Collaborative Research: Toward an understanding of the long-term deformation in the Mississippi embayment

The Center of Earthquake Research and Information (CERI), Ground Water Institute (GWI) at the University of Memphis

and

The University of Texas at Austin Institute for Geophysics

CRUISE REPORT

1-21 June 2008

Science Team

M. Beatrice Magnani	PI	CERI/U of M
Brian Waldron	Co-PI	GWI/U of M
Kirk McIntosh	PI	UTIG/JSG
Steffen Saustrup	Seismic tech	UTIG/JSG
Leah Mitchell	Watchstander	CERI/U of M
Michael Towle	Watchstander	CERI/U of M

M/V Strong Crew

Anthony Johnston	Master	USACE
Gary Arwood	First Mate	USACE
Michael Buie, Sr	Electrician	USACE
Dayton Mohon	Welder	USACE
Chris Caldwell	Seaman	USACE
Mack Hatton	Seaman	USACE
Robert Morton	Seaman	USACE

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Scientific Background

The New Madrid seismic zone (NMSZ), located in the Central United States (Figure 1), exhibits a high rate of seismicity and a puzzling lack of deformation both at the surface and in the subsurface. Paleoseismological observations suggest that this area has been active in the past with recurrence times of 500-1000 years for at least 5,000 years, while geodetic data show a limited amount of strain coincident with the active structures. To investigate the distribution of deformation in the Mississippi Embayment and reconcile the contradictory observations in this area, a 300 km-long marine seismic reflection profile was acquired in June 2008 along the Mississippi River from Caruthersville, Missouri to Helena, Arkansas (Figure 2).

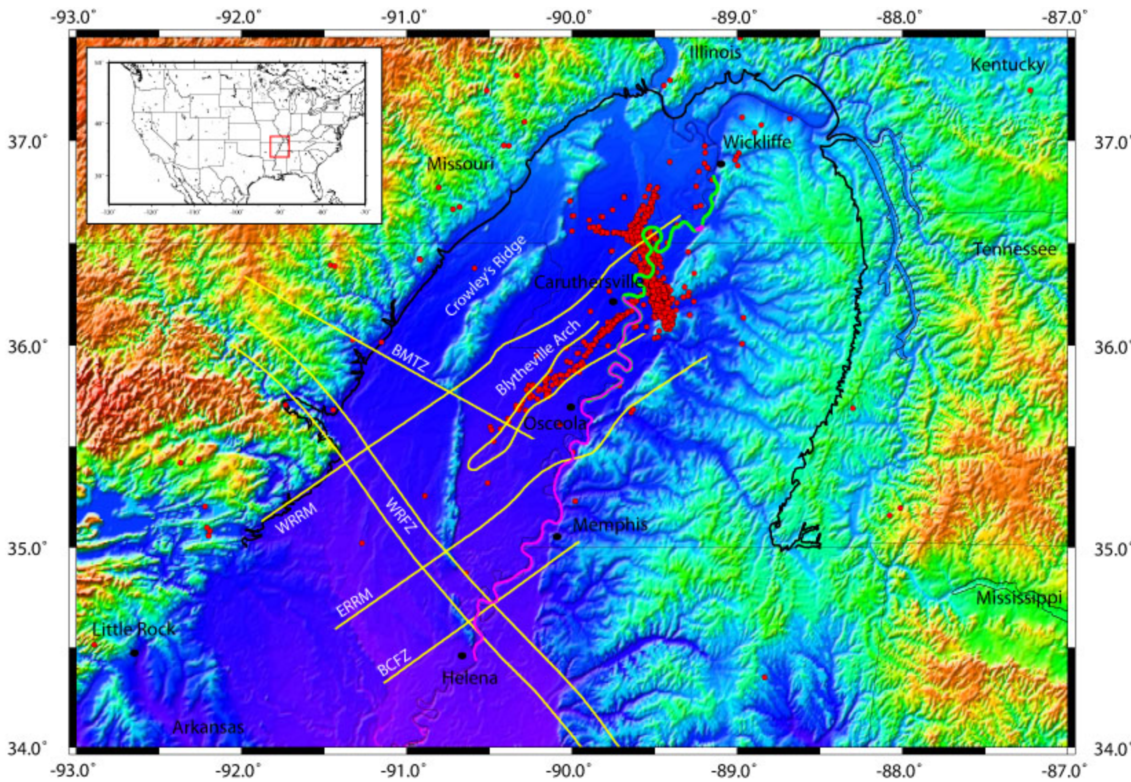

Figure 1. Mississippi Embayment. The black line indicates the edge of the Cretaceous. Red dots are seismicity from 2000 to 2008. Pink line indicates the survey conducted in June of 2008 and green line is the USGS survey conducted in 1981. Yellow lines indicate the tectonic features of the Mississippi embayment: Bolivar-Mansfield Tectonic Zone (BMTZ), White River Fault Zone (WRFZ), Western Reelfoot Rift Margin (WRRM), Eastern Reelfoot Rift Margin (ERRM), and Big Creek Fault Zone (BCFZ).

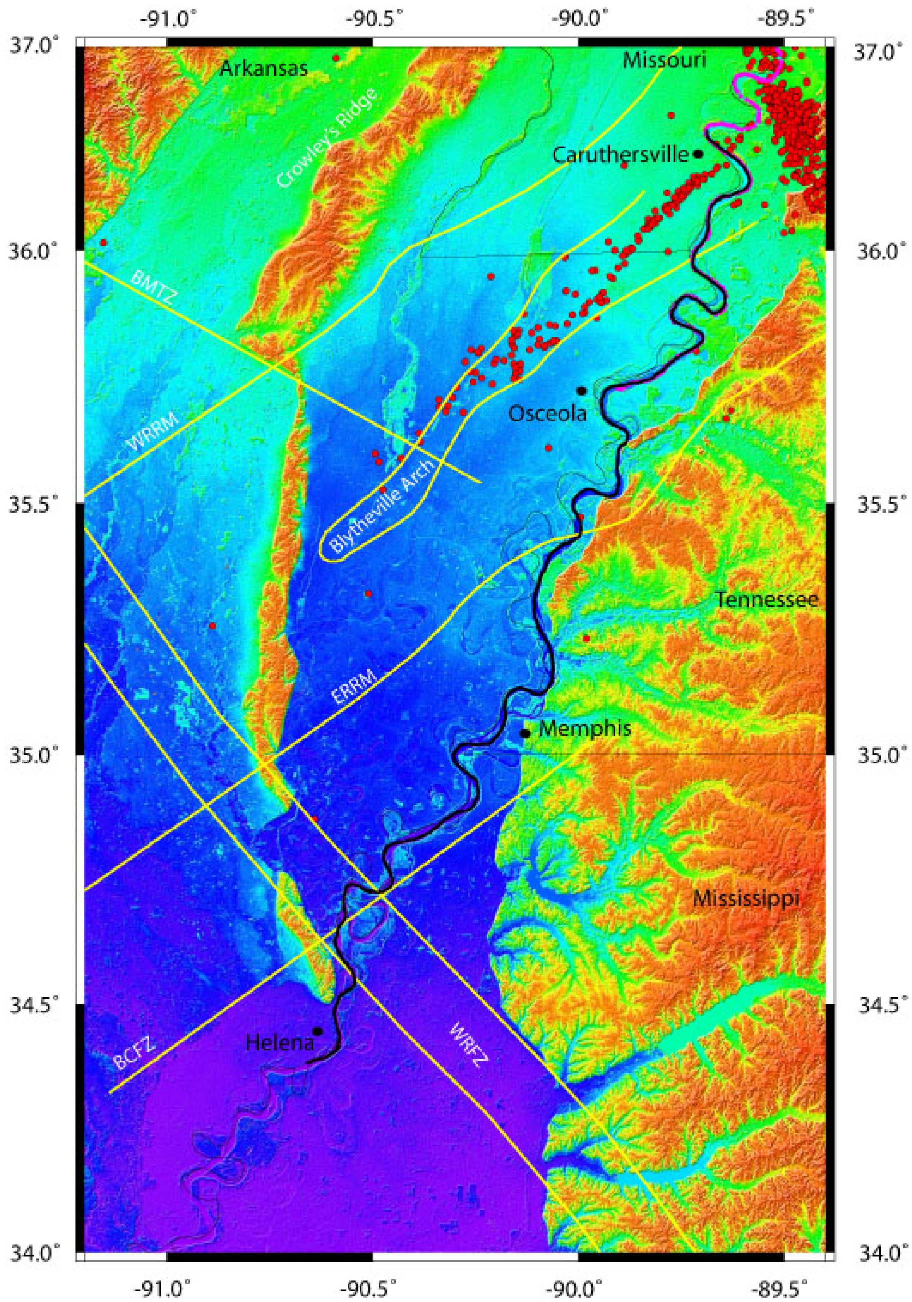

Figure 2. Close up view of the June 2008 survey (black line) conducted from Caruthersville, MO to Helena, AR. Red dots are seismicity from 2000 to 2008. Yellow lines indicate the tectonic features of the Mississippi embayment: Bolivar-Mansfield Tectonic Zone (BMTZ), White River Fault Zone (WRFZ), Western Reelfoot Rift Margin (WRRM), Eastern Reelfoot Rift Margin (ERRM), and Big Creek Fault Zone (BCFZ).

According to the plate tectonic theory, most earthquakes occur along plate boundaries in response to strain built by the relative movement between rigid plates. Intraplate seismicity is an exception to the general theory. With an average of 200 earthquakes a year, the New Madrid seismic zone (NMSZ) is the most active seismic zone east of the Rocky Mountains and is located in the interior of the North American plate.

The NMSZ is estimated to be between 2000 years and 64,000 years old (Russ, 1982; Mitchell et al., 1991; Gomberg and Ellis, 1994; Pratt, 1994). Pratt (1994) showed that extrapolating recent uplift rates (0.11 cm/yr) to the estimated age of the NMSZ predicts significant topographic and subsurface features. However, seismic reflection data (e.g., Shedlock et al., 1982) show little deformation in the post-Cretaceous sediments. Geodetic data show that the velocity of motion vectors decay quickly from ~ 2.7 mm/yr, across the Reelfoot thrust, to less than 1 mm/yr in the far field (Newman et al., 1999; Calais et al., 2005; Smalley et al., 2005). Paleoseismological data correlated to the seismicity along the NMSZ suggest that large magnitude earthquakes, similar to 1811 and 1812, have occurred roughly every 500 to 1000 years in the Holocene (Tuttle and Schweig, 1995; Kelson et al., 1996; Tuttle et al., 2001; 2002; 2005). Evidence is mounting of additional liquefaction structures in the Mississippi embayment whose age does not correlate with the timing of the seismic events that occurred along the NMSZ faults. These paleoliquefaction features suggest that there may be additional fault(s) south of the NMSZ that have been active in the past, and that have not yet been identified.

In order to reconcile the high rate of seismicity and the lack of recent Quaternary deformation, it has been suggested that the seismicity in the Mississippi embayment and in the NMSZ is episodic, migratory, or very young (Schweig and Ellis, 1994). In order to test these hypotheses, we acquired ~300 km of high-resolution seismic reflection and chirp data along the portion of the Mississippi river between Helena, Arkansas, in the south and Caruthersville, Missouri, to the north. We exploited the presence of the Mississippi river to acquire marine reflection data to image a large portion of the Mississippi embayment in a time and cost effective manner. We selected Helena, Arkansas as the southern end of the seismic survey because paleoliquefaction sites have been reported by Tuttle et al., (2006) near the town of Marianna, approximately 40 km to the west of Helena. The age of liquefaction observed at these sites has been dated from 5,000 to 7,000 years old, an age that is older than the known well-dated NMSZ paleoevents. The age of the liquefaction features observed in Marianna suggest that a yet to be identified fault has been active nearby. Tuttle et al. (2006) suggest that possible candidates for the structure responsible for the liquefaction features in Marianna are the White River fault zone, the eastern Reelfoot rift margin, and the Big Creek fault zone. The southern arm of the NMSZ was selected as the northern end of the seismic survey in order to overlap with the USGS 1981 seismic reflection acquisition (Shedlock et al., 1982).

The project, which acquired the descriptive name of Mississippi Moonwalk, was essentially a pilot study to determine whether high-quality seismic reflection data could be acquired in the Mississippi River. The idea is attractive because marine seismic acquisition is cost effective relative to land work and largely avoids many of the pitfalls of land seismic including statics problems and source-generated noise such as "ground roll". Previous attempt at Mississippi River seismic acquisition by the USGS in 1981 (Shedlock et al., 1982) had mixed results. Most importantly, that dataset generally did not provide good images of the shallow section (Eocene-Quaternary), which precludes any attempt to document recent faulting associated with ongoing deformation. To improve our ability to image the post-Cretaceous section we used a significantly different geometry than the previous work and an advanced seismic source that had been previously unavailable. Additionally, unlike the 1981 USGS survey, which proceeded upriver against the river current to acquire seismic data, we devised a downriver progression of data acquisition that allowed us to dramatically reduce the noise caused by the high speed of the recording equipment through the water.

Cruise Diary

Friday, May 30 2008 – JD 151

Kirk and Steffen drove from Austin, TX to Ensley dock with the seismic equipment.

Saturday, May 31 2008 – JD 152

Installation of gear aboard M/V Strong (Figure 3). The GI gun fired successfully.

Figure 3. USACE M/V Strong and barge.

Sunday, June 1 2008 – JD 153

Test data acquisition upstream from Ensley. Problems with Ecosounder acquisition, likely due to short-circuit in transducer pigtail. Tomorrow we'll order a new Ecosounder and will possibly have it shipped to Memphis by Wednesday.

Successful acquisition of ~350 shots with GI gun at 15/15 cu.in and 2000 psi. Tail buoy dives and swims at speeds greater than 6 mph through the water. Initial acquisition at 10 second rep rate, then changed to 15s and shot 150.

A big storm hit in the afternoon on our way to Helena, AR. We arrived safely in Helena in the evening.

Monday, June 2 2008 – JD 154

We left dock at 11:15 am and transited downstream to begin acquisition. At 12:12 turned upriver to deploy gear at River Mile (RM) 650 (Figure 4). We started data acquisition at 12:41 along line 101 at RM 651. Adjusted speed to ~7.5-8.5 mph through water and 3.5 – 4.2 km/hr over ground. We started firing at 10s interval and noticed a 60 –cycle noise on records. We stopped acquisition and moved the cable away from power lines. At 1:05 we still notice the 60-cycle noise on records. At 1:45 pm we moved the Geode box from the lab, where there is a large breaker box, to the bow of the M/V Strong, between the barge and the vessel, in an attempt to eliminate the 60 Hz signal. At 1:50 pm we started shooting again and the 60 Hz noise is still on records. We'll have to try to filter it out during processing. We made a longer trigger cable to move the Geode box all the way to the stern of the M/V Strong.

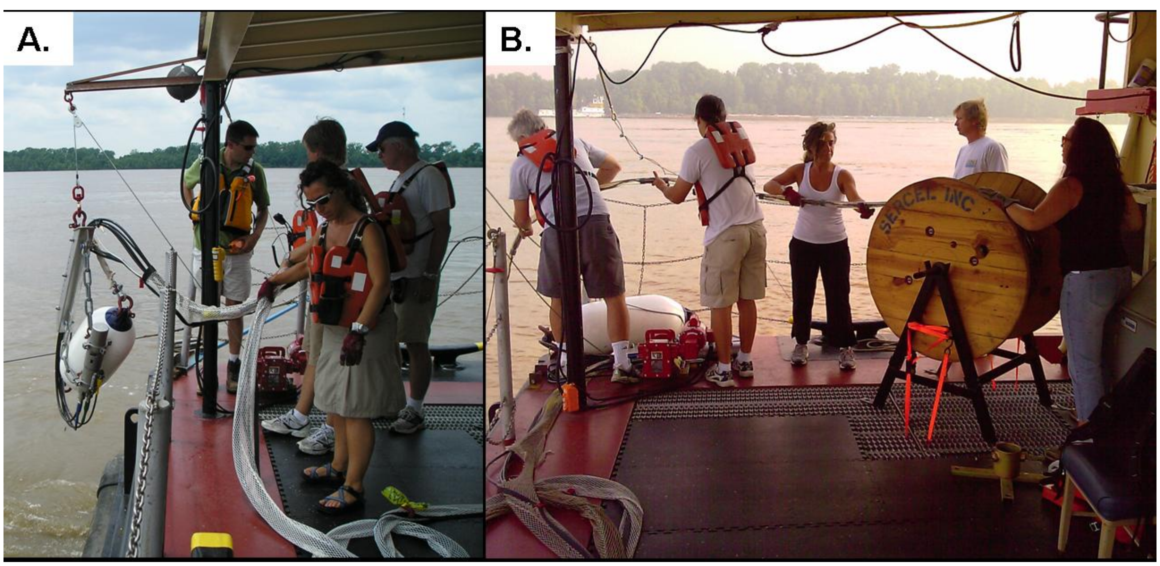

Figure 4. A.) Deployment of airgun and (B.)streamer .

At RM 654 the river crosses the Ouachita Thrust Belt.

At 2:14 pm we moved the airgun farther astern from ~11 m to ~ 15 m behind the stern. The near channel remains at 15 m behind the stern.

We noticed that at 7.5-8.5 mph over ground the tail buoy starts fishing and the streamer gets very noisy. Data quality is not good.

At 4 pm we decided to make a second pass across the edge of the projected end of the Crowley's Ridge, where the first pass showed a break in structure. We started drifting back down stream and Tony, M/V Strong's master, suggested that we keep collecting data as we moved backwards. As we did so, the data quality increased significantly as the speed of the equipment through the water decreases as well as the noise. Tonight we'll have to assess whether moving backwards is a feasible way to collect data and if navigation is manageable.

During acquisition we recorded side-swipe noise from the wall (revetment) along the west side of the Montezuma Island. This arrival correlates directly with distance from the island.

<u>Tuesday, June 3 2008 – JD 155</u>

Today we'll attempt to acquire a full day of data while drifting backwards! Why? Because the current has been over 5 kts, so that to make headway we have had to go about 7-8 mph through the water. At this speed the tail buoy has frequently become chaotic leading to significant noise. The expected parameters for acquisition today are the following:

Start at RM 671

End at RM 657

Drift down at ~2 mph (3.5-4.0 km/h)

Shot interval 10 s (because we can't go shorter with the GI gun).

At 10 s shot interval the compressor slowly loses pressure and after 4-5 hours of running we need to either stop for ½ hr or slow down and start shooting at 12s, as at this interval the compressor is slowly making pressure.

Wednesday, June 4 2008 – JD 156

Today we are continuing to drift down the river. We started at RM 684. The data are good. We are seeing many shallow arrivals and also a consistent event at 0.6 s, probably the top of the Paleozoic.

One problem we are having is that the streamer is getting pulled across the airgun. We are going to try to deploy the streamer book a little farther out/aft.

In the morning, Brian Waldron started feeling sick and recognized the symptoms of a kidney stone. The chase boat was called in and arrangements were made to haul him to shore and then to Memphis hospital to receive medical attention.

We received news that the Echosounder has arrived in Memphis. The Corps speed boat will bring it to the M/V Strong tonight so that we can start acquiring data.

The new way of collecting data requires a lot of skills from the pilot. It's like driving backward through town while towing a trailer! Today we had a problem with one of the navigation buoys that mark the navigable channel. As we were drifting down stream, we approached a river buoy at starboard. The tail buoy of the streamer cleared the river buoy and just when the airgun was about to clear the buoy too, a strong wind pushed the boat sideways toward the river buoy. The airgun was caught around the buoy and as the boat kept drifting sideways and southbound, the streamer wrapped around the buoy as it passed from starboard to port side. Luckily both the airgun umbilical and the streamer passed over the river buoy, which is sticking out of the water for about two feet, and became untangled. If the airgun and the streamer had dived under the river buoy and tangled on the steel cable that holds the buoy in place, very likely the equipment would have been lost or severely damaged, as the steel cable that tows the airgun is thinner than the river buoy cable. The winch brace that olds the pulley snapped and broke loose. We reeled the gear in to assess the damage. The net that wraps the umbilical cables was torn but the gun, the cables, and the streamer were not noticeably damaged. We deployed the gear again and noticed few random spikes that we did not observe before the accident. We resumed acquisition.

Friday, June 6 2008 – JD 158

We started acquiring data at 8:48am, after taking a day off to allow the ship to sail to the northern point, at RM 768. We plan to drift south to where we stopped acquiring data in Tunica, and then leap to Hickman, to image the plunge pool for the Corps.

The Echosounder is working fine and we can see few reflections. On the seismic data, we observe reflectivity down to 0.8 s.

Brian is back with us and he's feeling well. Everybody wonders if eating half a cow for supper every evening has anything to do with his kidney stones.

The crew on the M/V Strong added a second winch to the starboard side of the stern to control the distance between the airgun and the streamer during turns. We also removed 0.5 kg weight from the streamer.

Saturday, June 7 2008 – JD 159

Today we plan to collect data from RM 752 to 736. Drifting south at 2 mph, we should be able to collect this line in about 8 hrs, although it is difficult to maintain a constant speed due to the change in river current and incoming traffic.

We have a cameraman onboard, Greg Gray, who will be filming the main steps of the seismic acquisition and interview the science party. He'll create a documentary that will describe our project.

We placed a 0.5 kg weight on the streamer, between hydrophones 5/4.

Sunday, June 8 2008 – JD 160

We are collecting data in front of Memphis riverside and our target for the day is 10 miles. We'll have several news channel crews onboard so it's good that we planned a short acquisition.

We started collecting data around 9am, and we noticed a 60 Hz noise. We tried to eliminate the noise by unplugging all the power outlets on the stern (where the geode box is located) and by hanging the slack of the streamer cable outboard. Regardless of our effort the 60 Hz noise was still there when Brian decided to wrap the Geode with aluminum foil, like a giant baked potato, to shield it from the electric power frequencies. The noise disappeared. To test the system, Brian removed the foil. And the noise was still gone. Oh, well....

Tuesday, June 10 2008 – JD 162

We deployed gear at 8:30 am, on a cloudy, windless day. Unfortunately the airgun seemed to have problems and was not firing. We reeled it back on deck and we helped Steffen take it apart. We cleaned the elements and dried the solenoids and electric connectors. We then reassembled it and deployed it. It fired fine. We started collecting data along line 125 at 10:22. Our target today is to reach RM 699.

We added 0.5 kg weight on the streamer between channel 7/8 this morning and the streamer seems to be less noisy.

Saturday, June 14 2008 – JD166

We spent the last three days in Memphis, as the ship transited from the end of line 127 (RM 683) to Hickman, KY (RM 922). Yesterday afternoon we left Memphis and arrived in Reelfoot, TN, where the 1811-1812 earthquakes diverted the river and formed the Reelfoot Lake. The lake is one of the most impressive and lasting results of the seismic activity in this area. Studies carried out on the rings in the trunk of the cypress trees growing in the lake showed that the tree's growth changed during the 1811-1812 in response to the flooding of the area due to the earthquakes.

Today we are going to image the Hickman "plunge pool", an enigmatic structure on the bottom of the river. The pool is a deep area ~ 3.2 km long and 1 km wide located on the outer edge of a river bend, where the river bed drops from xx m to 50 m across a distance of few meters. The Corps of Engineers asked us to image the pool as they are concerned that the steep wall on the upstream side of the pool might collapse suddenly in case of a seismic event, releasing large amounts of sand and clay in the river and impeding navigation. The Corps have been monitoring the plunge pool for several years and did not observe a change in depth or a progression up or downriver. The stability of this structure seems to suggest that it is fault controlled. We hope that the reflection survey and the Echosounder will provide a clear image of the subsurface in this area, although the current in this area is extremely chaotic. The river in some cases flows northward and the water is churning over the plunge pool.

We tried a first pass across the pool and the river swept the streamer and the airgun and the seismic data quality dropped substantially. We did an additional pass along the same path and recorded only Echosounder data, as the oil pressure of the compressor started climbing too high. Steffen and the crew will perform maintenance on the compressor while we record Echosounder data. We plan to do at least three passes longitudinally and one transverse, across the river, to get the 3D structure of the plunge pool. Each pass is 2 miles long (from RM 922 to 920) and it will likely take most of the day to collect the data.

The Mississippi river has been flooding north of here and has picked up a lot of debris from the banks (Figure 5). We see all sort of debris coming down, from whole tree from roots to branches, to tires, logs. We have a support boat (the Echo) that the Corps is providing, that has been busy all day trying to divert the debris from the gear.

We stopped data collection after 6:00 pm and we went to Dyersburg to spend the night and to meet with Brian who has spent the last two days at home with kidney stones.

Figure 5. Chaser boat clearing an incoming log away from the path of the streamer and airgun.

<u>Sunday, June 15, 2008 – JD167</u>

The plan for today is to acquire data along the portion of the river that crosses the southern arm of the New Madrid Seismic Zone (NMSZ), known as the Blytheville arch. We started collecting data north of Caruthersville and slowly drifted south.

The data quality is excellent and we observe reflectors down to .8 s (probably the top of the Paleozoic).

While processing the data, we noticed that the amplitudes are overdriven. Steffen suggested fixing this problem by opening the Geode box and removing the jumpers inside the digitizer. We'll do it next time we have the opportunity to do so.

During acquisition we observe on the common receiver gather that some of the reflectors within the first .5 s appear to be truncated by what look like erosional features (paleo channels?). Reflectors are disrupted down to .2 s, which corresponds roughly to 200 m depth. Tomorrow we'll process the data and hopefully we'll be able to understand more about these structures.

Monday, June 16, 2008 JD 168

We started collecting data around 9:30am. For 1 hour everything worked fine. Steffen noticed that the compressor was making a knocking/rattling noise. Since during the last oil change we found pieces of shredded metal in the oil/filter, the knocking noise was considered a bad sing heralding an imminent failure. At 11:00 am we stopped acquisition, after collecting ~5 miles of data, to assess the damage and find possible solutions. Needless to say, without the compressor we can't collect data and therefore this problem could mark the end of the field campaign. After several attempts at finding a compressor of comparable capacity, we contacted Max-Air, the company that built the compressor to see if they could provide us with a solution. The compressor is relatively new and has been running for ~180 hrs. The company agreed to send a new block (pump?) from Texas to Memphis. Andrew, the engineer who built the compressor will drive all day tomorrow from Kerrville, TX, and will meet us in Dyersburg tomorrow night. He will supervise the replacement of the broken part.

The problem with the compressor will cost 2 days of no acquisition. We hope to make up for the lost time by taking full advantage of the light hours. We will have to collect 20 miles/day, which at a speed of 2 kts, means that we'll collect data for about 10-12 hr/daily.

Steffen processed the line we collected yesterday. Data processing has consisted so far in the geometry assignment, bandpass filtering (with or without a notch filter at 60 Hz), CDP sorting and stack.

The data we collected yesterday show several interesting features. Not only the reflector at about 80-120 ms (that we preliminarily interpreted as the Eocene/Quaternary unconformity – i.e. the top of the Upper Claiborne unit) is folded in several locations, but the stack shows even more clearly that the underlying reflectors appear to be truncated by what looks like a channel or an erosional feature. Why has the river incised so deeply? The bottom of the channel reaches 200 ms (~200 m for this depths). Are these structures present all over the course of the river or are they present only in this region (NMSZ)?

In general a river incises deep when the base level drops. This could be caused by a drop in sea level (global event) or by the uplift in the valley floor (mostly a local or regional event). If these structures are widespread along the river, then we should assume that the base level of the river dropped, likely due to a sea level change. However, if these structures are observed only in this region, across the seismic zone, then it is reasonable to infer that they are related to the deformation occurring along the area of active seismicity and could provide information about the deformation and the timing of the deformation occurring there. If the river incision reflects an uplift of the valley floor caused by the deformation associated with the NMSZ, then we could, theoretically, be able to date the onset of the uplift and therefore of the seismicity.

We spent the rest of the day at the hotel, catching up with work and sleep. Tomorrow we'll take the compressor apart and get it ready for the new block to be installed.

Tuesday, June 17 2008 JD 169

We decided to rest a bit today and have a late start. Everybody is tired and this is a good opportunity to catch up with lost sleep. We left the hotel at 8:30 am and drove to Caruthersville to meet with the M/V Strong. The plan for the day is to remove the damaged block from the compressor and prepare everything to mount the new part. Kirk, Brian and Steffen, helped by the crew of the Strong, did that in about 1 hour and we then wrapped the open compressor with a tarp. The rest of the morning was spent processing data and measuring the boat and the barge. Leah and Michael, armed with a tape measure, measured the distance of the three GPS antennae (the boat's, the Geodes' and the chirp's). This info will be used later to correct for the position of the airgun and the streamer.

After lunch, we returned to Dyersburg and spent the afternoon at the hotel's pool, waiting for Andrew to make it to Dyersburg. He arrived at 8:30pm and we were very happy to see him (and to see the new block!). Tomorrow we'll have an early start to install the new block and start collecting data as early as possible.

Wednesday, June 18 2008 – JD 170

We left the hotel at 6:30am and headed to Caruthersville, where the M/V Strong has been docking for the past 2 days. With the crane located on the barge, we moved the compressor's block from Andrew's truck to the boat. Andrew and Steffen installed it in less than two hours and by 9:30am we had tested the newly assembled compressor (Figure 6).

Figure 6. Fixing the air compressor.

It seemed to work fine, so we said so long to Andrew and his son (who was on his way to visit his cousins in Memphis) and headed to RM 833, where we had stopped acquisition the day before. We arrived to the beginning of the line at 10:30 am, deployed the gear and started drifting down the river. One hour later the compressor started leaking air and after several attempts at fixing the problem, we stopped acquisition (yet, again!), called Andrew (who, in the meantime, was on his way to Memphis) and asked him to reach us at the Cottonwood Point landing. He made it there two hours later, at 3:30 pm. It turned out that the problem was a flawed bolt, with a tiny nick, that at 2000 psi could not hold the pressure. Andrew replaced the bolt and we were back on the river at 4:30 pm. Data acquisition started again at 5:00pm. The compressor seemed to work fine. We were back in business!

We stopped data acquisition at 7:00pm, almost 5 miles down the river. We have 60 miles left to close the northern part of the profile and close the gap with the southern section, and three days available before we go back to Memphis, pack and ship part of the seismic gear to Seattle, where it will be used for another acquisition in the Pacific. If everything goes smoothly we should be able to collect data for 10 hr continuously and make it to the 20 miles/day target.

Thursday, June 19 2008 – JD 171

An early start again this morning. We'll try to acquire 20 miles today, which should take about 10 hrs, if everything goes smoothly. We started collecting data at 8:10am and we hope to be done by 6 pm. The compressor works fine. Everybody is tired but relaxed.

All data have been processed to a brute stack. Today we reviewed all the lines to check if we see erosional features along the 300 km long profile or if they are present only locally within the region of influence of the seismically active area. It looks that the only portion of the 300 km – long profile that exhibits such structures is the one close or across the NMSZ. That's intriguing!

We stopped acquisition around 7:00pm. We reached our target of 20 miles today, with 10 hours straight of acquisition. The only problem we had was keeping the debris away from the streamer and in a couple of instances the speed boat hasn't been able to divert all the logs coming down the river.

Friday, June 20 2008 – JD 172

We started early and stopped quite late (7:28pm). We need to stop before it gets dark as the speed boat that takes us to shore does not have lights and it would be dangerous to navigate the river after dark. The Corps have been very patient with us and they understand that we are trying to do everything possible to finish our acquisition in time.

Luckily there is not much to report today, except that at the end of the day, pulling the airgun on deck, we noticed that one of the o-rings was damaged and shredded (we shot so far around 40,000 shots!). Tomorrow we'll have to fix that before starting acquisition.

We made it to the hotel late, after dinner. We are all very tired.

Saturday, June 21 2008 – JD 173

We got an even earlier start today. We had to fix the shredded o-ring on the airgun (Figure 7) so we headed out of the door at 6am and we were onboard at 7am. As the M/V Strong transited to the beginning of the line, we took the airgun apart, cleaned, lubricated and replaced the damaged o-ring. The airgun has fired over 40,000 shots and this is the first part we replaced. We deployed gear and started acquiring data at 7:55am, with a long day ahead of us. Our target is to collect again 20.5 miles today, a total of 11 hours of acquisition and close the line at RM 768.

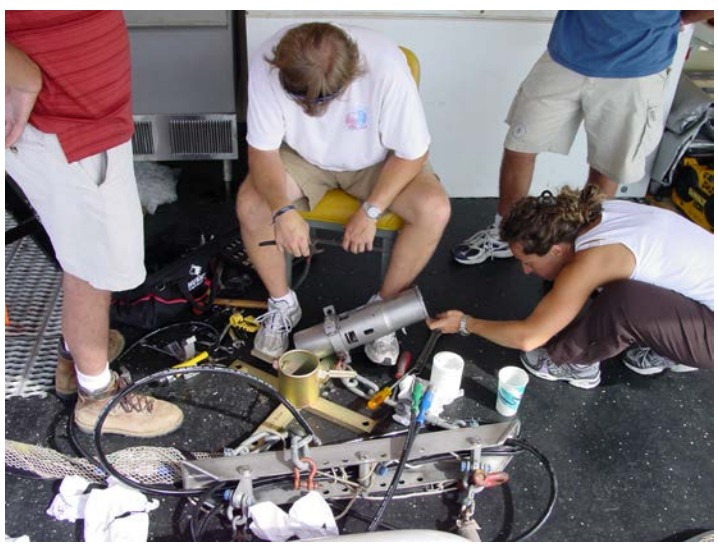

Figure 7. Replacing the o-ring on the airgun.

Along this line, the river runs along the bluffs made of loess deposits (wind deposited silt). The loess lies on top of the Quaternary Lafayette gravels and the Claiborne/Jackson clay (the blue clay, of Eocene age). This clay layer, the top of which outcrops here, is ~50 m thick and represents the aquitard of the Memphis aquifer (Memphis sands).

The acquisition was uneventful. Because there is less debris, we took trips on the speed boat to examine the bluffs and the Eocene/Quaternary unconformity. Brian and Beatrice have been working on a project that plans to image the aquitard in the Memphis area and it is interesting to see the formation in outcrop.

The river is eroding the bluffs fairly quickly. There is a house that used to be on the bluffs and half of which has fallen into the river due to the collapse of the bluffs.

We have to decide today if we want to shoot again the portion of the profile in front of Memphis. When we collected that portion of the profile, our data was plagued by the 60 Hz noise that we couldn't remove. We don't have a lot of time left, but considering that it is only a 10 miles stretch, we could do that in 5 hrs during the last day. To make that decision, Beatrice and Steffen looked at the data collected that day (June 6th) to assess whether the 60 Hz noise could be effectively removed from the data during processing. After testing with frequency filters we concluded that the noise can be removed during processing and decided that we won't collect data along that stretch of the river again. Everybody was happy with that decision. It means that we get to relax for half a day after packing tomorrow.

We arrived at RM 768 a little before 7:00 pm. This marks the end of our 300 km – long seismic survey along the Mississippi river.

Tomorrow we get to pack everything and ship part of the gear to Seattle. Tonight we sleep in Memphis!

Research Vessel and Chaser Boats

The M/V Strong is a United States Army Corps of Engineer (USACE) vessel that is usually attached to a barge in order to transport goods, deploy river buoys, and carry out other USACE contracts. In order to meet our research needs, the crew of the M/V Strong, along with other members of the USACE, reorganized and modified the vessel. The crew installed a boom off the side of the stern for streamer deployment, winches for airgun deployment, retrieval, and guidance, a mounted, rotating arm for echosounder deployment. Additionally the main cabin was reorganized to provide adequate space for our research lab (Figure 8). Two GPS units, additional to the main GPS for the M/V Strong, were installed aboard to provide navigation to the Geode and the Chirp system. The USACE also provided a chaser boat (Figure 9), either the Tiger Shark and the Echo (whichever was available), in order to prevent river debris or unwary river traffic from interfering with the submerged equipment. The positioning of the acquisition equipment aboard the vessel is shown in Figure 10.

Figure 8. A.) Inside seismic lab and (B.) Echosounder outside lab setups.

Figure 9. Chaser boat.

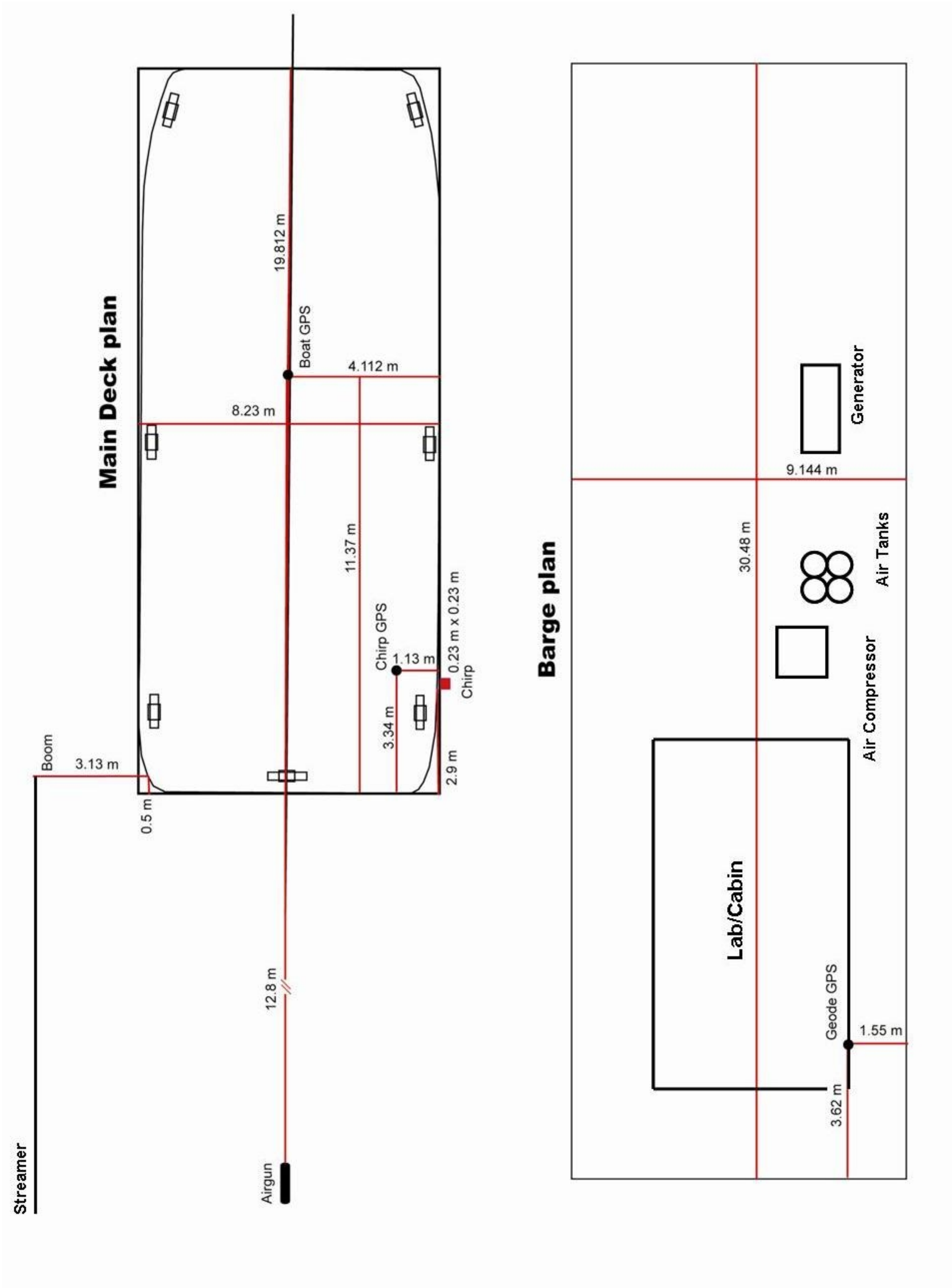

Figure 10. Layout of survey on the M/V Strong.

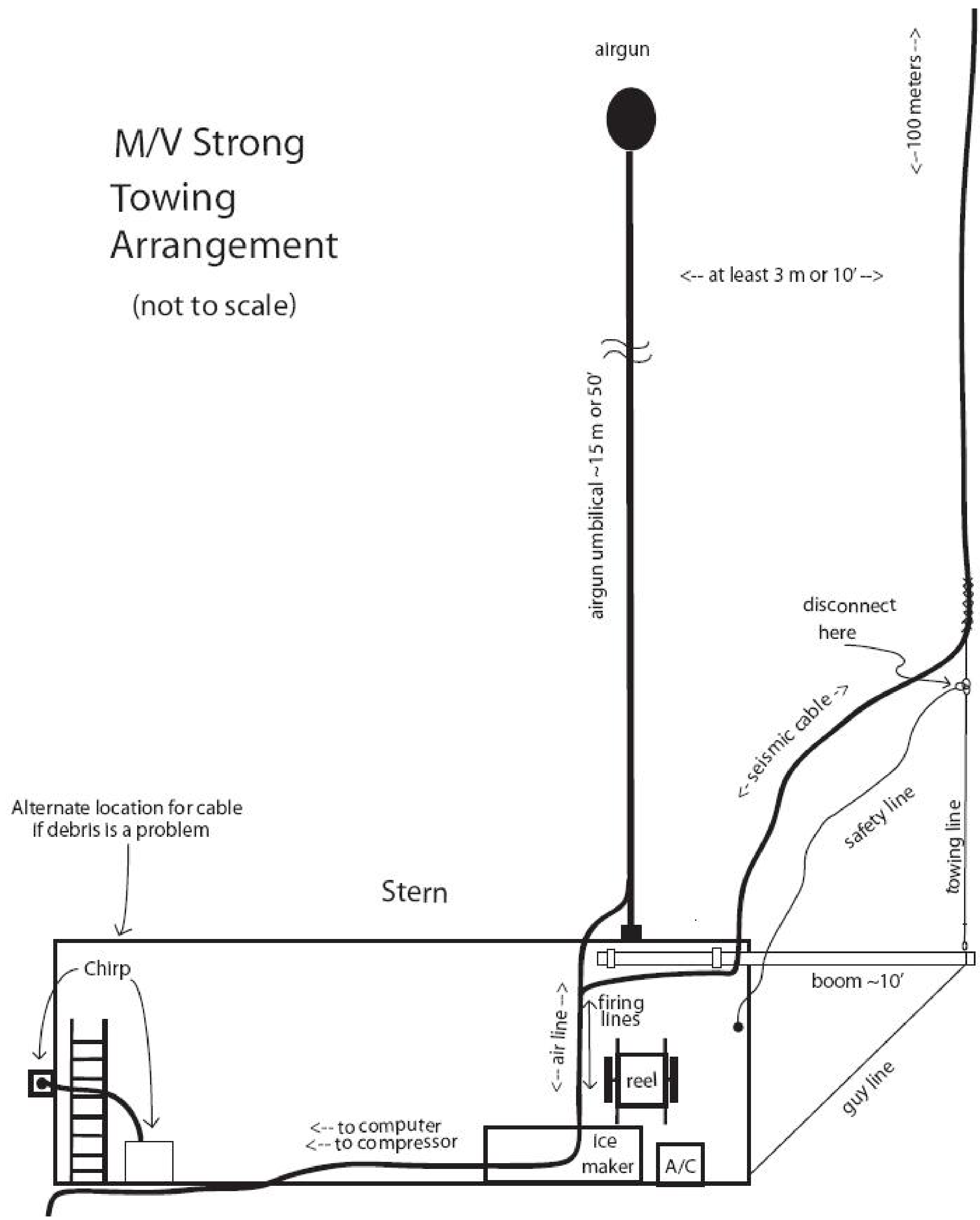

Figure 11. The arrangement of the stern of the M/V Strong

Seismic Acquisition and Data

The reflection data were acquired using a 15/15 c.u. mini-GI Sercel airgun (Figure 12) with a minimum offset of 3 m along and a 24 channel, 75 m-long active streamer (Figure 13). The geometry of acquisition was tailored as to have high resolution imaging of the sedimentary layers from the bottom of the river down to a depth of about 1.2 km (Table 1).

Acquisition Parameters	Mississippi River Seismic Survey
Streamer (#channels/length)	24 channels/ 75 m (active)
Streamer group int.	3.125 m
Near trace source/receiver offset	3 to 6 m
Shot interval	2 to 6.5 m
Sample interval	0.5 ms
Samples per trace	1500
Stacking fold	6 to 16 (depending on current)
CDP interval	1.6 m (nominal)
Airgun Make/Size	Sercel GI/ 15/15 in^3

Table 1. Mississippi River seismic survey acquisition parameters.

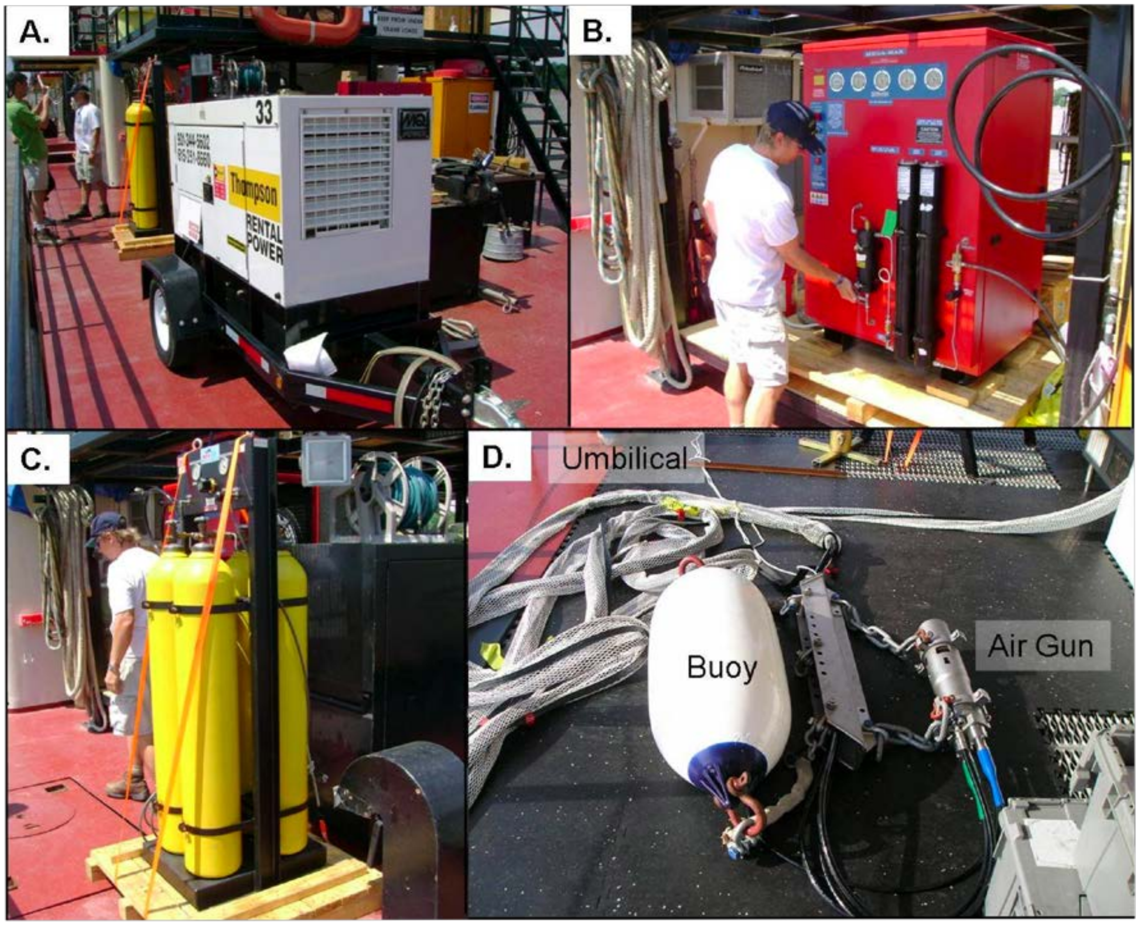

Figure 12. A.) Generator for air compressor. B.) Air compressor. C.) Air tanks. D.) Airgun shown with buoy, hoist and umbilical ready for deployment.

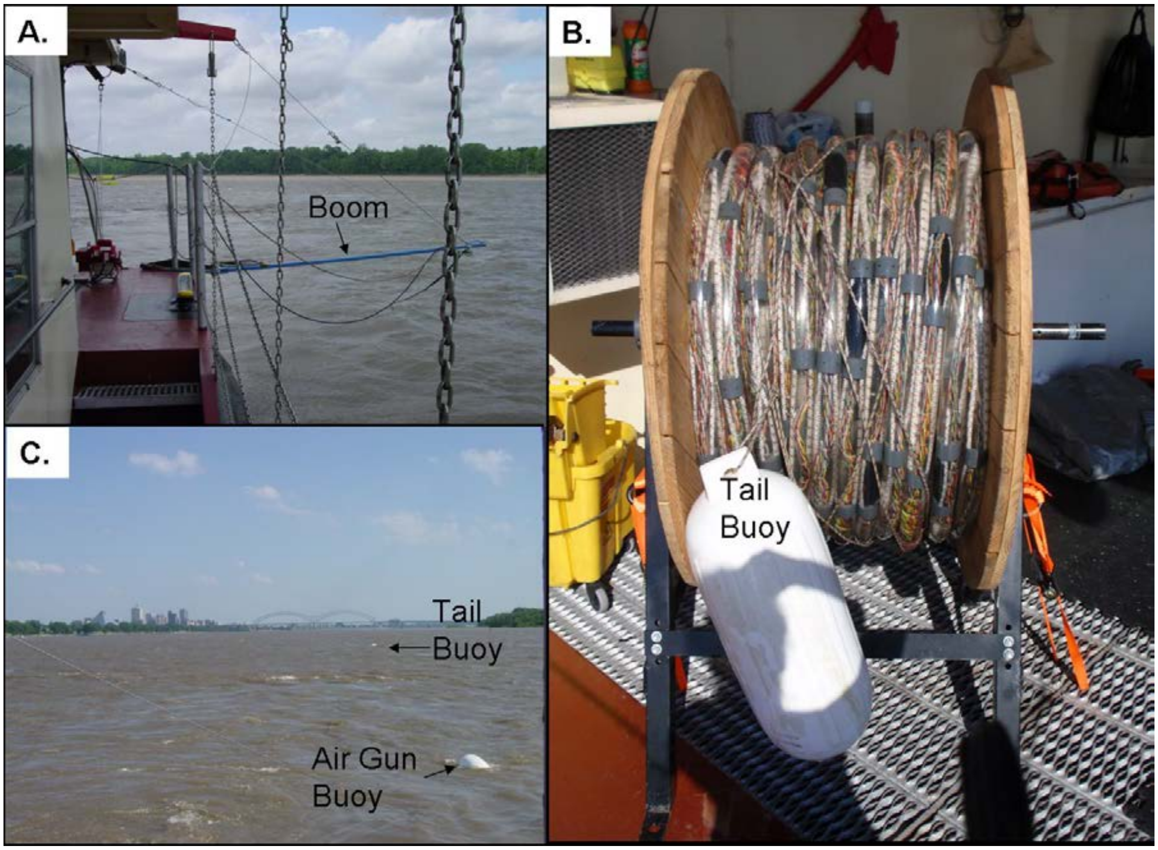

Figure 13. A.) Boom for holding streamer. B.) Streamer with tail buoy. C.) Streamer and airgun deployed.

The Mississippi River seismic survey acquired data by drifting downstream at a speed of ~3 m/s, while pointing northward against the river current. Since the river current average speed was 6 m/s, this configuration achieved a net speed of the equipment with respect to water of ~3 m/s. As a result, there was a dramatic decrease of stress and pull on the buoys and the streamer, therefore reducing the noise level. An example of the seismic reflection data collected is shown in Figure 14.

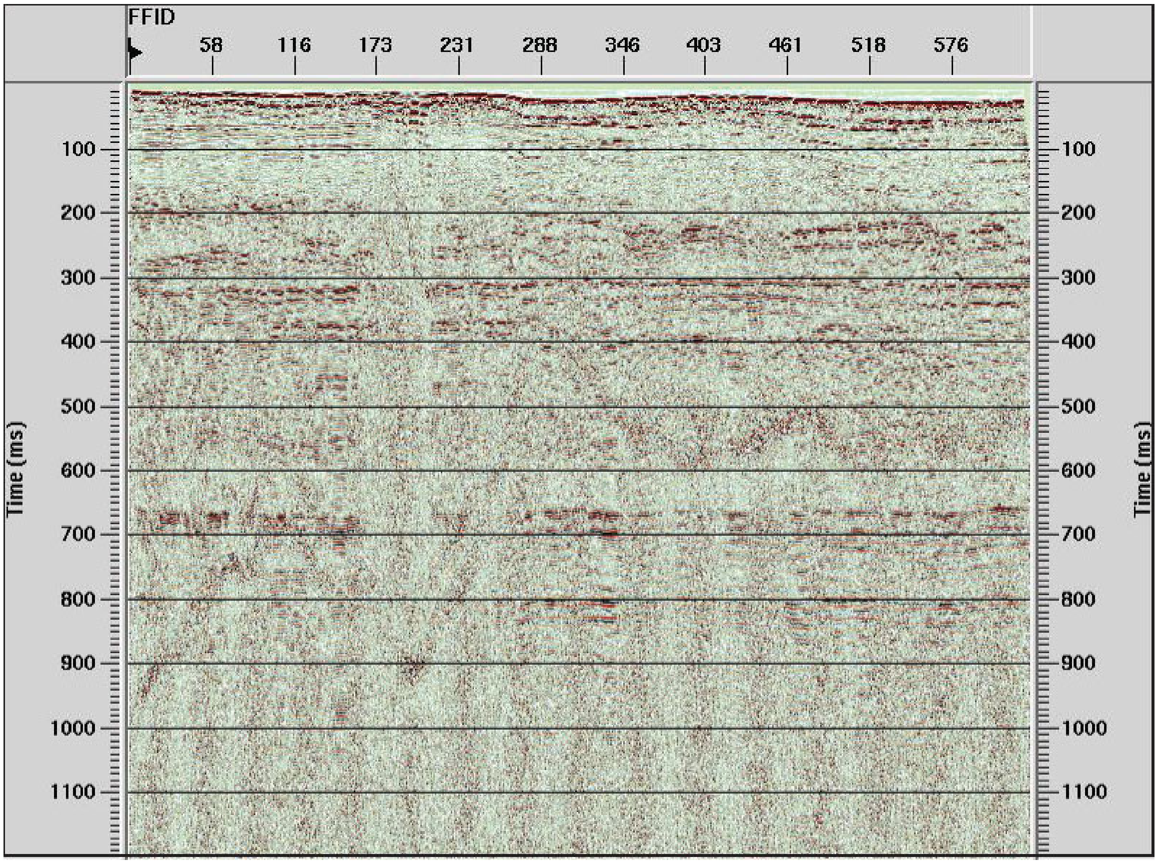

Figure 14. Example of the seismic reflection data brute stack with AGC = 150.

The Echosounder data was collected with a Knudsen 320PB chirp control box and Massa Echosounder (Figure 15). The pulse type was 6 ms chirp with a record length of 32 ms. The sample interval was 20 microseconds and the maximum number of samples of 1600. An example of the echosounder data is shown in Figure 16.

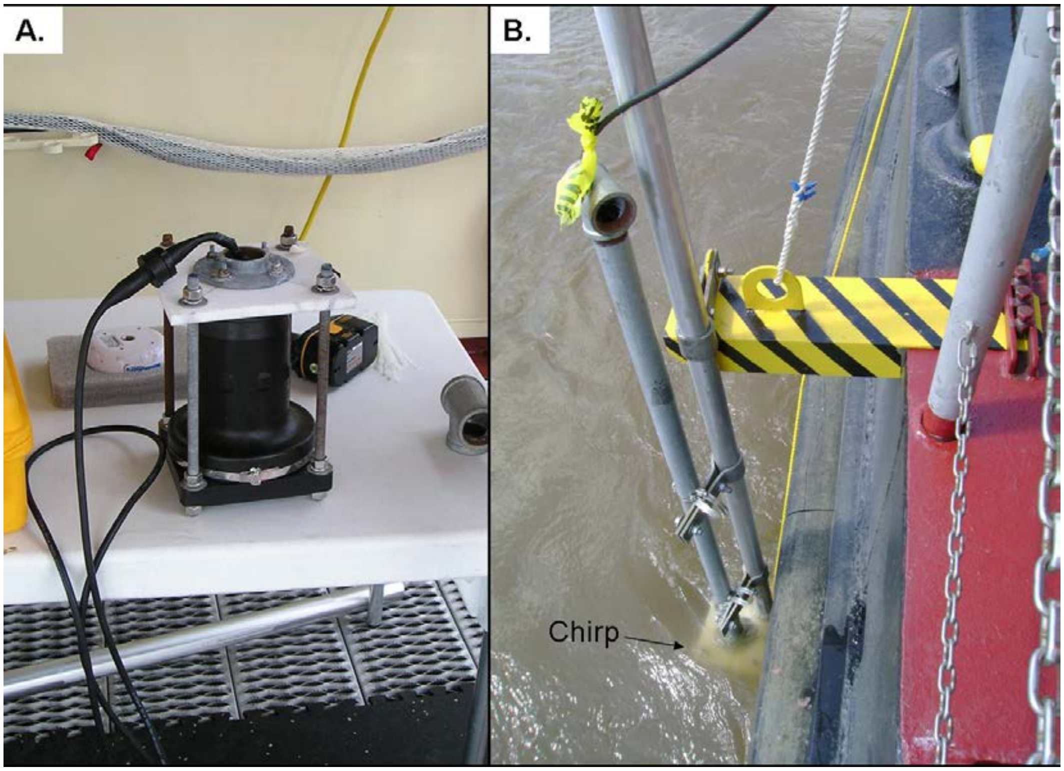

Figure 15. A.) Echosounder. B.) Echosounder deployed.

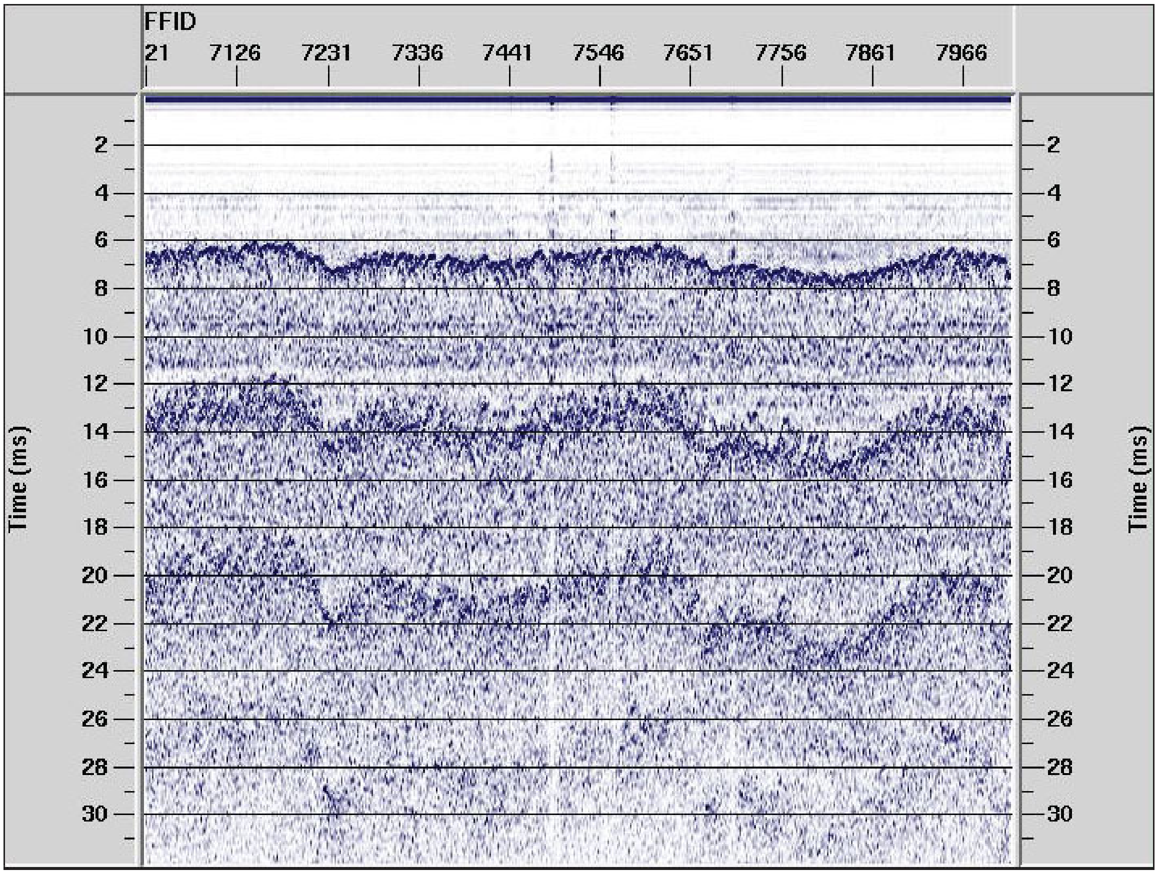

Figure 16. Example of unprocessed data collected by the echosounder.

	Line #	Date	JD	Time (CDT)	Shot point	Latitude (N)	Longitude (W)	RM
Start	101	2-Jun-08	154	12:41	16	34 22 55	90 39 29	653
End	101	2-Jun-08	154		293	34 23 22.40	90 37 49.55	
Start	102a	2-Jun-08	154	13:43	304	34 22 23.99	90 37 48.36	
End	102a	2-Jun-08	154	15:59	311	Waypoint 102	waypoint 102	
Start	102b	2-Jun-08	154	14:00	386			
End	102b	2-Jun-08	154	15:59	1100			
Start	103	2-Jun-08	154	16:00	1101			
End	103	2-Jun-08	154	16:35	1231			
Start	104	2-Jun-08	154	16:35	1232	34 24 28.49	90 35 11.96	
End	104	2-Jun-08	154	18:16	1836	34 26 18.92	90 34 47.18	
Start	105	3-Jun-08	155	9:49	1	34 36 23.09	90 35 04.52	671
End	105	3-Jun-08	155	13:35	1269			
Start	106	3-Jun-08	155	13:38	1270	34 32 29.55	90 32 36.31	666.2
End	106	3-Jun-08	155	18:13	2733	34 26 14.26	90 34 47.24	
Start	107	3-Jun-08	155	18:13	2734	34 26 14.26	90 34 47.24	
End	107	3-Jun-08	155	18:24	2781	34 26 24.45	90 34 52.86	
Start	108	4-Jun-08	156	8:27	3	34 43 25.36	90 30 18.27	684
End	108	4-Jun-08	156	10:47	830	34 43.5359	90 33.9432	679.5

Start	109	4-Jun-08	156	11:11	831	34 43.59.38	90 33.9584	679.5
End	109	4-Jun-08	156	12:40	1359	34 41.36	90 34.0	677
Start	110	4-Jun-08	156	14:14	1366	34 41.4897	90 34.1274	677
End	110	4-Jun-08	156	18:12	2754	34 36 04.87	90 34 50.64	671
Start	111	6-Jun-08	158	8:48	1	35 31 14.36	89 57 09.39	768
End	111	6-Jun-08	158	12:07	1116	35 29 33.55	90 00 42.63	
Start	112	6-Jun-08	158	12:11	1119	35 29 33.55	90 00 42.63	
End	112	6-Jun-08	158	17:05	2723	35 24 26.22	90 03 13.08	755.5
Start	113	6-Jun-08	158	17:07	2724	35 24 26.22	90 03 13.08	755.5
End	113	6-Jun-08	158	18:08	3079	35 23 03.39	90 04 29.51	755.5
Start	114	6-Jun-08	158	18:12	3080	35 23 05.57	90 04 25.30	755.5
End	114	6-Jun-08	158	18:57	3350	35 21 51.31	90 05 06.33	752
Start	115	7-Jun-08	159	9:07	7	35 21 52.06	90 05 05.63	752
End	115	7-Jun-08	159	14:38	1967	35 13.0408	90 04.3334	741
Start	116	7-Jun-08	159	15:30	1977	35 13.1190	90 04.3244	741
End	116	7-Jun-08	159	18:14	2926	waypoint 1160	waypoint 1160	736
Start	117	8-Jun-08	160	10:32	279	35 08.9245	90 03.8368	736
End	117	8-Jun-08	160	11:13	518	35 07.9243	90 04.4174	
Start	119	8-Jun-08	160	11:22	534	35 07.9512	90 04.4229	735

End	119	8-Jun-08	160	15:27	1996	35 06.4433	90 10.5728	728.5
Start	120	8-Jun-08	160	15:48	1997	35 06.4761	90 10.5654	728.5
End	120	8-Jun-08	160	16:11	2132	35 06.1368	90 10.6445	728.5
Start	121	8-Jun-08	160	16:13	2133	35 06.1409	90 10.6396	728.5
End	121	8-Jun-08	160	17:09	2468	35 04 39.15	90 10 37.94	725.5
Start	122	9-Jun-08	161	8:51	12	35 04 40.22	90 10 37.49	726
End	122	9-Jun-08	161	15:07	2206	34 59 35.06	90 18 10.93	715
Start	123	9-Jun-08	161	15:20	2207	34 59 39.92	90 18 11.11	715
End	123	9-Jun-08	161	17:54	2977	34 57 12.89	90 15 14.63	711
Start	125	10-Jun-08	162	10:22	55	34.954272	90.256495	711
End	125	10-Jun-08	162	17:28	2603	34.834942	90.386797	698
Start	126	11-Jun-08	163	8:48	33	34.836347	90.381647	698
End	126	11-Jun-08	163	10:37	679	34.823205	90.444135	694.5
Start	127	11-Jun-08	163	10:48	680	34.822358	90.443960	694.5
End	127	11-Jun-08	163	17:00	2911	34.730340	90.517112	683.5
Start	128	14-Jun-08	166	9:47	7	36 34 60.52	89 12 36.34	922
End	128	14-Jun-08	166	11:16	535	36.563450	89.246545	920
Start	129	14-Jun-08	166	13:36	541	36.584245	89.210127	922.5
End	129	14-Jun-08	166	14:58	1033	36.565812	89.245980	920

Start	130	14-Jun-08	166	16:01	1046	36.582743	89.217453	922
End	130	14-Jun-08	166	17:11	1464	36.571663	89.246988	920
Start	131	15-Jun-08	167	8:54	5	36.235752	89.686418	850
End	131	15-Jun-08	167	17:00	2841	36.100035	89.661862	836
Start	132	16-Jun-08	168	9:38	6	36.101237	89.655145	836.3
End	132	16-Jun-08	168	11:24	623	36.065157	89.682260	833
Start	133	18-Jun-08	170	10:46	9	36.071198	89.681608	833
End	133	18-Jun-08	170	12:05	470	36.034368	89.687130	831
Start	134	18-Jun-08	170	16:58	473	36.039782	89.685867	831.5
End	134	18-Jun-08	170	17:54	799	36.019385	89.694690	829.5
Start	135	18-Jun-08	170	17:54	807	36.019293	89.694643	829.5
End	135	18-Jun-08	170	19:00	1205	35.994158	89.716923	827.5
Start	136	19-Jun-08	171	8:12	6	35.995451	89.715983	827.7
End	136	19-Jun-08	171	17:21	3295	35.899445	89.755323	810.5
Start	137	19-Jun-08	171	17:21	3296	35.899417	89.755125	810.5
End	137	19-Jun-08	171	19:09	3946	35.859552	89.762333	807.5
Start	138	20-Jun-08	172	8:18	14	35.881885	89.769820	809
End	138	20-Jun-08	172	19:28	4018	35.730468	89.918825	788.7
Start	139	21-Jun-08	173	7:55	11	35.738920	89.904803	789.5
End	139	21-Jun-08	173	18:47	3912	35.522128	89.956555	768