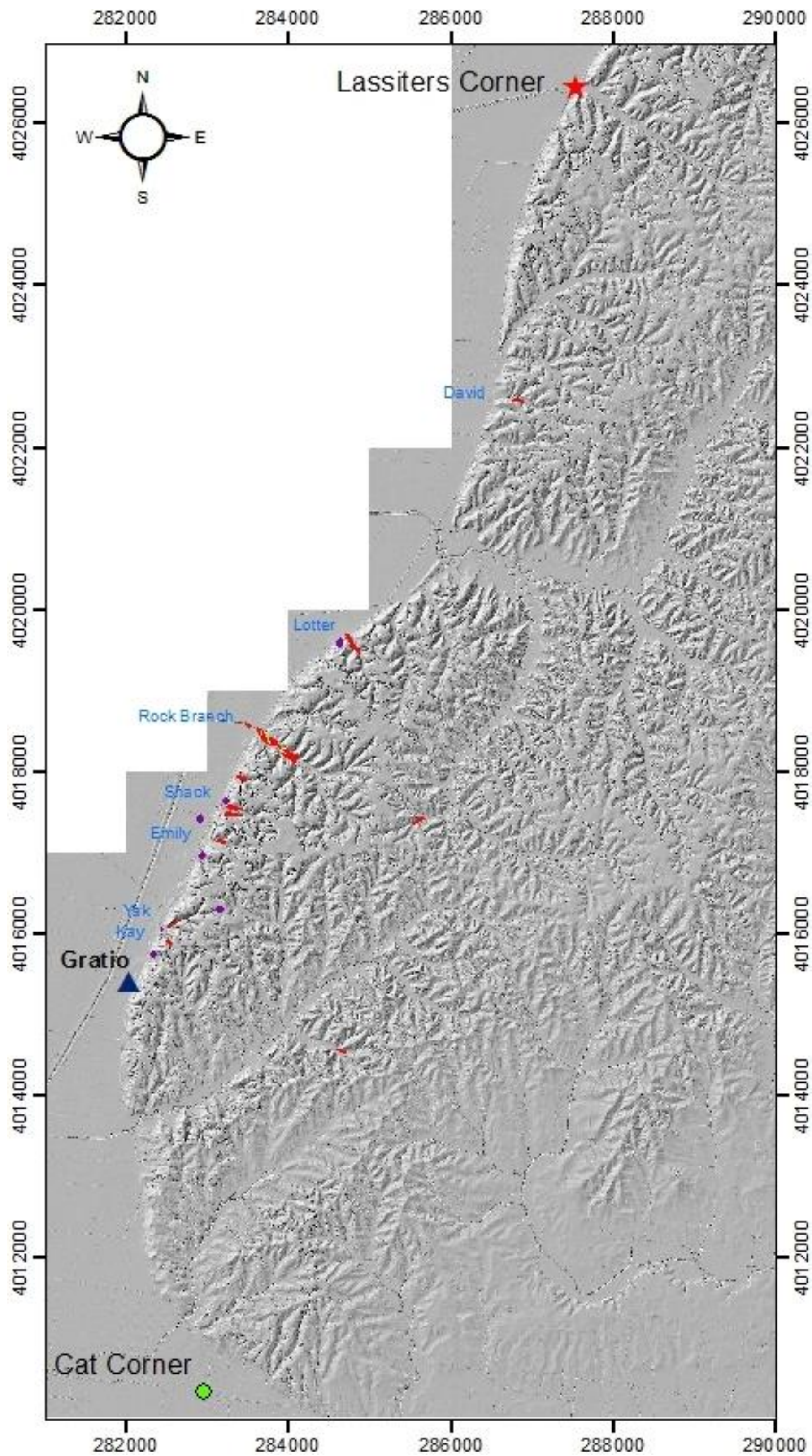

Figure 9. LiDAR image of study area where geologic and geomorphic mapping was conducted. Red polygons are terraces, and purple ovals are gravel pits. UTM coordinates.

the valley walls at an elevation higher than the furthest upstream extent of gravel in the adjacent modern stream bed, 3) a marked change in slope seen in the field and/or in topographic profiles drawn perpendicular to the hillslopes on the LiDAR images suggested a change from the steep loess slope to the less steep underlying UC slope. Once all positions and elevations of the top and bottom contacts of the Upland Complex were compiled, a south-to-north cross section (using Golden Software's Grapher 10 program) was made along the bluff line to look for fault displacement.

2.2 Geomorphic Analysis

Due to the resolution of the LiDAR dataset (vertical +/- 9.25 cm and horizontal +/- 1 m or better) geomorphic analysis within the bluffs was conducted using remote sensing and spatial analysis techniques in both Surfer 12 and ArcGIS 10.2 programs. Surface deformation such as fault scarps, terraces, knickpoints, and creek characteristics were sought out to try and identify any extension of the Reelfoot fault and accompanying structure. Fault scarps were searched for within the LiDAR data through various programs including, Surfer 12, ArcGIS 10.2, and Google Earth Pro, looking for any semi-linear landscape feature in the highly dissected bluffs.

Changing of the vertical exaggeration and aspect as well as viewing the LiDAR dataset in multiple formats including hillshade (shaded relief) and 3D surface were also done in the effort to find any evidence of surface deformation. Creek terraces were also mapped throughout the bluffs using the LiDAR and field observations. For the creeks within the bluffs outside of the walked area, topographic profiles were drawn perpendicular to suspected terraces and visual inspection was undertaken using both hillshade and rotated 3D LiDAR images. Knickpoints and creek characteristics including abrupt changes in orientation were also noted. Drainage analysis was also completed in ArcGIS 10.2 following processes as outlined by the Hydrologic Engineering Center in their Geospatial Hydrologic Modeling Extension Version 1.1 (HEC-GeoHMS) (Doan, 2003). This software allowed the development of a hydrologic model, which collectively described the drainage patterns of the watershed. This information was used to perform a preliminary delineation of the creeks and subbasins.

2.3 Seismic Reflection Analysis

Two seismic reflection lines were acquired where the projection of the Reelfoot fault intersects the bluff line, which was identified in the geologic mapping and geomorphic analysis completed earlier in this project (Fig. 4). Seismic data were acquired and interpreted by Dr. Edward Woolery of the University of Kentucky and myself. The location for these seismic lines was also constrained through the acquisition of 7 seismic soundings spaced 0.5 km apart along Bluff Line Road by Woolery, to look for significant variation in the elevation of major stratigraphic boundaries. Seismic data acquisition parameters are presented in Van Arsdale et al. (2015).

The first reflection line was 1 km long and shot on Bluff Line Road (seismic line A) to locate the Reelfoot fault, while the second 0.33 km long line was shot parallel but in the adjacent field (seismic line B) to acquire greater depth resolution (Fig. 4). Geologic interpretation of the reflectors was attained by comparison with previous seismic reflection investigations in the area (Stephenson et al., 1995; Van Arsdale et al., 1998; 1999). Reflector picks were made on the top of the Memphis Sand, top of the Wilcox Group, top of Porters Creek Clay Formation, top of the Cretaceous, and the top of the Paleozoic section. The ~4 km long seismic line completed by the USGS in 2008 started

1.0 km south of seismic line A, which extended our seismic reflection data all the way to Gratio, Tennessee (Fig. 4). This allowed for a nearly continuous 6 km long reflection line along the bluff line to be investigated for faulting.

Chapter 3

Results

3.1 Geology

Figure 10 is a topographic contour map illustrating where UC exposures were mapped in creek valleys in the Mississippi River bluffs. From these exposures, a south-to-north cross section of the top and bottom of the UC was made (Fig. 11). Approximately 6 m of down-to-the-north displacement is evident on the lower contact of the UC between Lotter Creek and Pictsweet Creek (Figs. 11 and 12). Displacement is not seen on the upper contact, although an overall down-to-the-north slope is apparent in both profiles. A linear regression line north and south of Lotter Creek on the lower UC contact, illustrates a southerly slope south of Lotter Creek and a northerly slope north of Lotter Creek (Fig. 12). Strike and dip measurements were also taken on insitu Eocene bedrock at Yak Creek and at Rock Branch Creek (Fig. 10). At Yak Creek the bedrock dips 9° southwest along a bearing of 225°, while at Rock Branch the dip is horizontal.

3.2 Geomorphology

The locations of creek terraces are illustrated in Figures 9 and 10. All terraces are restricted to the uplifted hanging wall of the Reelfoot fault, with the exception of a single unpaired terrace at David Creek. The only creek with two terrace levels is Rock Branch. Terraces are also primarily confined to creeks which flow west out of the bluffs and onto the Mississippi River/Running Reelfoot Bayou floodplain, with only two 2 m high terraces east of the bluffs (Figs. 9 and 10). Figure 13 shows the height of each terrace located along the bluff line. The average height of the high terraces along the bluff

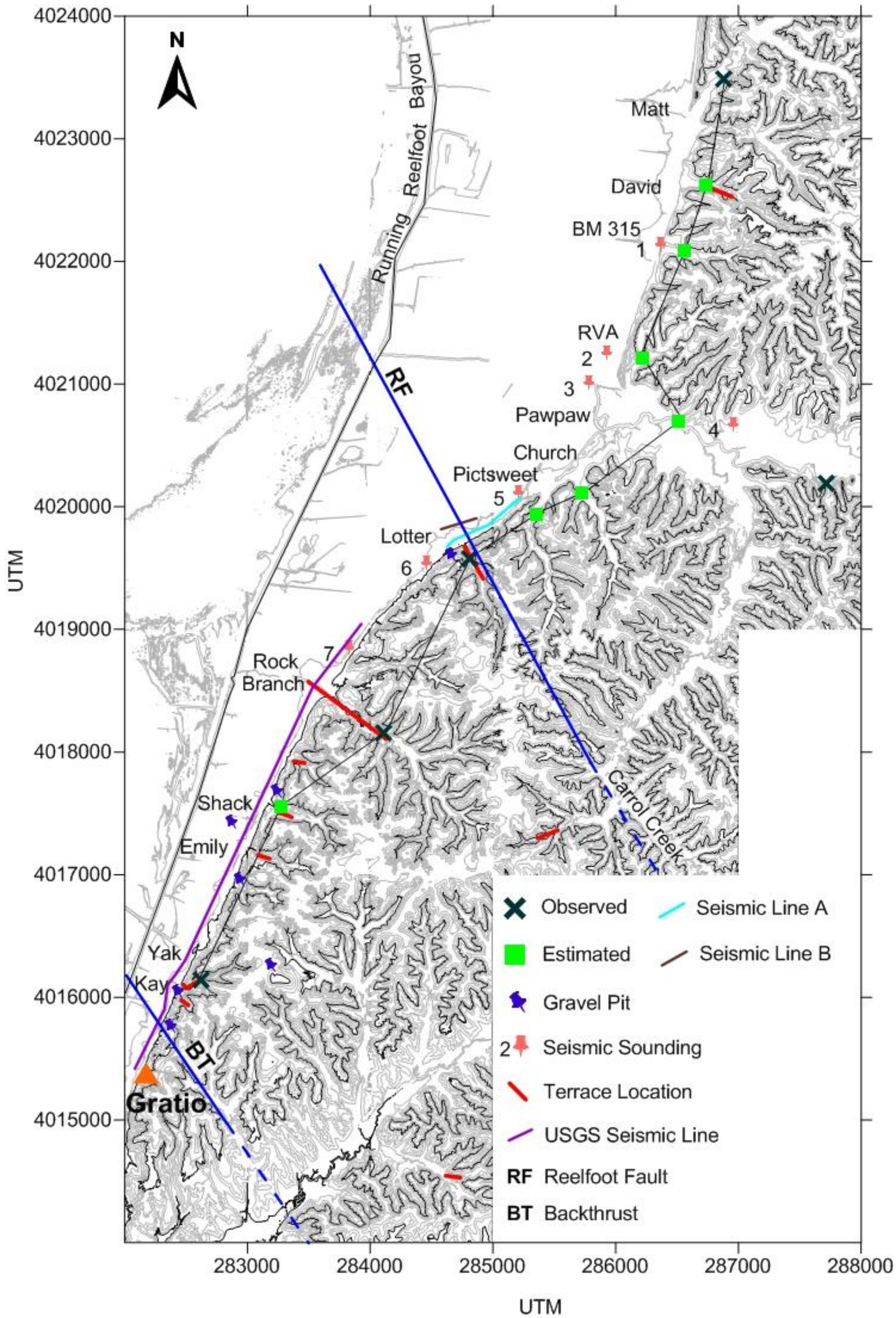

Figure 10. Contour map showing locations of where UC contact measurements were taken, seismic soundings, seismic reflection lines, terraces, gravel pits, and my interpretation of where the Reelfoot fault and its accompanying backthrust are located.

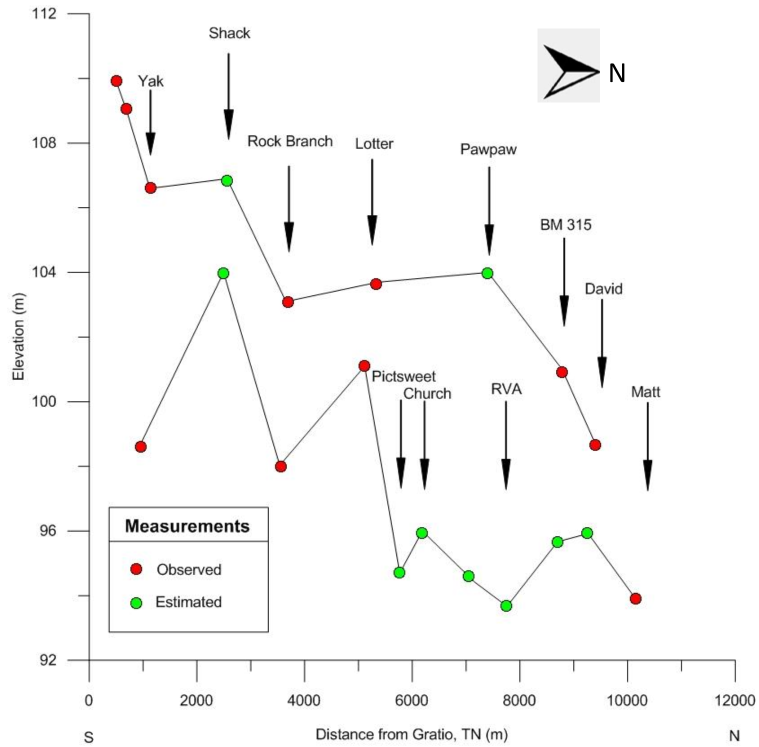

Figure 11. Cross section of the top (upper line) and bottom (lower line) of the Upland Complex. Locations where measurements were taken are shown in Figure 10.

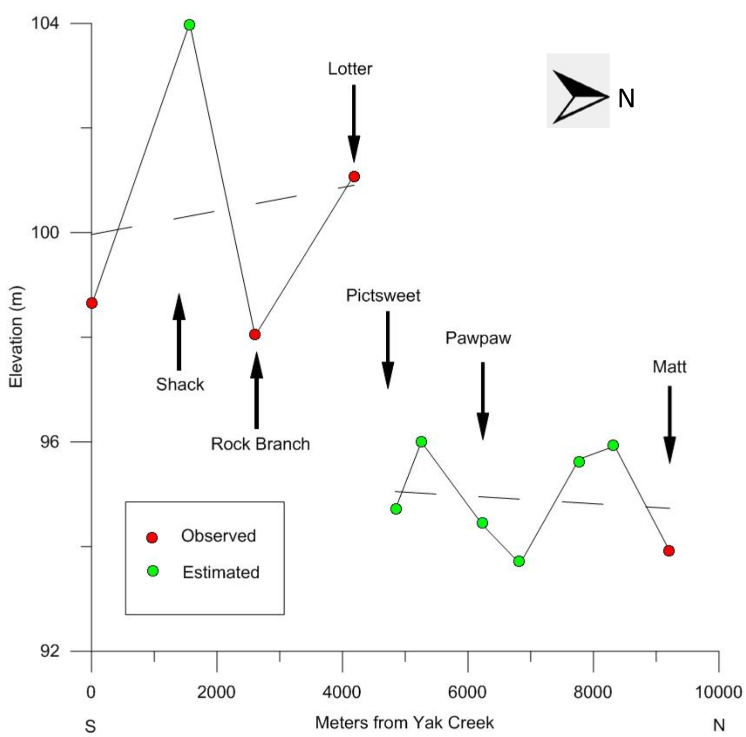

Figure 12. Regression trends south and north of Lotter Creek on the lower contact of the Upland Complex.

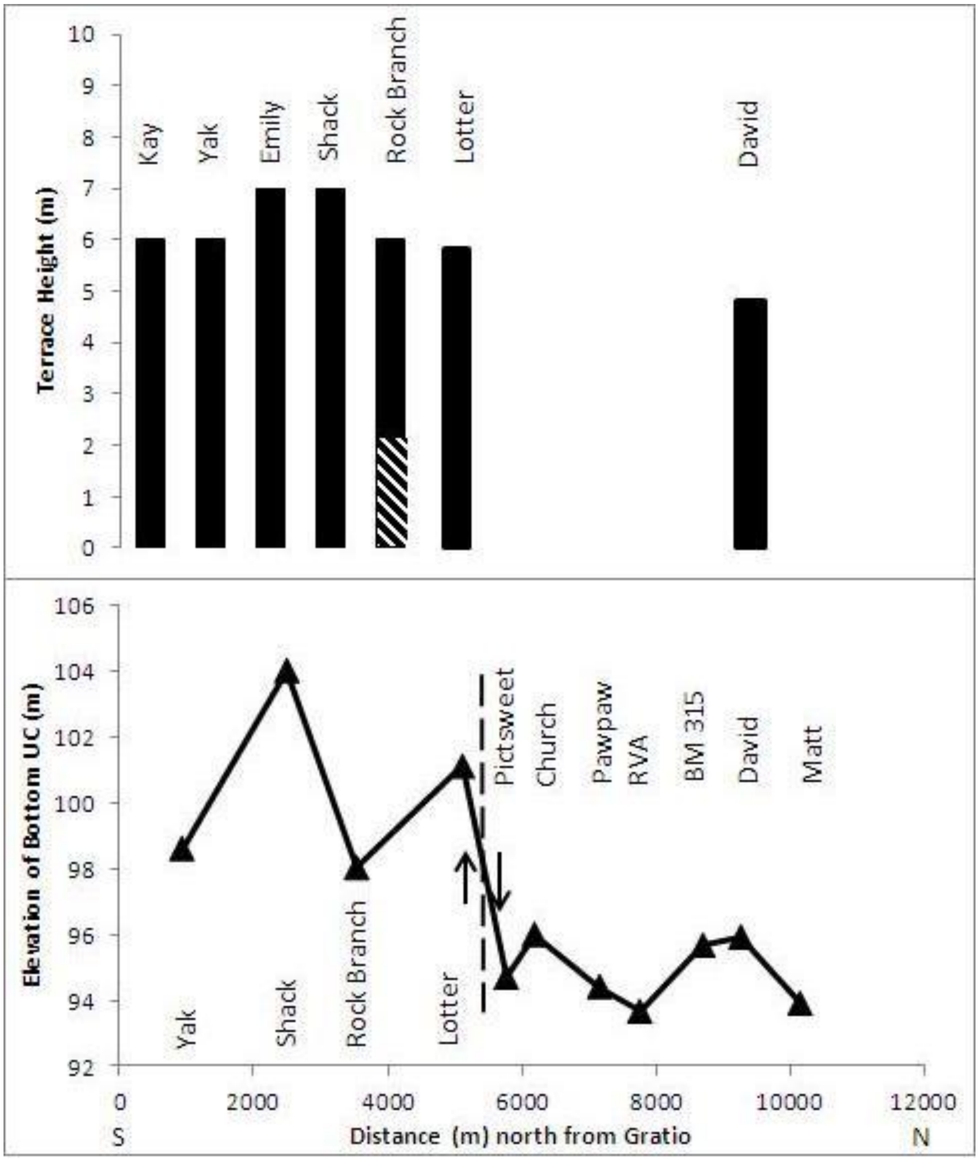

Figure 13. (Top) Bar graph showing the height of each terrace found on creeks flowing west out of the bluffs and onto the Mississippi River/Running Reelfoot Bayou floodplain. (Bottom) Profile of the lower contact of the Upland Complex with interpretation of the Reelfoot fault.

margin is 6 m. Figure 14 shows an example of a terrace along Lotter Creek. Evidence of a fault scarp was not found within the bluffs. Drainage analysis, including the delineation of individual watersheds, was completed but provided little information in relation to the presence of surface deformation within the bluffs.

However, projection of the Reelfoot fault into the bluffs coincides with an abrupt ninety degree turn of a major creek (Carroll Creek), with the creek flowing along strike of the fault projection for approximately one kilometer (Fig. 10). Gravel pits, located through field observations in addition to those mapped on the Ridgely 7.5 minute topographic map, are limited to the area between Kay and Lotter creeks (Figs. 9 and 10).

3.3 Seismic Reflection

Figures 4 and 10 show the locations of all three seismic reflection lines that were interpreted in this project. Figure 15 illustrates seismic reflection lines A (top) and B (bottom), as well as the geologic interpretation of seismic line B. Displacement measurements were made on the labeled stratigraphic tops on seismic line B due to its greater depth resolution. Displacement on the Paleozoic is 65 m, 40 m on top of the Cretaceous, 31 m on top of the Paleocene Porters Creek Clay Formation, 20 m on the top of the Paleocene Wilcox Group, and 16 m on the top of the Eocene Memphis Sand. Figure 16 is the unpublished seismic reflection line acquired by the USGS in 2008 (left top and bottom), as well as seismic line B (right top and bottom). The USGS line shows a northeast-dipping reverse fault with diminished displacement up-section from approximately 20 m of displacement on the top of the Paleozoic to approximately 6 m on the top of the Memphis Sand.

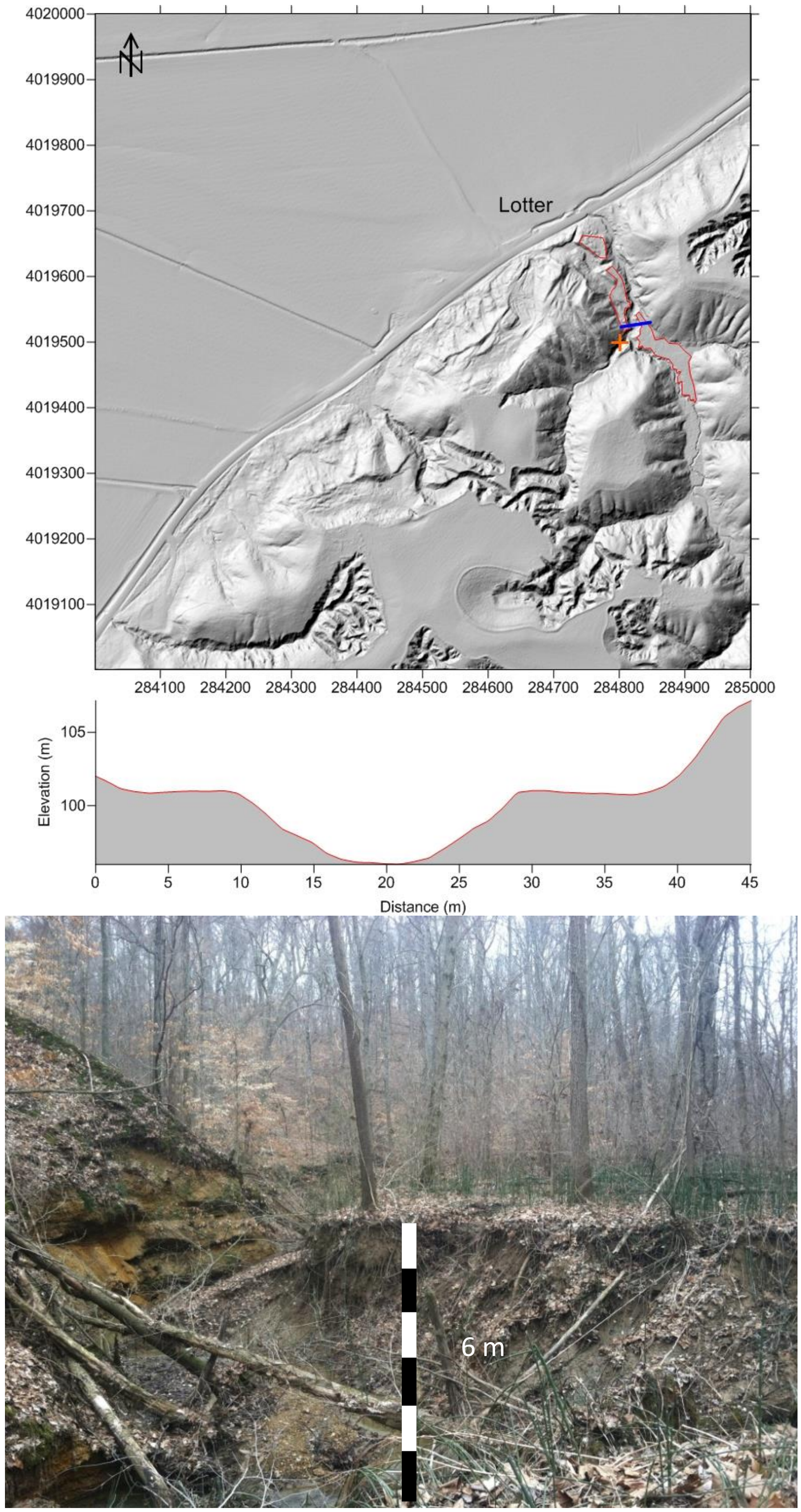

Figure 14. (Top) LiDAR image of Lotter Creek with topographic profile. Terraces with red outline and topographic profile location (blue line). Orange cross indicates where the picture below was taken. (Bottom) Picture of Lotter Creek terrace with view downstream to the northwest.

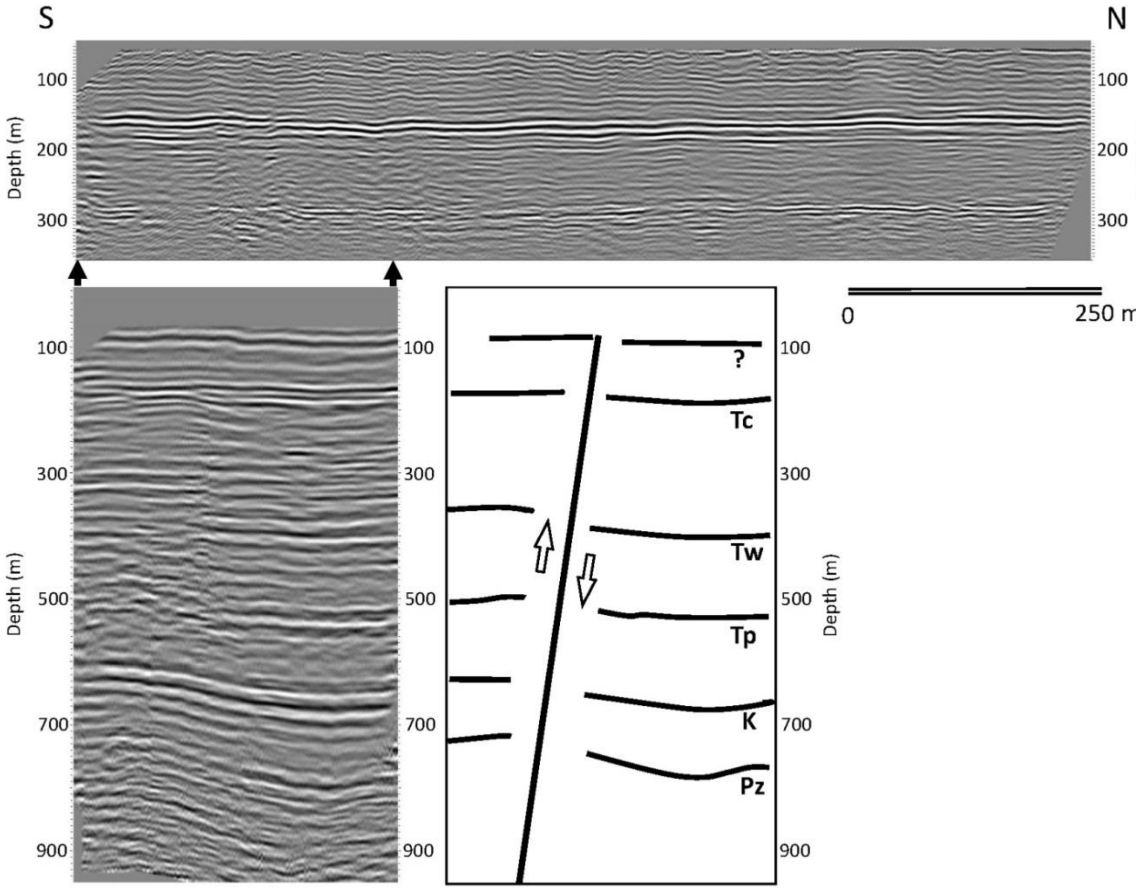

Figure 15. (Top) P wave seismic reflection line A located in Figures 4 and 10. (Bottom) P wave seismic reflection line B located in Figures 4 and 10 and its interpretation with lines representing stratigraphic tops. Tc = Tertiary Claiborne Group (Memphis Sand), Tw = Tertiary Wilcox Group, Tp = Tertiary Porters Creek Clay, K = Cretaceous, Pz = Paleozoic.

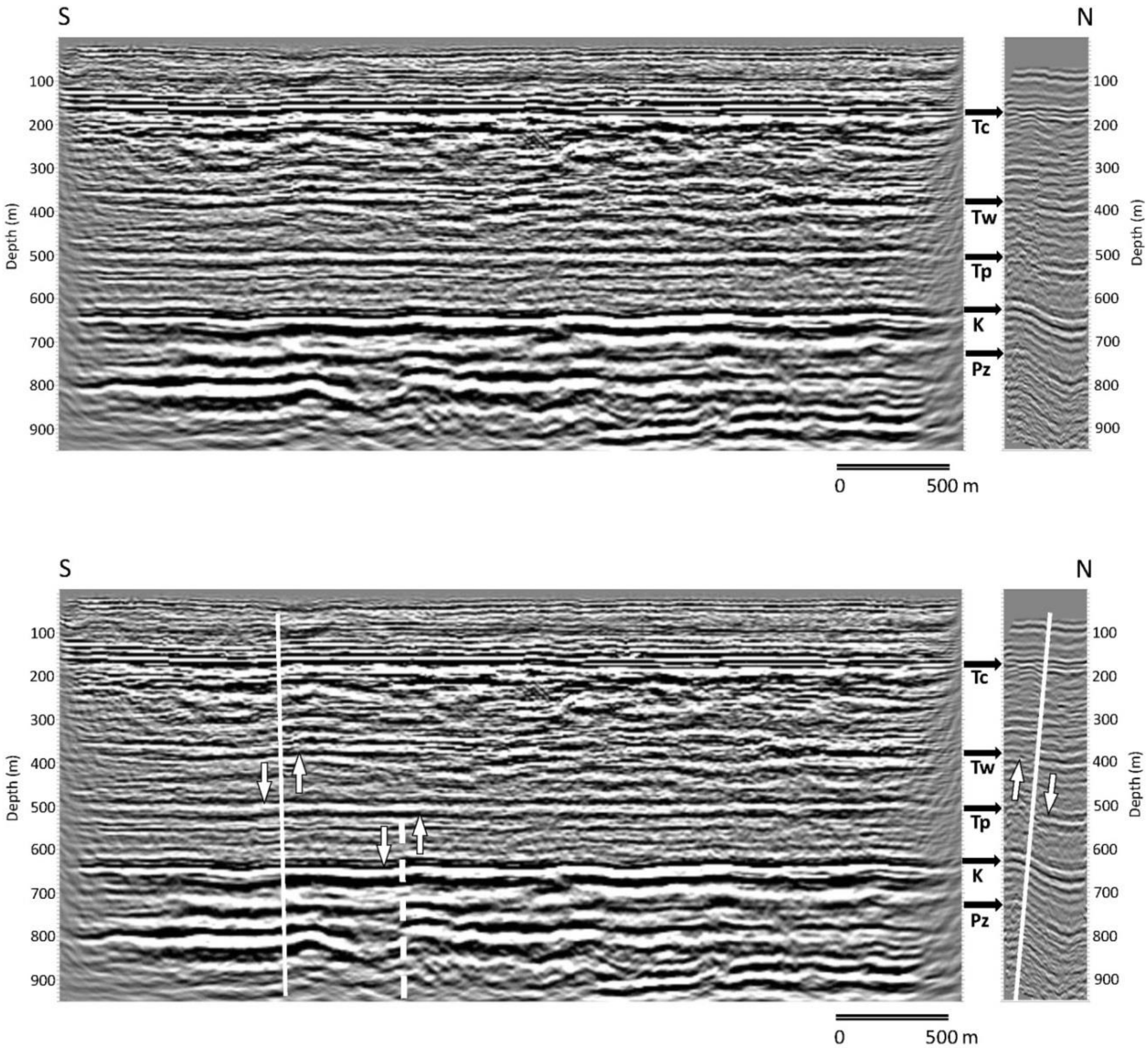

Figure 16. (Left) Uninterpreted and interpreted P-wave seismic reflection line acquired by the USGS in 2008 located in Figures 4 and 10. (Right) Uninterpreted and interpreted P-wave seismic reflection line B located in Figures 4 and 10. Distance between the two seismic lines is one km. Arrows between seismic lines point to stratigraphic tops. Tc = Tertiary Claiborne (Memphis Sand), Tw = Tertiary Wilcox, Tp = Tertiary Porters Creek Clay, K = Cretaceous, Pz = Paleozoic.

Chapter 4

Discussion

Within the Mississippi River bluffs of the study area, the Pliocene Upland Complex (UC) top and bottom contacts slope down-to-the-north (Fig. 11). This is opposite of what one would expect for alluvium deposited by a south-flowing river, suggesting that this slope is a consequence of post-deposition deformation. More specifically, the lower contact of the UC appears to be displaced 6 m down-to-the-north between Lotter Creek and Pictsweet Creek, although the upper contact does not show the same apparent displacement. This absence of displacement could be due to a lack of upper contacts of the UC at this crucial area within the bluffs (namely at Pictsweet, Church, and Pawpaw creeks). Alternatively, the upper contact of the UC is an erosional contact and thus fault displacement may have been removed by post-UC erosion.

The geologic mapping indicates that the Reelfoot (South) fault passes into the bluff line immediately north of Lotter Creek. The distribution of gravel pits between Kay and Lotter Creeks (Figs. 9 and 10) also supports this location of the Reelfoot (South) fault. The gravel pit distribution is interpreted as indicating that the Pliocene Upland Complex gravel was mined in the uplifted hanging wall of the Reelfoot fault because the gravel was displaced to a higher elevation and thus became more accessible to mining than in the footwall northeast of the Reelfoot fault. Terrace distribution also supports this location, with all terraces being confined to the hanging wall of the Reelfoot fault with the exception of the David Creek terrace. These terraces were investigated in the field, and were confirmed to be strath rather than fill terraces, further supporting that these terraces were formed as a result of tectonic uplift. In addition, the average height of all the high terraces along the bluff margin was 6 m which corresponds to the amount of apparent fault displacement on the UC, suggesting a common origin.

A possible explanation for the terrace at David Creek is that it was formed due to a northeast-striking fault. Projection of an unnamed fault as described by Liu (1997) to the northeast into the Mississippi River bluffs would pass through David Creek at the western (downstream) edge of the terrace, which could account for this creek having a terrace. Landslides are common along the bluff line, and to assess whether landslides could have caused stream terrace formation, previously mapped landslides (Jibson and Keefer, 1988) were superimposed on my LiDAR dataset (not illustrated). Only on Shack Creek has a landslide been mapped across the mouth of the creek and thus I think it unlikely that the terraces are due to landslide damming.

Updip projection of Reelfoot fault displacement on seismic reflection lines B and A would intersect the ground surface immediately north of Lotter Creek (Figs. 10 and 15). This supports the displaced UC, creek terrace distribution, and gravel pit distribution evidence for the location of the Reelfoot (South) fault trending southeast into the bluffs near Lotter Creek.

The northeast-dipping reverse fault near the southern end of the USGS 2008 seismic reflection line is interpreted to be the backthrust of the Reelfoot fault. This backthrust is also interpreted to be the southern boundary fault of the Tiptonville dome. If this fault is projected to the ground surface, it is located approximately 0.5 km north of Gratio, Tennessee at the southern limit of the creek terraces and gravel pits (Fig. 10). Although strike and dip measurements on Eocene strata were limited, the two measurements support extension of the Tiptonville dome within the bluffs, with the southern measurement at Yak Creek having a southwestern dip and the approximate center of the Tiptonville dome at Rock Branch Creek having a nearly horizontal dip.

Comparing the seismic line just south of Reelfoot Lake (Figs. 4 and 6) (Van Arsdale et al., 1998) to seismic line B (Fig. 15), the displacements are similar with the largest displacement occurring on top of the Paleozoic section and the smallest on top of the Eocene section/base of the Quaternary section (Table 1). To determine if the Reelfoot North fault and the Reelfoot South fault have moved concurrently and thus could be considered a continuous fault, the two faults were evaluated using displacement ratios on the Reelfoot Lake line as compared to seismic line B. In doing so, it should be noted that the uppermost pick on the Reelfoot Lake seismic line is at a slightly higher elevation (base of the Quaternary section) as compared to the uppermost pick on seismic line B (top of Memphis Sand).

In addition, it is under the assumption that the stratigraphic reflector picks were made on the same reflectors on each seismic line. Reelfoot Lake line has a displacement ratio for the top of the Eocene section/base of the Quaternary section and top of the Wilcox (Tw) of 0.5 (15 m/30 m), top of Tw and Porters Creek (Tp) of 0.8 (30 m/40 m), top of Tp and Cretaceous (K) of 0.7 (40 m/60 m), and top of K and top of the Paleozoic (Pz) of 0.9 (60 m/70 m). In comparison, seismic line B showed the following: top of Memphis Sand/Tw of 0.8 (16 m/20 m), Tw/Tp of 0.7 (20 m/31 m), Tp/K of 0.8 (31 m/40 m) and K/Pz of 0.6 (40 m/65 m).

Due to the similarity of these displacements and displacement ratios, it appears that the Reelfoot North fault as seen in the Reelfoot Lake line, and the Reelfoot South fault as seen in seismic line B, have occurred concurrently and thus the Reelfoot fault appears to be one continuous fault for 84.5 km. In addition, the Reelfoot North fault scarp strikes southeast and projects into the Mississippi River bluff at Lotter Creek, indicating that the right-lateral Axial fault has not displaced (segmented) the Reelfoot fault (Fig. 4).

The greatest displacements on every stratigraphic reflector are on the Reelfoot Lake reflection line, lesser on seismic line B, and the least on the Lane seismic line. This indicates that Reelfoot fault displacement diminishes southeastward from Reelfoot Lake. This diminishing fault displacement is also reflected in the terrace heights. Terraces on the bluff margin have an average height of 6 m and terraces east of the bluff margin have an average height of 2 m.

Table 1

Displacement Measurements

Stratigraphic Reflector	Reelfoot Lake Seismic Line	Seismic Line B
Top of Eocene section	15 m	?
Memphis Sand	?	16 m
Wilcox Group	30 m	20 m
Porters Creek	40 m	31 m
Cretaceous	60 m	40 m
Paleozoic	70 m	65 m

Chapter 5

Conclusions

Investigation of the Mississippi River bluffs southeast of Reelfoot Lake has identified faulting and near-surface deformation using geologic, geomorphic, and seismic reflection methods. Geologic mapping revealed a northerly slope of the Upland Complex (UC) within the study area, indicating post-deposition deformation. Specifically, the Reelfoot fault was identified as extending into the bluffs just north of Lotter Creek through an apparent 6 m displacement of the lower contact of the UC (Figs. 10 and 12). Geomorphic and geologic indicators support extension of the Reelfoot fault just north of Lotter Creek and its backthrust near Kay Creek. Most terraces and all gravel pits are confined to the hanging wall (Tiptonville dome). The David Creek terrace may be due to uplift on an unnamed fault as described by Liu (1997) (Fig. 10). In addition, the terraces along the bluff margin display the same 6 m height as exists on the UC fault displacement suggesting that they were formed from a common uplift event (Fig. 13).

Seismic lines A and B reveal diminishing fault displacement up-section on top of each stratigraphic reflector and when projected updip would intersect the surface immediately north of Lotter Creek (Figs. 10 and 15). The 2008 USGS seismic reflection line reveals reverse up-to-the-north fault displacement but with a lesser amount than the Reelfoot South fault (Fig. 16). This lesser and opposite sense of displacement is reconciled when this fault is viewed as a backthrust of the Reelfoot fault (e.g. Fig. 5B). This northeast-dipping reverse fault is interpreted to be the southern boundary of the Tiptonville dome. When this backthrust is projected to the ground surface it is located just north of Gratio, Tennessee at the southern limit of the creek terraces and gravel pits, confirming that these features are limited to the extension of the Tiptonville dome (Fig. 10).

Comparing seismic lines A and B with the Reelfoot Lake seismic line (Figs. 6 and 15) displacements are similar on every stratigraphic reflector, the only major difference being greater displacement on the Reelfoot Lake seismic line. When the displacement ratios are compared there are differences between the first ratio (0.5 vs 0.8) and the last ratio (K/Pz—0.9 vs 0.6), but the middle two ratios displayed very similar results (Tw/Tpc—0.8 vs 0.7 and Tpc/K—0.7 vs 0.8). The difference in the first ratio is influenced due to the discrepancy of the uppermost reflector picks, with the Reelfoot Lake seismic line using the top of the Eocene section and seismic line B using the top of the Memphis Sand. The differences in the remaining ratios could be due to errors in the comparison of the stratigraphic reflectors from one seismic line to another, since we are going under the assumption that the picks from all the seismic lines are made on the exact same reflectors.

Despite these minor discrepancies whether real or exaggerated due to errors, the pattern of displacement seems to mirror one another throughout the stratigraphic section. These similarities argue for concurrent displacement on the Reelfoot North fault as seen on the Reelfoot Lake seismic line, and on the Reelfoot South fault as seen on seismic line B. As a result, it can be argued that these two faults have very similar displacement histories and thus the Reelfoot fault is one continuous fault rather than two discreet faults. In addition, when the Reelfoot North fault is projected to the southeast into the Mississippi River bluffs it intersects at Lotter Creek (Fig. 4), suggesting that it has not undergone any strike-slip movement by the Axial fault further indicating that the Reelfoot fault is not segmented into two faults.

Comparing the seismic lines from Reelfoot Lake southeast to Lane, Tennessee it becomes evident that the displacements on every stratigraphic reflector diminishes to the southeast, with the greatest seen on Reelfoot Lake seismic line, less on seismic lines A and B, and least on the Lane seismic line. This diminishing displacement to the southeast is also reflected in terrace height within the bluffs, with higher terraces (6 m) occurring on the margin of the bluffs and lower terraces (2 m) occurring inboard east of the bluff margin. This diminishing displacement to the southeast coupled with diminishing displacement upsection could explain why no fault scarp has been found southeast of Reelfoot Lake and why drainage analysis within the bluffs has not revealed any anomaly except for the bend in Carrol Creek.

Future work should entail constraining the dates of faulting. What can be said now is that faulting is post Upland Complex deposition (3.1 Ma), and likely post loess deposition. Post loess deposition is suggested due to the fact that there was no evidence of eolian loess on the terraces indicating that faulting occurred after the youngest loess deposit which for this area is the 18 ± 2 ka Peoria Loess (Rodbell et al., 1997). This would place the most recent faulting event as being late Wisconsin or Holocene. To help constrain the time of most recent faulting, dating of the creek alluvium beneath the terraces should be done since terrace formation occurred after deposition of the underlying alluvium.

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