FINAL TECHNICAL REPORT

Award Number 08HQGR0008

# INVESTIGATION OF SEISMICALLY-INDUCED LIQUEFACTION IN NORTHEAST LOUISIANA

Principal Investigator: Randel Tom Cox

Institute of award
Department of Earth Sciences
University of Memphis
Memphis, TN 38152

Telephone: 901-678-4361
Fax: 901-678-2178
E-mail: randycox@memphis.edu

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Randel Tom Cox, Department of Earth Sciences, University of Memphis, Memphis, TN 38152, Telephone: 901-678-4361, Fax: 901-678-2178, E-mail: randycox@memphis.edu

ABSTRACT

We examined aerial photography of parishes in northeastern Louisiana within the Wisconsinan and Holocene portion of the Lower Mississippi Valley for possible seismically-induced sand blows. Two areas or "fields" in Morehouse, Richland, and Franklin Parishes of northeastern Louisiana have circular to elliptical tonal anomalies that are similar in size, shape and spacing to the aerial photography signature of sand blows to the north in the Mississippi Embayment, but are well outside the known region of liquefaction associated with the New Madrid seismic zone (NMSZ) in the northern embayment (>330 km to the north). Following our previous approach of coring, ground conductivity surveying, trenching, sedimentological/soil analysis, and age analysis by $^{14}C$ and luminescence techniques, we conclude that these Louisiana sand blow fields are seismically-induced blows of late Holocene age, except the eastern half of the southern-most field is an area of Holocene eolian dunes rather than sand blows.

We found evidence for two sand blow episodes in Morehouse Parish that occurred between 340 and 3830 yr B.P. and for one in Richland Parish between 330 and 5500 yr B.P. The older blow in the Morehouse Parish field has a large vent several meters wide, and we interpret this older blow as a lateral spread sand blow that may have been triggered by a larger earthquake than the later blows that show a "shotgun" surface pattern indicating hydraulic fracturing rather than lateral spreading. The age constraints of the Louisiana sand blows can accommodate any of three dates of possible regional events in southern Arkansas liquefaction fields (700, 2300, and 3500 yr B.P.). Based on spatial and temporal relationships, we speculate that the paleo-earthquakes that triggered the sand venting episodes in northeastern Louisiana were along the Saline River fault zone in southern Arkansas.

INTRODUCTION

Northeastern Louisiana has a strong signature of block tectonics active throughout late Quaternary (Schumm et al., 1982; Burnett and Schumm, 1983). Although the region is characterized by an absence of historic seismicity, it is outside the low-magnitude detection range of the seismic networks operating in the Central and Eastern United States (Mitch Withers, CERI, personal communication). In this study we collected field evidence of seismically-induced paleoliquefaction that indicates unrecognized seismic sources in the vicinity of northeastern Louisiana. This area is crossed by major bridges on the Mississippi River, the route of future Interstate Highway I-69, and by pipeline infrastructure which distributes petroleum and refined products from production in the Gulf of Mexico to users in the Memphis region and in the eastern and northeastern U.S. (American Petroleum Institute, 2003). Disruption to such critical infrastructure could extend the impacts of a regional earthquake to much of the country. In addition, seismic sources in the region pose a hazard to a regional population center (Monroe, LA) and the Grand Gulf Nuclear Power Plant.

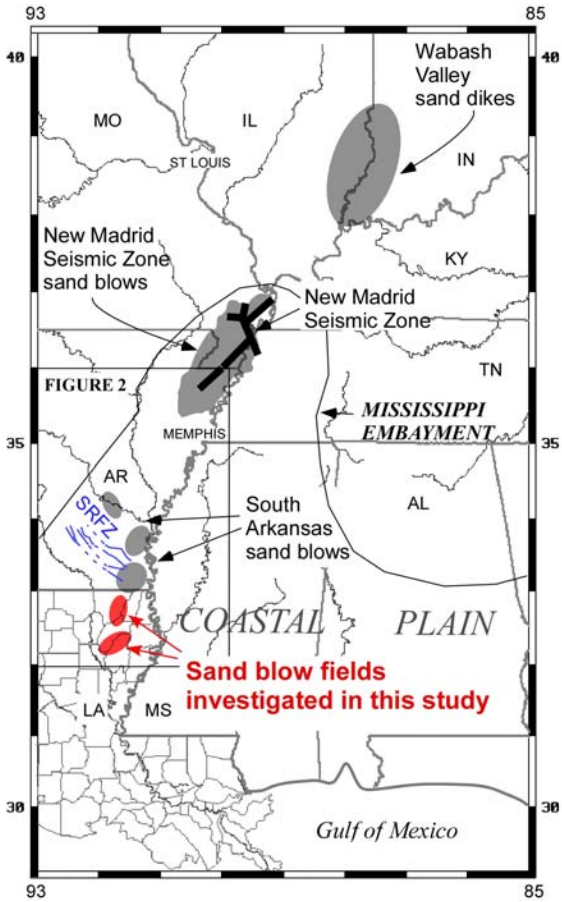


Figure 1. Regional setting of this liquefaction study showing the previously documented areas of seismically-induced liquefaction (gray shading) and the proximity of the study area to the New Madrid seismic zone. SRFZ = Saline River fault zone.

This current phase of trenching built upon our preliminary investigations of three large areas (>500 km2) of intense late Holocene sand venting in southern Arkansas (Figs. 1 and 2)(Cox et al., 2004, 2007). Sand blows we excavated in Louisiana are also late

Holocene, significantly expanding the known area that has experienced recent strong ground shaking. This study addresses the following research questions:

1. How many seismic events generated sand blows in northeastern Louisiana?

2. What is the age of each venting episode?

3. How do these ages relate to large historic and/or prehistoric New Madrid seismic zone liquefaction events?

PREVIOUS INVESTIGATIONS

Our previous work identified three sand blow fields that exhibit a distinct chronology of strong ground motion for southern Arkansas: 1) The Ashley County, Arkansas sand blow field, near the Arkansas/Louisiana state border, experienced four or more Holocene sand venting episodes; 2) to the north, the Desha County field experienced at least two episodes of liquefaction; and 3) the Lincoln-Jefferson Counties field had at least one episode (Figs. 2 and 3)(Cox et al., 2004, 2007). These southern

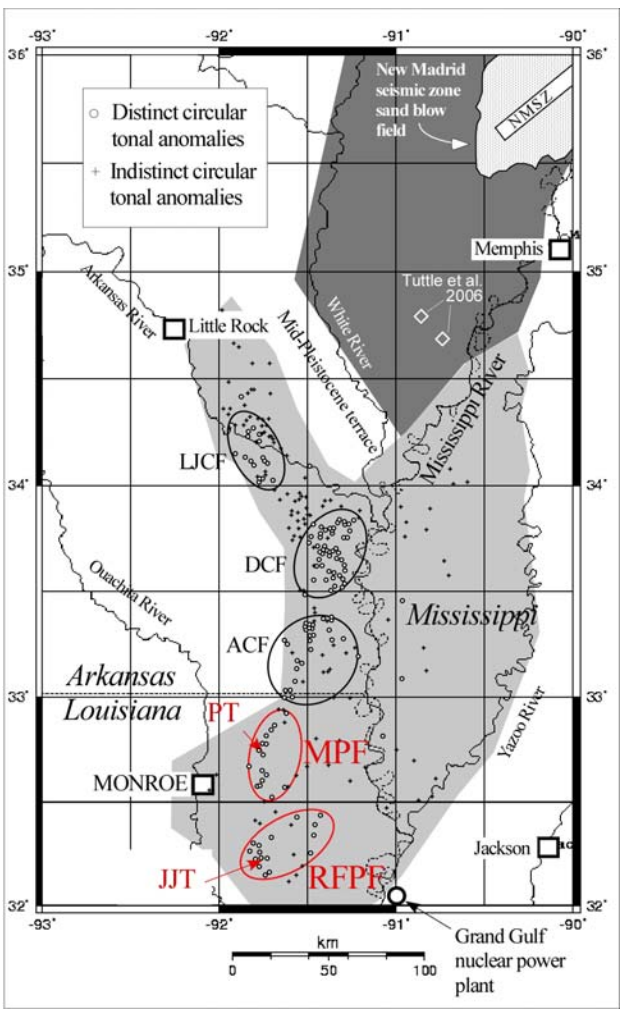


Figure 2. Map showing the region reconnoitered for sand blows by the inspection of aerial photography. Light shading denotes the region of Wisconsinan/Holocene alluvial valley I surveyed by inspection of pre-1950 aerial photography at the National Archives and Records Administration, College Park, MD. Dark shading denotes region surveyed for liquefaction features by other workers.

Sand blow fields investigated in this study in northeastern Louisiana are denoted by ellipses labelled MPF (Morehouse Parish field) and RFPF (Richland-Franklin Parish field). PT = Tip Pugh trench site; JJT = Junior Jones trench site.

Sand blow fields we have documented by previous geophysical surveys, coring, and trenching are denoted by ACF (Ashley County field), DCF (Desha County field), and LJCF (Lincoln-Jefferson Counties field)(Cox et al. (2007). Diamonds denotes liquefaction sites of Tuttle et al. (2006).

Arkansas liquefaction fields are >175 km southwest of the southern margin of the recognized liquefaction field of the New Madrid seismic zone (NMSZ) and >300 km southwest of the epicenters of the earthquakes responsible for the NMSZ sand blows. The results of cone penetration tests (CPT) conducted in and between these sand blow fields are not consistent with distal liquefaction associated with NMSZ earthquakes but rather suggest that these sand blow fields are associated with strong earthquakes on local faults (Cox et al., 2007). This conclusion is consistent with the differences in timing of the southern Arkansas sand venting episodes and those in the New Madrid seismic zone.

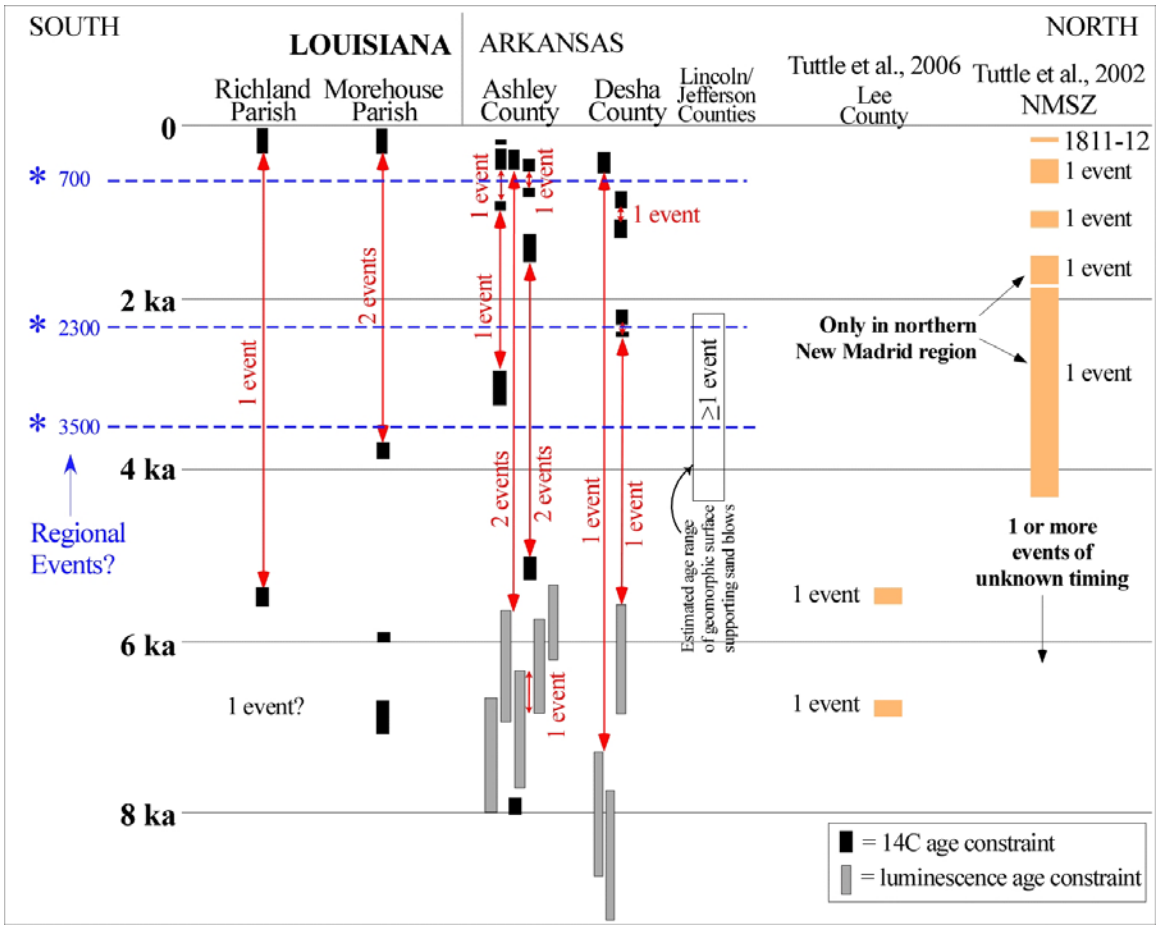


Figure 3. Sand blow chronology of the Lower Mississippi Valley including results from this study for Louisiana (after Cox et al., 2007). Red double arrows denote the time range for sand venting episodes as constrained by $^{14}C$ and luminescence dating. NMSZ = New Madrid seismic zone.

## STUDY AREA

This paleo-liquefaction research project was conducted in northeastern Louisiana in Morehouse, Richland, and Franklin Parishes (Fig. 4). This area is part of the Lower Mississippi Valley late Quaternary alluvial plain that is underlain by liquefaction-susceptible sediments, but it had not been previously investigated for prehistoric liquefaction deposits.

We selected specific field investigation sites based on remote sensing and geophysical data in the form of aerial photography and ground conductivity surveys, and confirmed with field reconnaissance. In addition, we tried to select excavation sites near the center of the two principal sand blow fields.

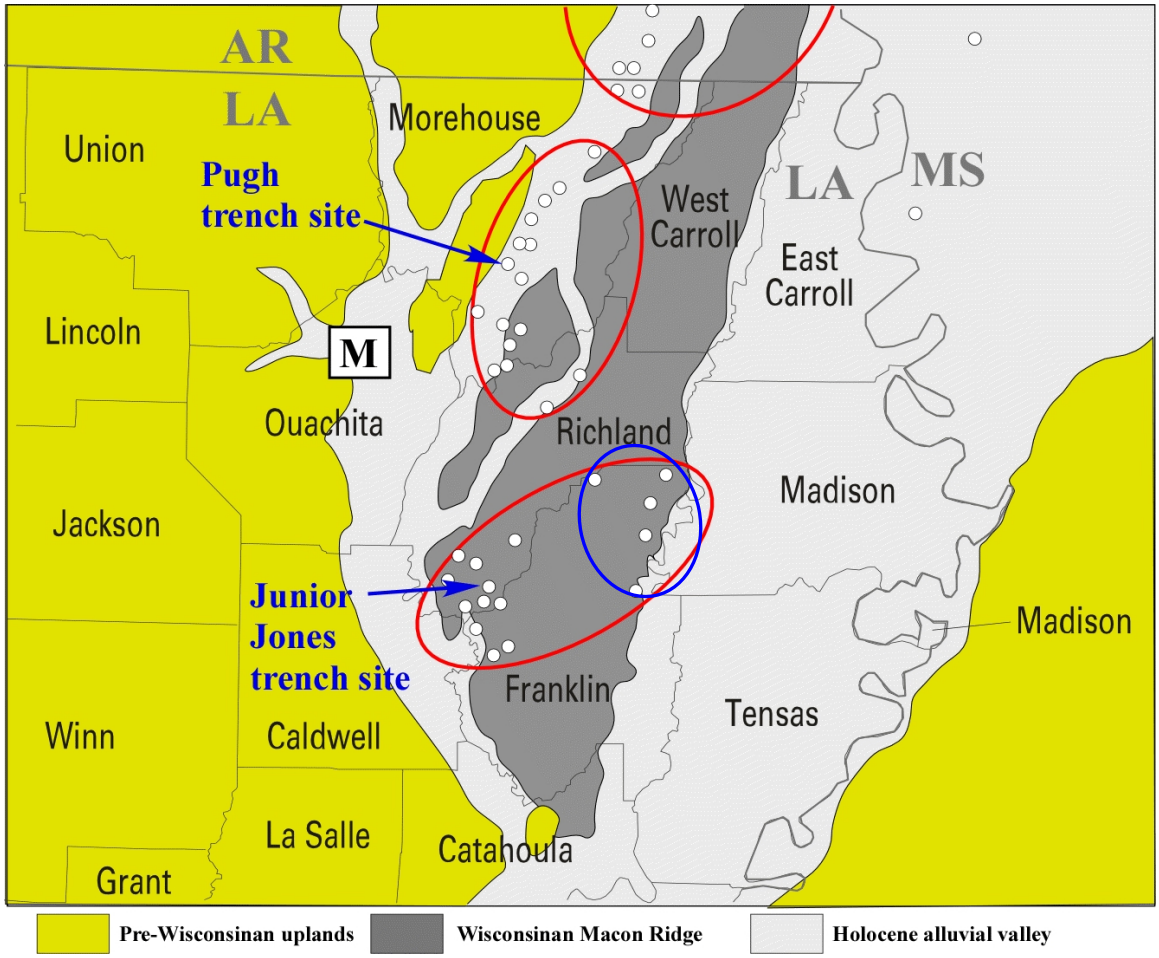


Figure 4. Generalized map of surficial geology of the study area (after Saucier, 1994) showing the location of the Morehouse and Richland-Franklin Parishes sand blow fields. The red ellipses denote the limits of the sand blow fields as identified on aerial photos. The blue ellipse denotes that portion of the Richland-Franklin Parish field that turned out not to be sand blows, but rather eolian dunes (pimple mounds).

INVESTIGATIONS UNDERTAKEN

We excavated two trenches during this phase of the project, the Tip Pugh trench (Morehouse Parish sand blow field) and the Junior Jones trench (Richland-Franklin Parishes sand blow field), each named for the land owner or current farmer of the property. Sand blows were excavated by backhoe, and trench walls were logged in detail to describe the stratigraphic relationships of vented liquefaction deposits to alluvial deposits and soil horizons. Organic-rich soil and borrow fill, along with soil carbonate nodules and charcoal from substrate units, were collected for radiocarbon age analysis. In addition, buried silt and/or sand units were sampled for luminescence age analysis (optically stimulated luminescence). This phase of our study is a continuation of our

investigation of liquefaction features across the southern Mississippi Embayment and northern Gulf Coast, and methods and techniques used are consistent with our previous effort to systematically document and delineate areas of past strong ground motion in this region.

TABLE 1. Results of $^{14}C$ analyses. Analyses conducted by the NSF-Arizona AMS Laboratory.

| **Lab No.** | **Sample Material** | **Sample Collecting Location** | **$\delta^{13}C$ ‰** | **Radiocarbon age yr BP** | **Calibrated 2σ calendar age*** *minor area*** |
|---|---|---|---|---|---|
| UM-RC08-2 | Charcoal | Jr. Jones trench meter 4.0 depth-0.7 | -27.5 | 4705+-43 | 3632-3558 BC<br>3537-3485 BC<br>3474-3371 BC |
| UM-RC08-3 | Charcoal | Jr. Jones trench meter 7.2 depth+0.1 | -25.8 | 136+-39 | 1669-1781 AD<br>1798-1894 AD<br>1904-1946 AD |
| UM-RC08-7 | Charcoal | Tip Pugh Trench meter 16.95 depth -0.5m | -9.3 | 157+-50 | 1663-1892 AD<br>1907-1953 AD |
| UM-RC08-8 | Soil $CaCO_3$ nodule | Tip Pugh trench meter 1.5 depth -1.1m | 0.8 | 4311+-44 | *3083-3066 BC*<br>3027-2877 BC |
| UM-RC08-9 | Soil $CaCO_3$ nodule | Tip Pugh Trench meter 0.5 depth -0.7m | -0.3 | 3496+-43 | 1931-1734 BC<br>*1715-1694 BC* |
| UM-RC08-12 | Bulk soil | Tip Pugh trench meter 0.6 depth -0.4m | -21.2 | 5,971+-85 | *5202-5176 BC*<br>5070-4668 BC<br>*4660-4668 BC*<br>*4638-4618 BC* |
| UM-RC09-1 | Bulk soil | Tip Pugh trench meter 18.1 depth +0.1m | | Awaiting lab results | |

*CALIB software (Stuiver et al., 2005).

** The peak areas of the italicized time intervals are small, and it is unlikely the true age of the sample falls within this interval.

## RESULTS

### Morehouse Parish field

This sand blow field is developed on the terrace of a middle Holocene Arkansas River paleochannel mapped mostly as Hpa-5 meander belt (circa 9 to 7 ka) and associated Hb backswamp of Saucier (1994) (Fig. 4). Small portions of the field near Start, Louisiana are mapped as Arkansas River Hpa-3 meander belt (circa 7 to 4 ka) and Wisconsinan terraces Pve-1 and 2 by Saucier (1994). The size of this field may be limited by non-liquefiable deposits of thick loess on the west ("Bastrop Hills" portion of the Sangamon Prairie terrace) and on the east (older Wisconsinan terraces Pve-3 and 4 of eastern Macon Ridge).

The sand blows in this field are discreet circular to elliptical sand bodies (Fig. 5). These type of "popcorn" or "shotgun" sand blows are characteristic of hydraulic fracturing relatively near a seismic source, rather than linear and curvilinear sand blows caused by lateral spreading on slopes that can occur at greater distances from the seismic source (Obermeier et al., 2005). Prominent alignments of blows in our Tip Pugh trench site vicinity display branching patterns and converge southeastward, suggesting the source sands are a crevasse splays of Arkansas River meander belt Hpa-5 to the east.

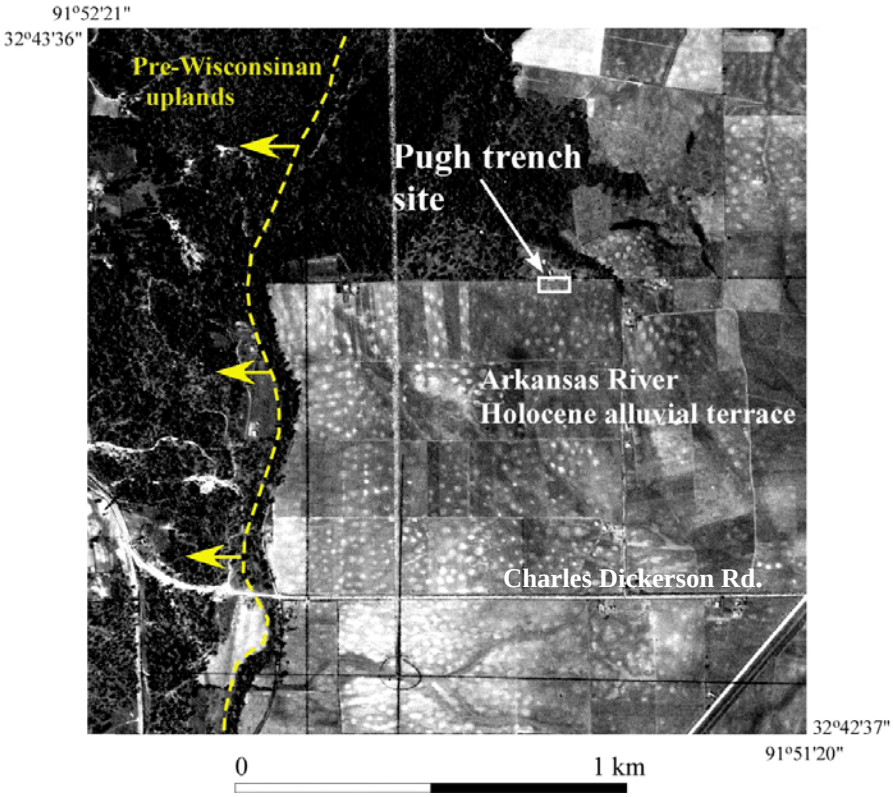


Figure 5. Aerial photograph (1941) of a portion of the Morehouse Parish field north of Collinston, Louisiana showing the location of our Tip Pugh trench site. The light tonal anomalies are "popcorn" or "shotgun" sand blows. The dashed yellow line denotes the eastern scarp of the "Bastrop Hills" portion of the Sangamon Prairie Terrace.

Tip Pugh trench site:

The Tip Pugh trench was located in south-central Morehouse Parish north of Collinston, Louisiana off Charles Dickerson Road (Fig. 5). We logged the south trench wall, collected bulk sediment samples for lab analysis, carbon samples for radiocarbon dating, luminescence samples for dating, and photographed the trench wall. Geochronologic samples were submitted for analysis to the NSF-Arizona AMS Laboratory in Tucson, Arizona for $^{14}C$ dating and to the Luminescence Dating Research Laboratory, University of Illinois at Chicago for optically stimulated luminescence (OSL) dating. OSL and additional $^{14}C$ dating results are expected in mid 2009.

The Tip Pugh trench exposed two generations of sand blows composed of fine sand and a large vent >3 m wide associated with the older blow (Fig. 6, meter 3 to 5). The older blow, a structureless fine sand exposed from meter 2 near the east end of the

trench continuously to the west end, was vented onto a cross-bedded alluvial sand containing well-defined horizons of soil carbonate nodules (< 4 cm diameter) that post-date the alluvium. These nodules were entrained and transported upward at meter 3.8 to 5.6 in the vent area of the older blow. Radiocarbon AMS analysis of two of these nodules yields calibrated ages of ~3830 yr B.P. at meter 0.5, depth -0.7 m (sample # UM-RC08-9, Table 1) and ~5070 yr B.P. at meter 1.5, depth -1.1 m (UM-RC08-8). An Ao soil horizon is developed on the older blow from meter 0 to 10. The bedding of the sub-blow alluvium east of the older blow from meter 0 to 1.9 appears slightly brecciated or "jumbled", but we observed no clear fractures. Soil development extends through the alluvium in the lower trench wall (Fig. 7), and soil development may obscure any fractures in the alluvium at the east end. Organic-rich sediment from the top of the sub-blow alluvium at meter 0.6, depth -0.4 m yields a calibrated $^{14}$C age of ~6870 yr B.P. (UM-RC08-12, Table 1). Charcoal from the older blow that yields a calibrated $^{14}$C age of <340 yr B.P. (UM-RC08-7, Table 1) may be bioturbated and younger than the blow.

Two younger sand blows overlie the older blow, one from meter 9 to 17 and the other from meter 17 to the west end. This episode of sand venting gives rise to the "shotgun" tonal anomalies on the aerial photography, and we interpret these two surficial sand bodies to be coeval sand blows. These surficial blow deposits truncate the Ao soil developed on the older blow, and they have convex-down bases. These geometries indicate that craters were excavated by water expulsion and then filled by extruded sand, rather than subsidence beneath the blow deposit due to sand extrusion. This interpretation is consistent with the planarity of the sub-blow alluvium from meter 9 to the west end.

An A/B soil horizon is developed under the surficial blows. We interpret this horizon as a post-blow soil that was localized by the increased permeability of the blow sand. From trench meter 9.6 westward, narrow sub-vertical bodies of fine sand consistent with the sand of the surficial blows extend downward into this A/B horizon and the older blow. Some of these were cylindrical, and we interpret them as root casts, but many were planar and may be filled extension fractures. The vents for the surficial blows were not exposed in the trench. We are awaiting the $^{14}$C age of burrow-fill sediment at meter 18.1.

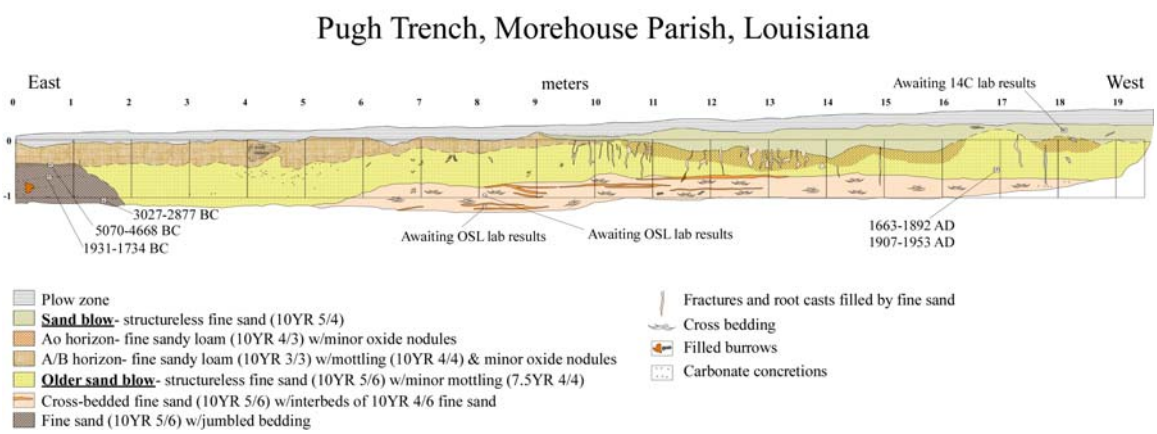


Figure 6. Log of our Tip Pugh trench. BC and AD dates are $^{14}$C ages (see Table 1). Continuous lines between stratigraphic and/or soil horizons denote a sharp contact, dashed lines denotes a clear contact, and no line denotes a gradual contact.

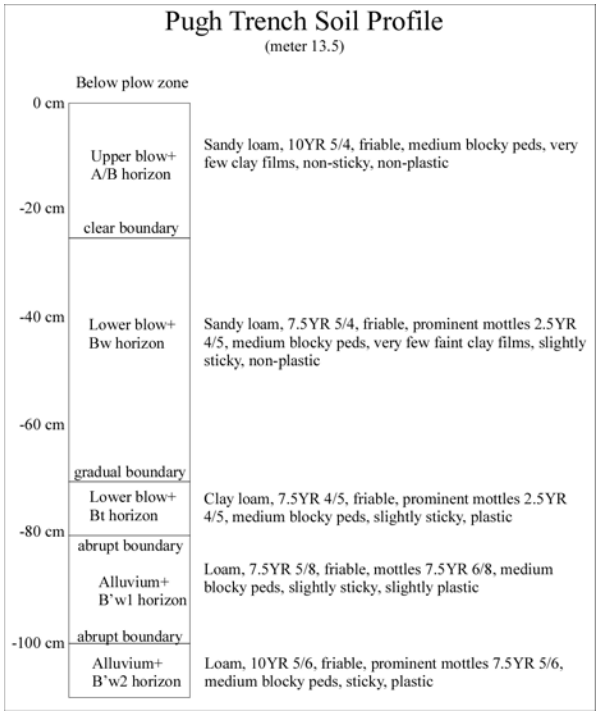


Figure 7. Description of soil properties for our Tip Pugh trench.

A push core was collected adjacent to the Tip Pugh trench site that revealed clay beds at 2.8 to 3.6 m depth and 4.9 to 5.6 m depth that could provide a hydraulic cap for sand blow venting to occur (Fig 8). There is possible source sand for either of the blows exposed in the trench at 3.6 to 4.9 m depth in the core log. However, we interpret the interval of "no recover" below 5.6 m depth to be a wet sand bed that was too weak to stay

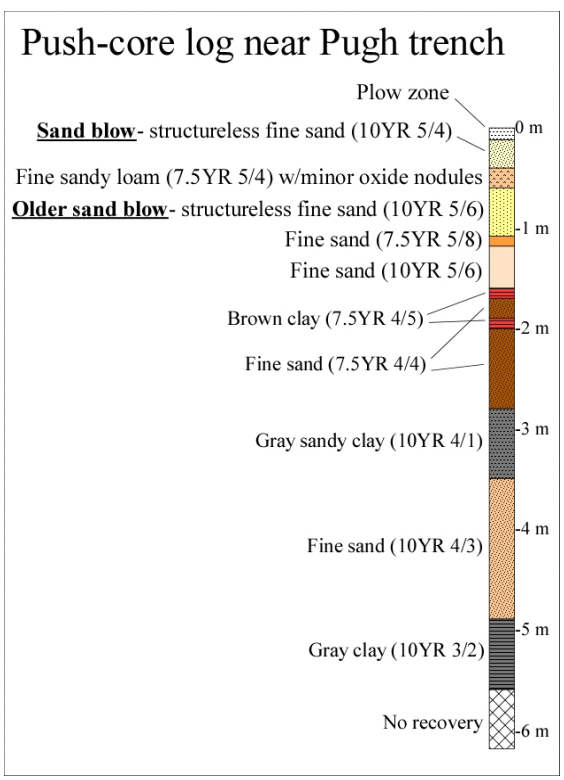


Figure 8. Log of push core collected adjacent to our Tip Pugh trench.

in the core barrel. This sand is likely to be susceptible to liquefaction and may be the source of one or both of the sand blow deposits in the trench.

Richland –Franklin Parishes field

This sand blow field is primarily developed on Wisconsinan terraces of Macon Ridge mapped as Pve-1 in the western part of the field and as older Pve-4 in the eastern part (Saucier, 1994)(Fig. 4). These blows show subtle south-southwest alignments that appear to follow the braided paleo-channel pattern of the Wisconsinan terraces. A small area in the southwest of the field is on Hb backswamp associated with Arkansas River Hpa-3 meander belt.

It is unlikely that the part of the field mapped as Pve-4 in northern Franklin Parish near Crowville, Louisiana contains sand blows because we found no sand bodies, we found an undisturbed acreage with prominent relict eolian silt dunes (pimple mounds), and the light tonal anomalies on aerial photographs are on an early Wisconsinan terrace with thick loess and a low susceptibility to liquefaction (Saucier, 1994). Sand blows are easily confused with pimple mounds on aerial photography (Seifert et al., 2009). Indeed, sand blows were misidentified as pimple mounds on aerial photography in southern Arkansas until sand dikes were discovered by recent trenching (Cox et al. 2004, 2007). Typically, sand blows are found on liquefiable Holocene alluvial terraces and pimple mounds are found on Pleistocene terraces. We cored a pimple mound near Crowville and found eolian silt typical of these features in the mid-continent (Seifert et al., 2009).

Junior Jones trench site:

The Junior Jones trench was located in Richland Parish southwest of Mangham, Louisiana near the end of Parish Road 5569 (Fig. 9). The trench was excavated on an unplowed surface at the margin of a small drainage channel between crop fields. We

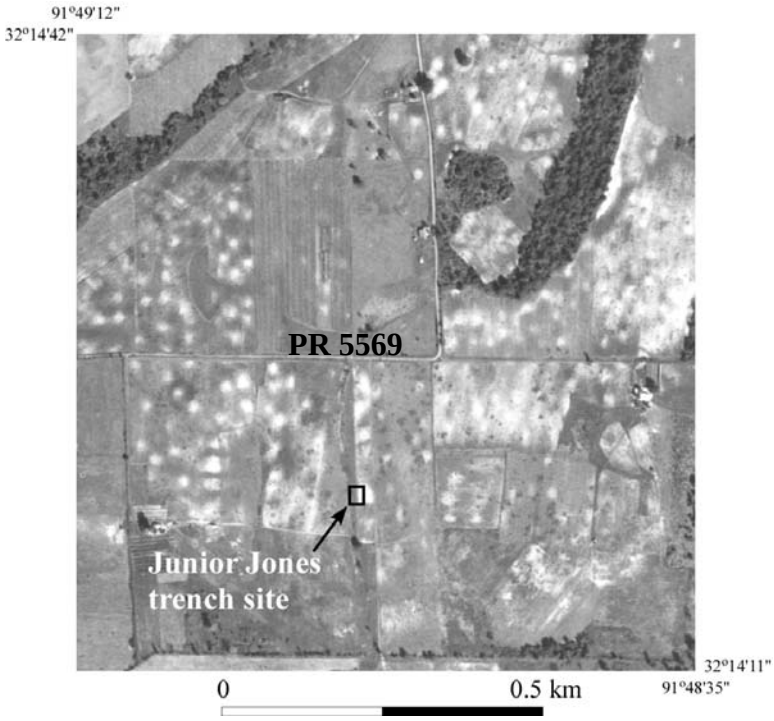


Figure 9. Aerial photograph (1941) of a portion of the Richland Parish southwest of Mangham, Louisiana showing the location of our Junior Jones trench site. The light tonal anomalies are “shotgun” sand blows.

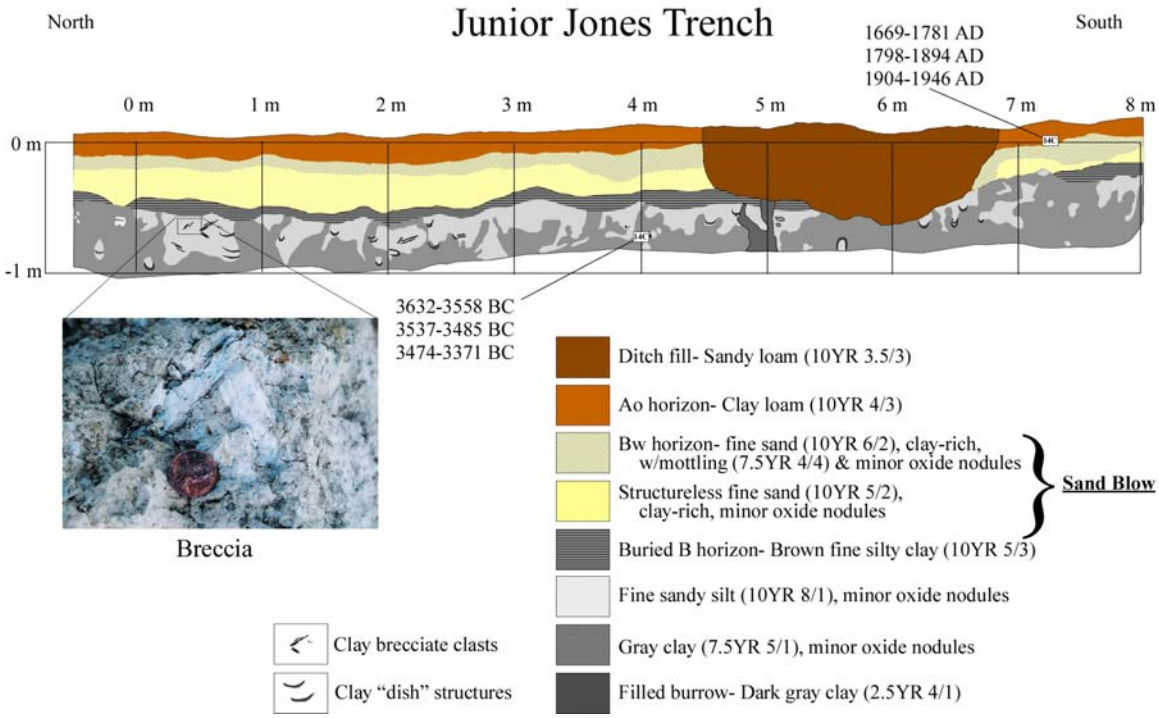


Figure 10. Log of our Junior Jones trench. BC and AD dates are $^{14}$C ages (see Table 1). Continuous lines between stratigraphic and/or soil horizons denote a sharp contact, dashed lines denotes a clear contact, and no line denotes a gradual contact.

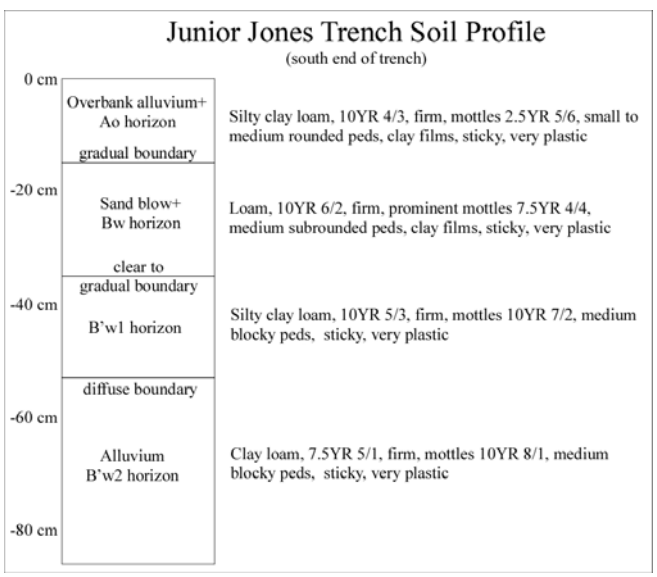


Figure 11. Description of soil properties for our Junior Jones trench.

logged the east trench wall, collected bulk sediment samples for lab analysis, carbon samples for radiocarbon dating, and photographed the trench wall. Geochronologic samples were submitted for analysis to the NSF-Arizona AMS Laboratory in Tucson, Arizona for $^{14}$C dating.

The Junior Jones trench exposed a convex-down lens-shaped body of structureless fine sand that is continuous with one of the surficial sand blows (Figs. 9 and 10). An Ao soil horizon is developed in ~ 20 cm of overbank alluvium above the blow deposit, and a Bw soil horizon is developed in the upper 10 to 20 cm of the blow. A sediment-filled historic ditch cuts through the blow from meter 4.5 to 6.9. The sand blow overlies an unstratified gray clay that contains numerous irregular bodies of sandy silt. The silt bodies in turn contain breccia clasts of white clay (<15 cm) and crescentric lenses of dark clay (~10 cm across) that are typically concave-up ("dish" structures). A buried Bw soil horizon is well developed in the upper 10 cm of the sub-blow surface, and no features cross-cutting this soil that could be vents of the sand blow were observed in the trench. However, the breccia and dish structures contained within the sub-blow gray clay suggest disruption of the sediment and upward fluid flow that may have been coeval with sand venting or related to an earlier liquefaction episode (but bioturbation cannot be ruled out).

Charcoal from the base of the surficial Ao soil horizon yields a $^{14}C$ age of <330 yr B.P. (UM-RC08-3, Table 1), and charcoal from the sub-blow gray clay yields an age of ~5500 yr B.P. (UM-RC08-2). The burrow at meter 5 could provide no age constraint because we do not know its cross-cutting relationship to the blow deposit.

We found several medium sands in the push core above refusal depth at 3.4 m depth that do not appear to be the source sand for the blow because they are coarser than the blow deposit (Fig. 12). We speculate that refusal may have been due to a clay that acted as a hydraulic cap during liquefaction and the source sand lies below that.

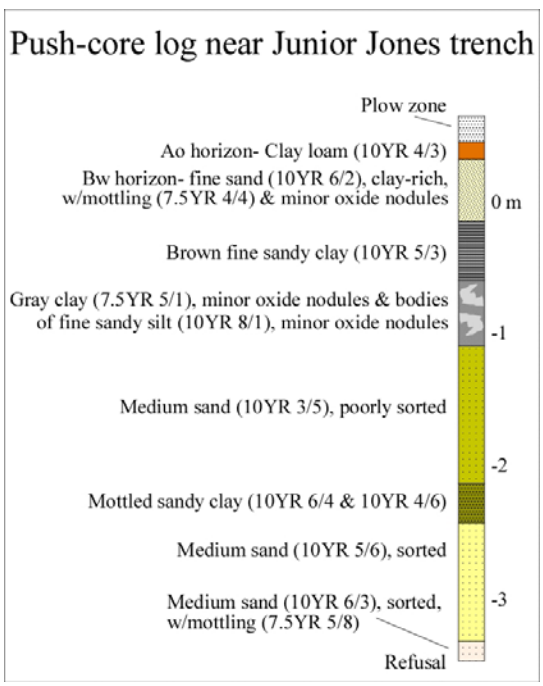


Figure 12. Log of push core collected near our Junior Jones trench in a crop field.

## CONCLUSIONS

Our excavations reveal two sand blow episodes in Morehouse Parish between 340 and 3830 yr B.P. and one in Richland Parish between 330 and 5500 yr B.P. The surficial

blows in both fields have a “shotgun” pattern that is characteristic of sand venting through a hydraulically fractured clay cap and is indicative of a relatively close seismic source (Obermeier et al., 2005). The older blow in the Morehouse Parish field has a large vent several meters wide that is characteristic of vents associated with lateral spreads above slopes and river banks. The host alluvium of this vent is brecciated on the east side of the vent toward the middle Holocene Hpa-5 Arkansas River meander belt, consistent with movement of the host sediment on the east side of the vent as a slide block toward the river channel. Thus, we interpret the older blow in the Tip Pugh trench in Morehouse Parish as a lateral spread sand blow that may have been triggered by a larger earthquake than the later blows and perhaps at a greater distance.

The sand venting history of northeastern Louisiana is simpler than that of the Ashley County, Arkansas field immediately to the north but similar to the Desha County field farther north in Arkansas. The age constraints of the Louisiana sand blows can accommodate any of three dates of possible regional events in southern Arkansas liquefaction fields (700, 2300, and 3500 yr B.P.)(Fig. 3). We do not attribute Louisiana sand venting to New Madrid seismic zone earthquakes because there appears to be an absence of similar aged sand blows in the intervening area and at equivalent epicentral distances in Holocene alluvium in Mississippi. Based on these spatial and temporal relationships, we speculate that the paleo-earthquakes that triggered the sand venting episodes in northeastern Louisiana were in the vicinity of Ashley County, Arkansas. Holocene surface ruptures along the Saline River fault zone in Ashley, Bradley, Cleveland, and Drew Counties, Arkansas show that an active source exists in that area (Cox et al., 2000, Gordon and Cox, 2008, Gordon, 2008).

We end with the caveat that we have not inspected aerial photography for possible sand blows or otherwise reconnoitered for sand blows or other evidence of liquefaction or recent faulting to the south of Franklin Parish. Any discoveries of these features farther to the south will necessitate revision of these conclusions.

ACKNOWLEDGEMENTS

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## NON-TECHNICAL SUMMARY

Aerial photography of a portion of the southern Mississippi River and Arkansas River valleys was inspected for light spots characteristic of earthquake-generated sand blows, and numerous occurrences were identified in northeastern Louisiana. We documented the dates of prehistoric earthquakes that produced the sand blows by collecting sediments that predate and postdate the blows and then established the ages of the sediments by laboratory analyses. In this phase of the project, we identified at least one sand blow event by excavating a trench in southeastern Richland Parish (Junior Jones site) and at least two sand blow events in our trench in southern Morehouse Parish (Tip Pugh site). We also identified another area in Franklin Parish as prehistoric wind blown silt dunes rather than sand blows. This work adds to our initial phase of study that documented at least four earthquakes in this region and advances us toward our goal of finding out the recurrence interval of strong earthquakes in this region. Our ultimate goals also include mapping the geographic extent of each liquefaction event, and from these maps we will make an estimate of epicenter and magnitude of the earthquake associated with each event.

## REPORTS PUBLISHED

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