PROPOSAL: Integrated Geophysical Surveying of Seismotectonic Structure in the New Madrid Seismic Zone, Central United States

PROBLEM:

The New Madrid seismic zone (NMSZ) controls much of seismic hazard in the central U.S. (**Fig. 1**); however, many of the associated parameters such as slip rate, total displacement, strain accommodation, and geographic Quaternary-active fault location, etc. remain poorly constrained. This is in large part due to the lack of geologic exposure in the region, because seismogenic structure are largely masked by the Mississippi embayment sediment with few surface manifestations. The lack of subsurface geologic control in the area northeast of the NMSZ's highly active central step-over arm, marked by the red rectangle in **Figure 1**, is greater due to the sparse number of investigations in this part of the embayment.

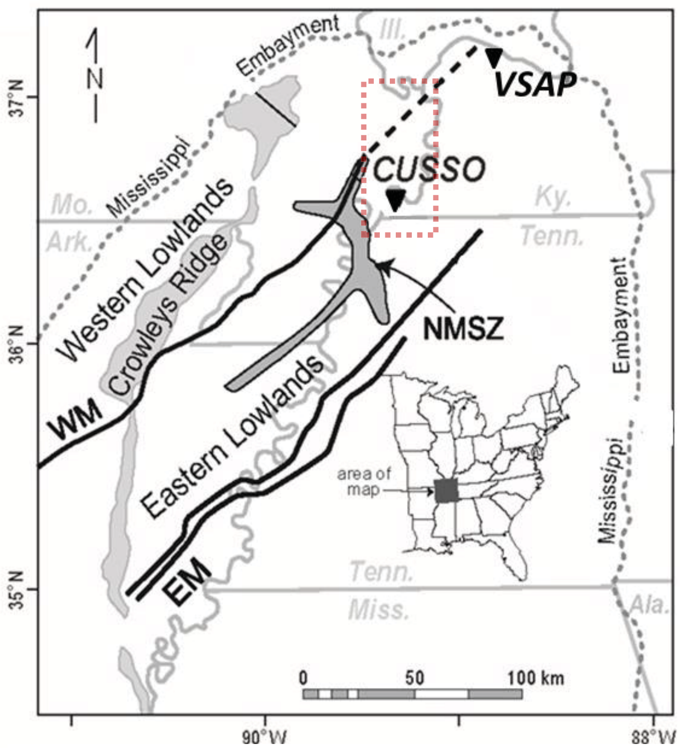


Figure 1. The NMSZ (dark gray shaded area) is located primarily inside the Reelfoot rift (heavy black lines) (modified from Csontos et al., 2008). The regional seismotectonic features are overlain by the Mississippi embayment sediments.

<u>*Field Study #1.*</u> Woolery and Almayahi (2014) recently collected a series of high-resolution seismic-reflection profiles at the Central United States Seismic Observatory (CUSSO) site that imaged a set of steeply dipping N 30° E striking faults with uplifted and arched post-Paleozoic sediments in a manner consistent of dextral transpressional displacement. The adjacent well-constrained CUSSO borehole log allowed them to establish the sub-parallel fault strands Quaternary-active. In addition, their projecting these faults along the northeast strike 22 km to an intersection with the nearest subsurface dataset (i.e. lower-resolution industry seismic reflection profile) immediately south of Wolf Island, Missouri, coincided with a discrete 0.75-km-wide set of observable faults having the style and offset similar to those imaged by the high-resolution lines (**Fig. 2**). Now, for Field Investigation #1 we seek to acquire a series (~5 km) of high-resolution P- and SH-wave seismic reflection profiles at the 12-km back-strike-projection intersection with a right-lateral offset in the Reelfoot scarp stepover (**Fig. 3**). Positive confirmation for the southwest fault zone extension, along with the previously defined northeast extension, will provide kinematic and geographic evidence for a hypothesized northeast continuation of the NMSZ's southern Axial shear zone across the central stepover, thus accommodating the problematic differential right-lateral strain observed between the surface scarp and seismogenic depth (Odum et al., 2010; Pratt et al., 2012). Confirming the first physical evidence toward the long-standing strain accommodation problem will provide a conceptual leap in our understanding of the seismotectonic kinematics for the NMSZ in general, and a reduction in the seismic hazards uncertainty in particular.

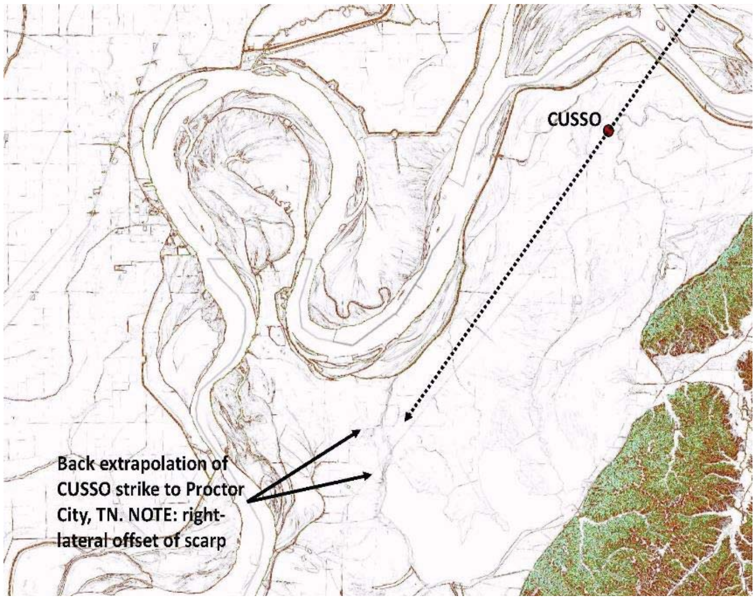


Figure 2. The 10-m LiDAR image of CUSSO back-strike-projection to the Reelfoot fault intersection. Note the right-lateral offset in scarp at its intersection with the projected

<u>*Field Study #2.*</u> Faults of the northern-most segment of the NMSZ are also poorly constrained due to soft sediment cover; consequently, the principal argument for northeast faulting from New Madrid, Missouri is earthquake epicenter trends. A recent study of 517 electric logs associated with 91 m (300 ft.) deep lignite exploration wells has provided excellent subsurface data for the geology of southeastern Missouri, however (**Fig. 4**) (Pryne et al., 2014). The study discovered a previously unknown subsurface stratigraphic uplift that has been named the Charleston uplift. The Charleston uplift trends N48°E from immediately north of New Madrid, Missouri across Mississippi County, Missouri and underlies the towns of Charleston, Missouri, and probably Cairo, Illinois/Ballard County, KY. Epicenters of contemporary seismicity are coincident with the uplift boundaries (**Fig. 5**). Many of these earthquakes have northeast-oriented fault plane solutions that exhibit dextral reverse movement including a M3.9 (Feb. 21, 2012) earthquake near Charleston, Missouri (**Fig. 4**). The well data indicate the uplift is 7.2 km (4.3 mi.) wide by 30 km (19 mi.), and hypothesized to be fault bounded based on 36 m (120 ft.) of relief at the unconformity surface separating the Paleogene and Quaternary sections. P-wave walkaway soundings on both sides of the uplift's northern boundary indicate 60 m (198 ft.), 47 m (155 ft.), and 19 m (63 ft.) of structural relief across the top of Paleozoic, top of Cretaceous, and intra-Tertiary horizons, respectively (**Fig. 6**). A preliminary or trial microgravity survey across the southern boundary evaluated the effectiveness of this geophysical method for resolving the hypothesized structure (**Fig. 7**). The resultant integrated datasets reduce the likelihood that the uplift could have a full erosional origin, but do not fully evaluate the spatial and temporal characteristics. Therefore, Field Study #2 proposes acquiring one additional along strike microgravity transect across the southern boundary. Based on the results, subsequent P- and SH-wave seismic reflection profiles will be acquired to image the potential fault across the deep (i.e., K and Pz horizons) and shallow (i.e., Te and Qua horizons), respectively. Confirmation of a fault-controlled Charleston uplift and its interpretation as an extension of the New Madrid north fault provides a physical fault location, as well as adding 30 km to the known fault length, thus capable of generating a larger earthquake than current estimates. In addition, the uplift appears to possibly cross beneath the Mississippi River into adjacent Illinois and Kentucky as evidenced by the torturous meander in the river at their projected intersection (**Fig. 8**). If the hypothesized Charleston uplift as an extension of the New Madrid north fault is true, then there exists an important new seismic source zone that extends from the New Madrid seismic zone into adjacent Kentucky and Illinois, providing a definitive structural link between the Reelfoot rift and the Rough Creek graben.

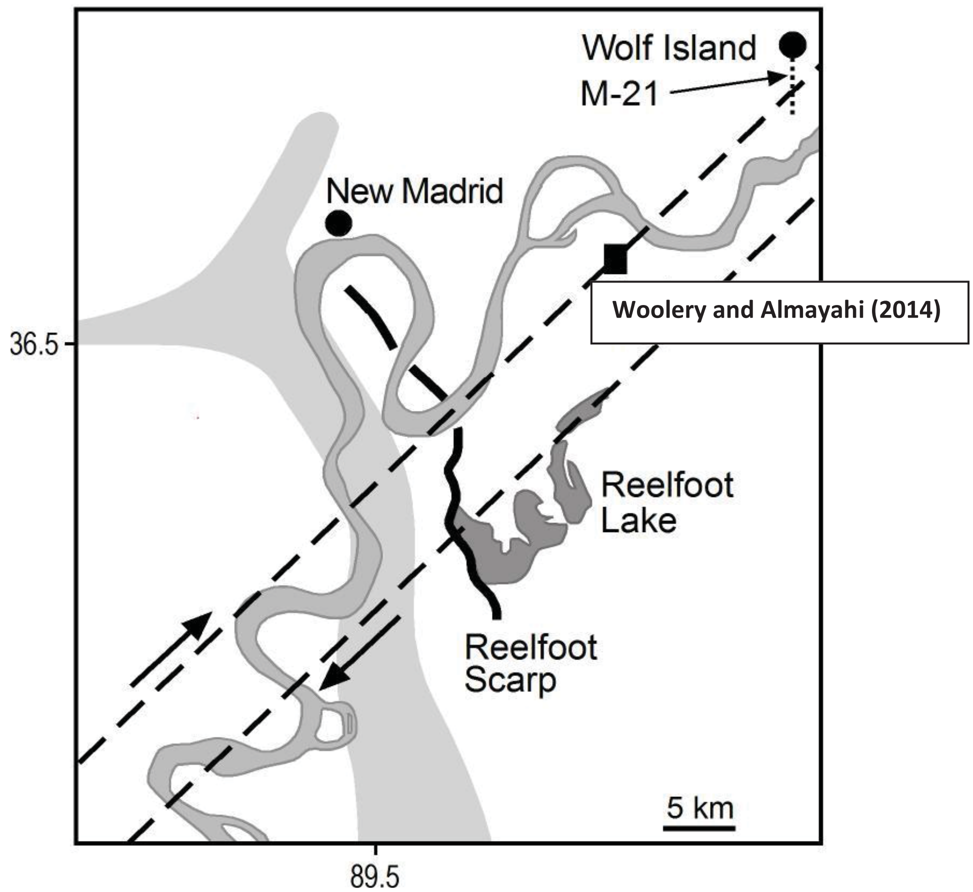


Figure 3. Northeast striking shear zone representing the southern Axial fault zone and its projection (dashed lines) across the Reelfoot fault stepover as generally defined by the northwest-oriented contemporary seismicity (light gray area). The "bend" in the seismicity pattern near the intersection of the stepover with the Axial fault is between 10 and 12.5 km of right-lateral offset along the Reelfoot fault. However, only ~5.5 km of lateral surface displacement along the Reelfoot scarp (black solid line). This significant difference in the subsurface and surface displacement estimates suggest a northeast continuation of the shear zone. The Woolery and Almayahi (2014) high-resolution seismic reflection lines were collected in an area (black rectangle) 12 km northeast of the Reelfoot scarp and along the northwestern edge of the projected Axial fault. A section from a lower-resolution industry seismic line, M-21 (dotted line), also crosses western edge of the projection, and was used for regional correlation. M-21 is located 22 km northeast of the high-resolution data near the community of Wolf Island, Missouri.

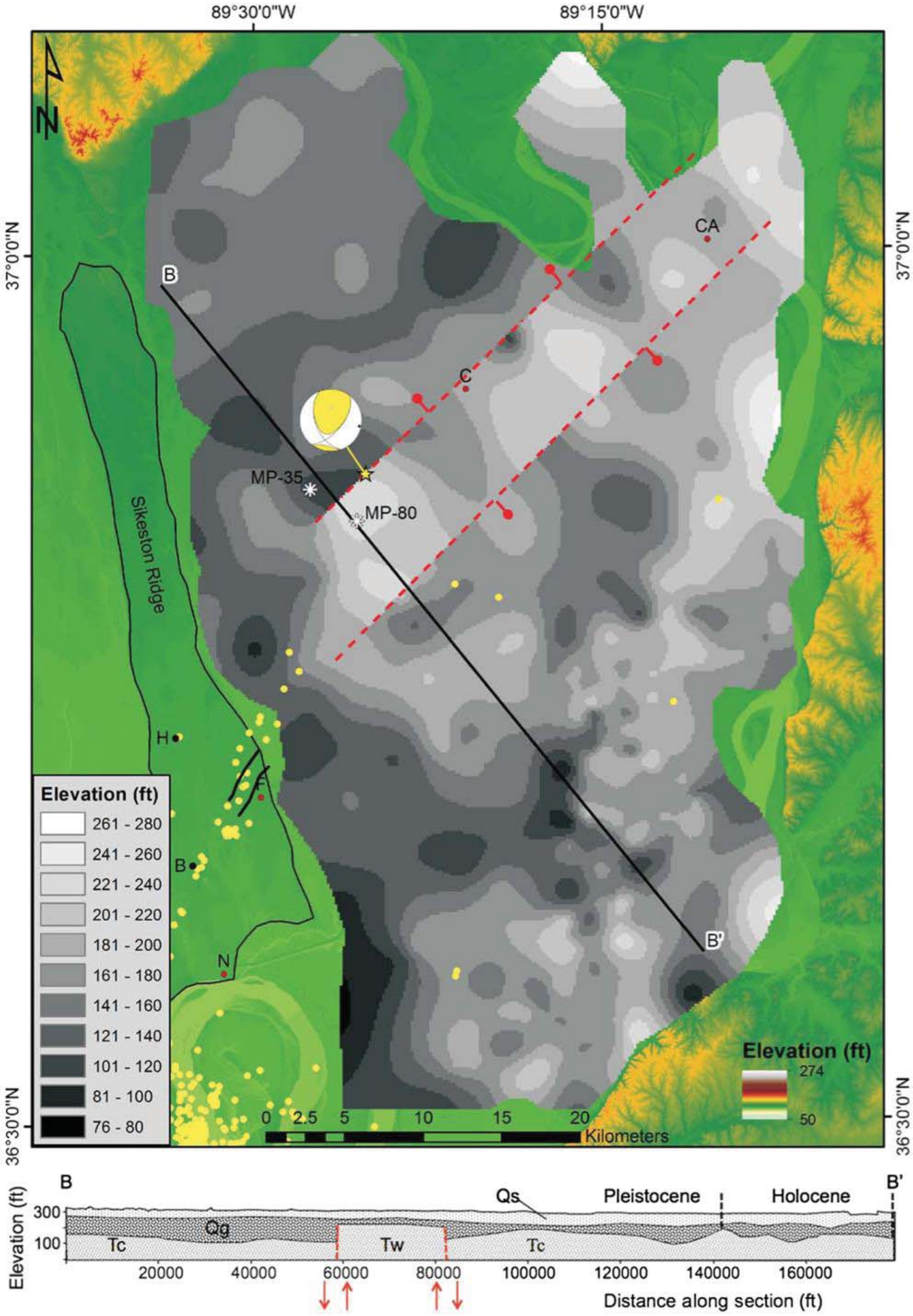


Figure 4. Bottom of Quaternary structure contour map. The Charleston Uplift is shown in cross section BB'. The 21 February 2012 M 3.9 earthquake location and interpreted faults (dashed lines with barbs on downthrown side). Yellow dots are earthquake epicenters; two white asterisks, example seismic-reflection sounding locations MP-80 and MP-35 (see Fig. 6). Cross section BB' with interpreted Charleston uplift. Qs-Quaternary alluvial sand; Qg-Quaternary alluvial gravel; Tc-Tertiary Claiborne; Tw?-probable Paleocene Wilcox clay (from Pryne et al., 2014).

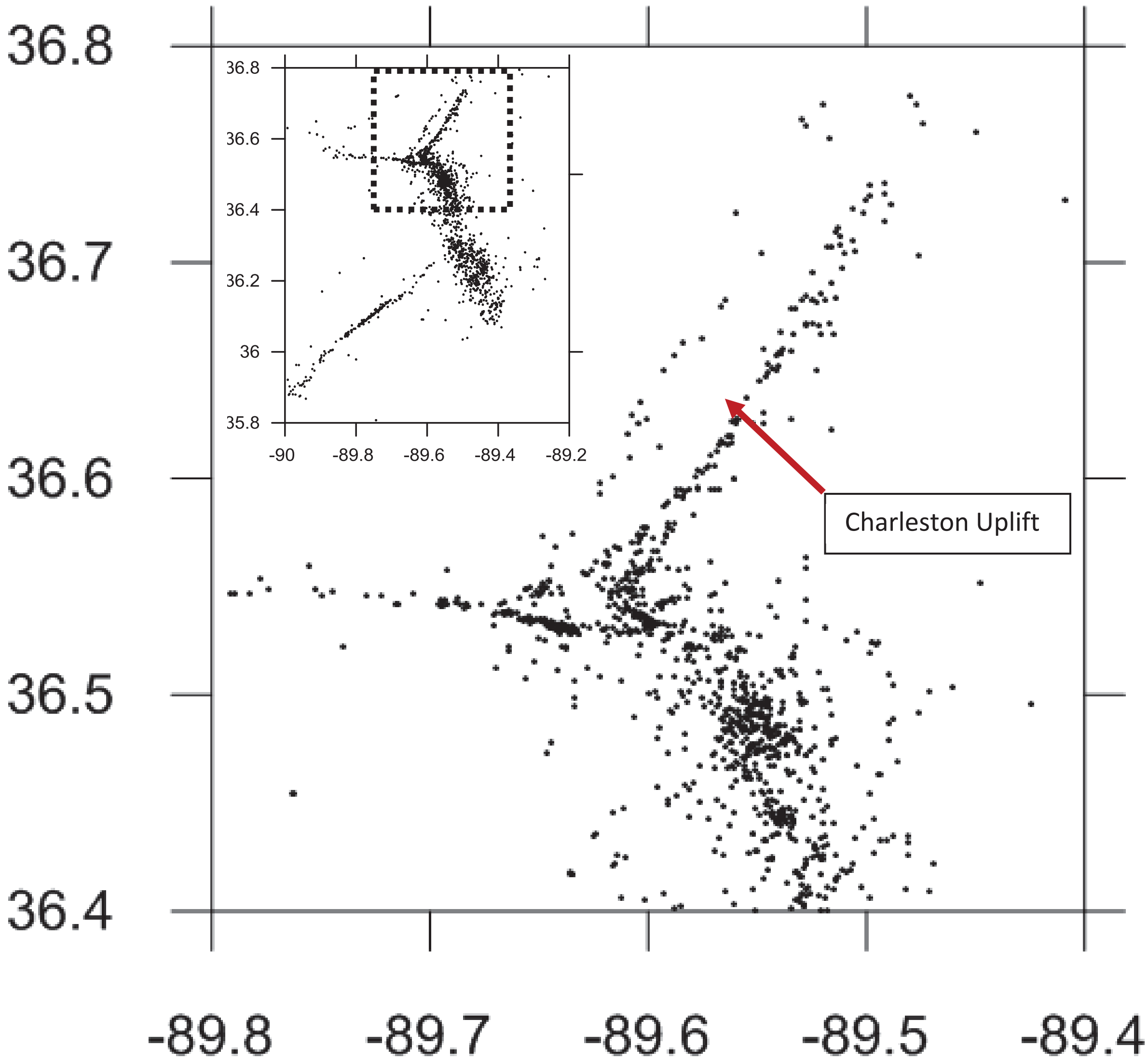


Figure 5. The three primary arms of NMSZ epicentral seismicity are in the inset. A closer view of the northeastern arm of seismicity is in the main view. The two linear trends of northeast-oriented seismicity are coincident with the boundaries of the recently interpreted Charleston uplift.

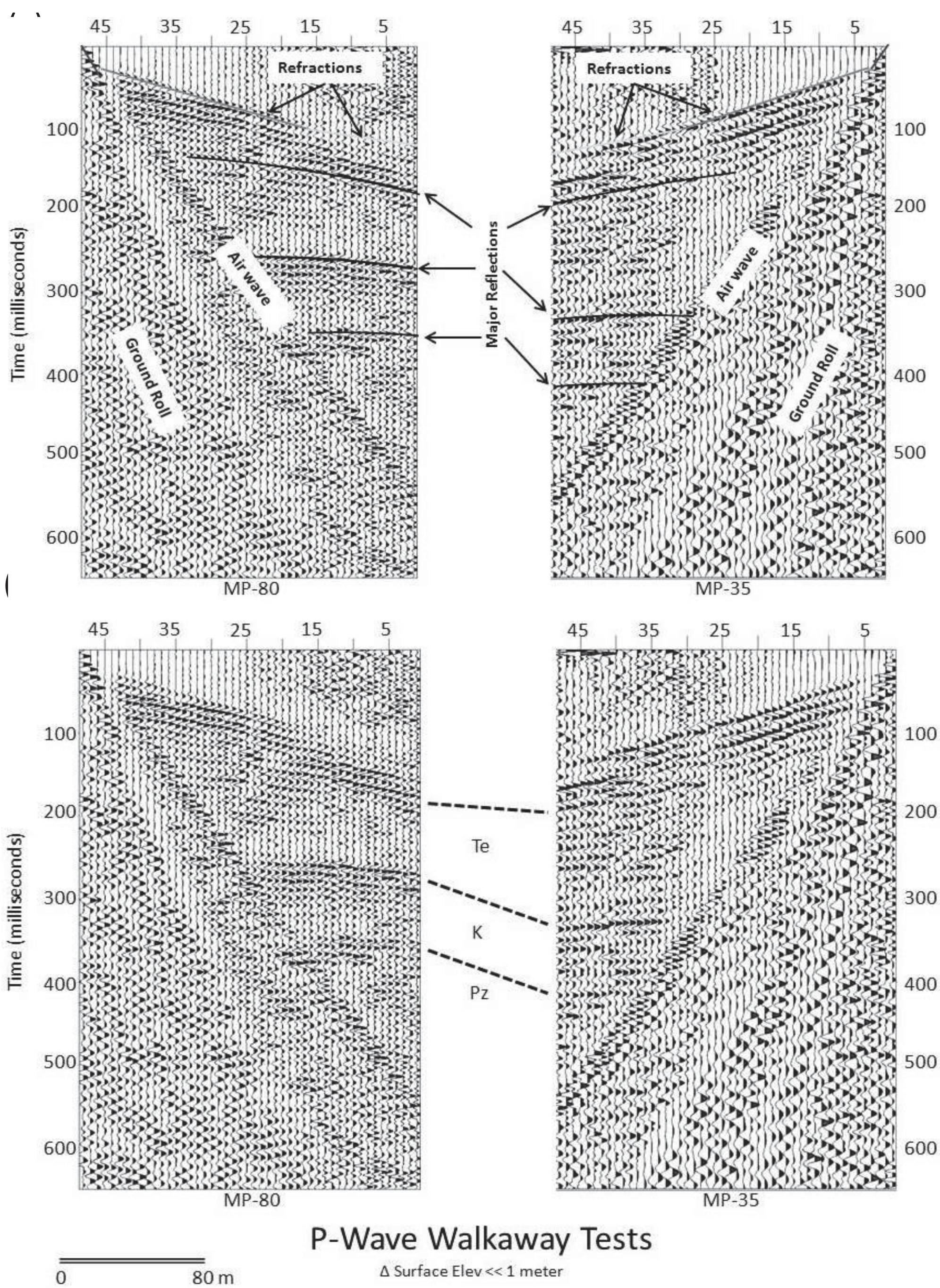
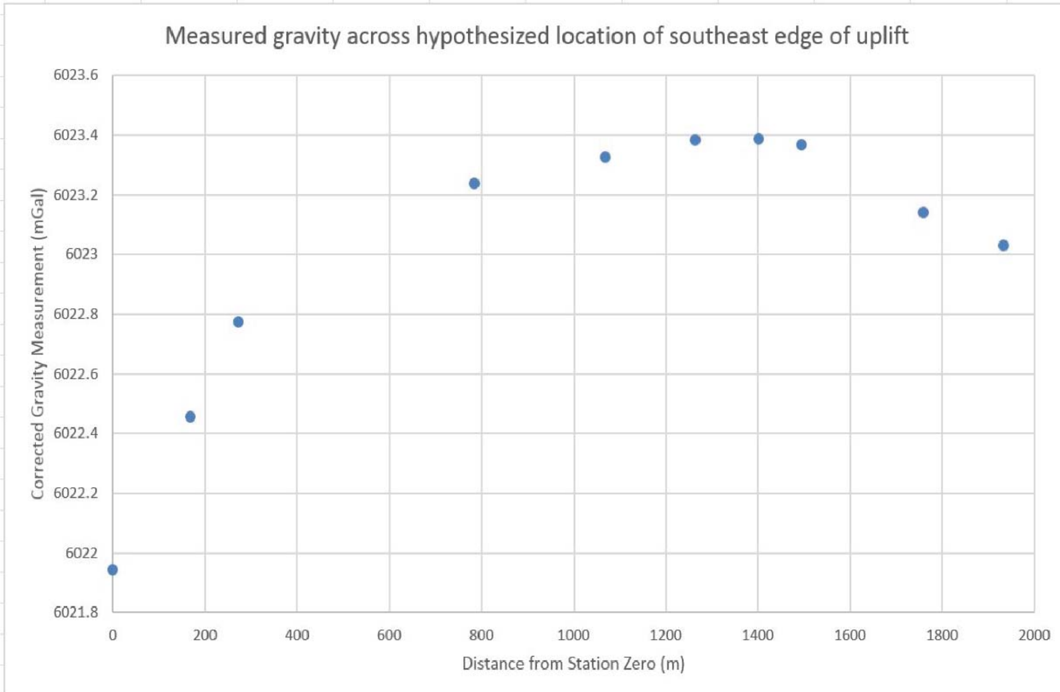


Figure 6. Two seismic-reflection soundings, MP-35 and MP-80, were performed north of the uplift and within the uplift, respectively. (a) Coherent phases are shown on the two seismograms, including ground roll, air wave, direct wave/refractions, and three significant reflections. (b) The two most prominent deeper reflections seen on both profiles are interpreted as the tops of the Cretaceous (K) and Paleozoic (Pz) horizons. A shallow reflection is also seen in both soundings. It is interpreted as the top of the Tertiary Ft. Pillow Sand. The relief across the K and Pz between the sites is 47 m and 60 m, respectively. There are 19 meters of relief across the Te horizon.



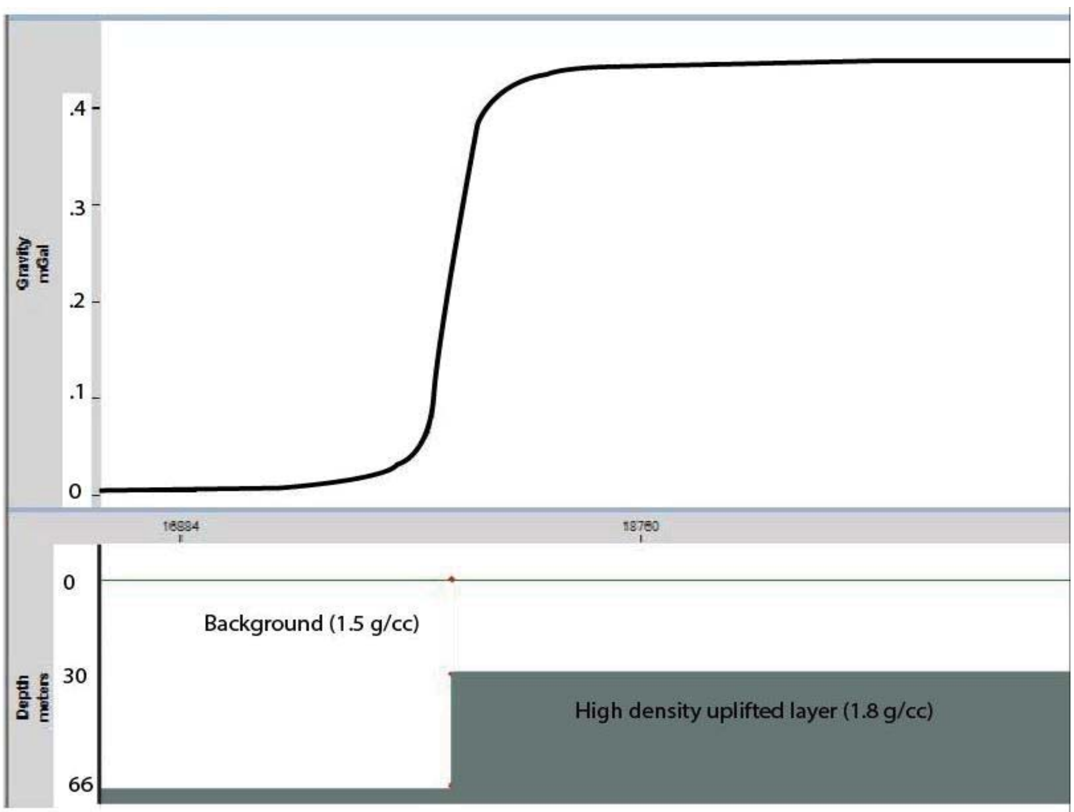


Figure 7. Observed and modeled trial microgravity survey across the hypothesized southern boundary of the Charleston Uplift. Moving from left to the right corresponds to crossing from the footwall to the hanging wall northeast toward Charleston, MO.

Figure 8. A closer view of the Pyrne et al. (2013) projection of the Charleston uplift crossing the Mississippi River near Cairo, Illinois. The intersection is marked by a meander that changes 180 degrees and flows up valley for nearly 10 km in order to get around the Charleston uplift. This geomorphic signature is similar to the torturous meander in the river (the Kentucky Bend) at New Madrid, Mo., where it changes flow direction 180 degrees and flows up valley for approximately 15 km in order to get around the Tiptonville dome/Lake County uplift (Van Arsdale et al., 1995).

Project Management Plan

Task	University of Kentucky 12-month Plan																							
	2018												2019											
	J	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
Study 1				X	X	X	P	P	I	I	I	W	W	W	W									
Study 2					X	X	X	P	I	I	I	W	W	W										

X = Data Acquisition

P = Data Processing

I = Data Interpretation

W = Thesis/Report Writeup

BUDGET REQUEST

Budget Category	Field Study 1	Field Study 2	Total
Personnel (salary)	$0	$0	$0
Personnel (benefits)	$0	$0	$0
Subtotal Personnel	$0	$0	$0
Travel	$3500	$3500	$7000
Equipment	$0	$0	$0
Supplies	$350	$350	$700
Subcontracts*	$0	$0	$0
Subtotal	$3850	$3850	$7700
Indirect Costs	$1175	$1175	$2350
Total	**$5,025**	**$5,025**	**$10,050**