Investigation of Seismically-induced Liquefaction in the southern Mississippi Embayment

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INTRODUCTION

We continued our preliminary investigations of two local areas of intense sand venting ≥175 km southwest of the recognized New Madrid seismic zone (NMSZ) liquefaction field and ~250 km southwest of the epicenters of the earthquake responsible for the NMSZ sand blows. Individual sand blows in the lower Mississippi River Valley of southeastern Arkansas are similar in size, shape and spacing to sand blows in the NMSZ. These southern sand blows (~1 m thick, ~10 to 30 m in diameter, and circular to elliptical in plan view) were vented from mid to late Holocene natural levee, channel fill, and crevasse splay sand deposits overlain by clays and silts along abandoned Arkansas River courses (Cox et al., 2000; 2002). Previously, we identified one field of sand blows in Ashley County, Arkansas and one 40 km to the north in Desha County, Arkansas by inspecting aerial photographs and subsequent push-coring and trenching. During this phase of the project, we identified another possible liquefaction field on aerial photography to the northwest in Lincoln and Jefferson County, AR (Fig. 1). The Lincoln/ Jefferson County sand blows are less densely-spaced and more widely distributed than the Ashley and Desha County liquefaction fields.

The southern sand blow fields may be distal liquefaction due to NMSZ earthquakes or they may be due to local seismogenic faults. If related to NMSZ earthquakes, these sand blows greatly expand the recognized limit of NMSZ liquefaction and hence the area of strong ground shaking. Equally important, if these sand blows are due to local faults, then these possible seismic source zones should be recognized and characterized.

Previous trenching of sand blows at Kelso in Desha County and at Montrose and Portland in Ashley County revealed stratigraphy and cross-cutting relationships that showed evidence of multiple events of seismically induced sand venting. Various correlations of liquefaction events between these two fields and between each of these fields and the NMSZ can be accommodated by our radiocarbon and infrared stimulated luminescence (IRSL) ages of sediments pre-dating and post-dating vented sand deposits in our trenches. These ages show a major liquefaction event at both the Ashley and Desha County fields between 4600 and 5500 years ago and a major event at the Ashley County field ca 700 years ago. The early venting episode is older than the documented NMSZ chronology, and so we do not know if it can be ascribed to a NMSZ seismic source. The age of the later venting episode is within the time span of the NMSZ chronology but is not consistent with a NMSZ event. Our trench logs show at least three other moderate to minor sand venting episodes at the Ashley County field and two at the Desha County field. One of these venting episodes may be the same event at both fields ca 2200 years ago. Building from these previous investigations the current work summarized here seeks to establish the ages and extent of liquefaction features in southwestern Arkansas. This work fills in spatial gaps in the previous investigations and will aid in the definition of liquefaction fields and in constraining the dates of venting and perhaps in constraining the seismic source.

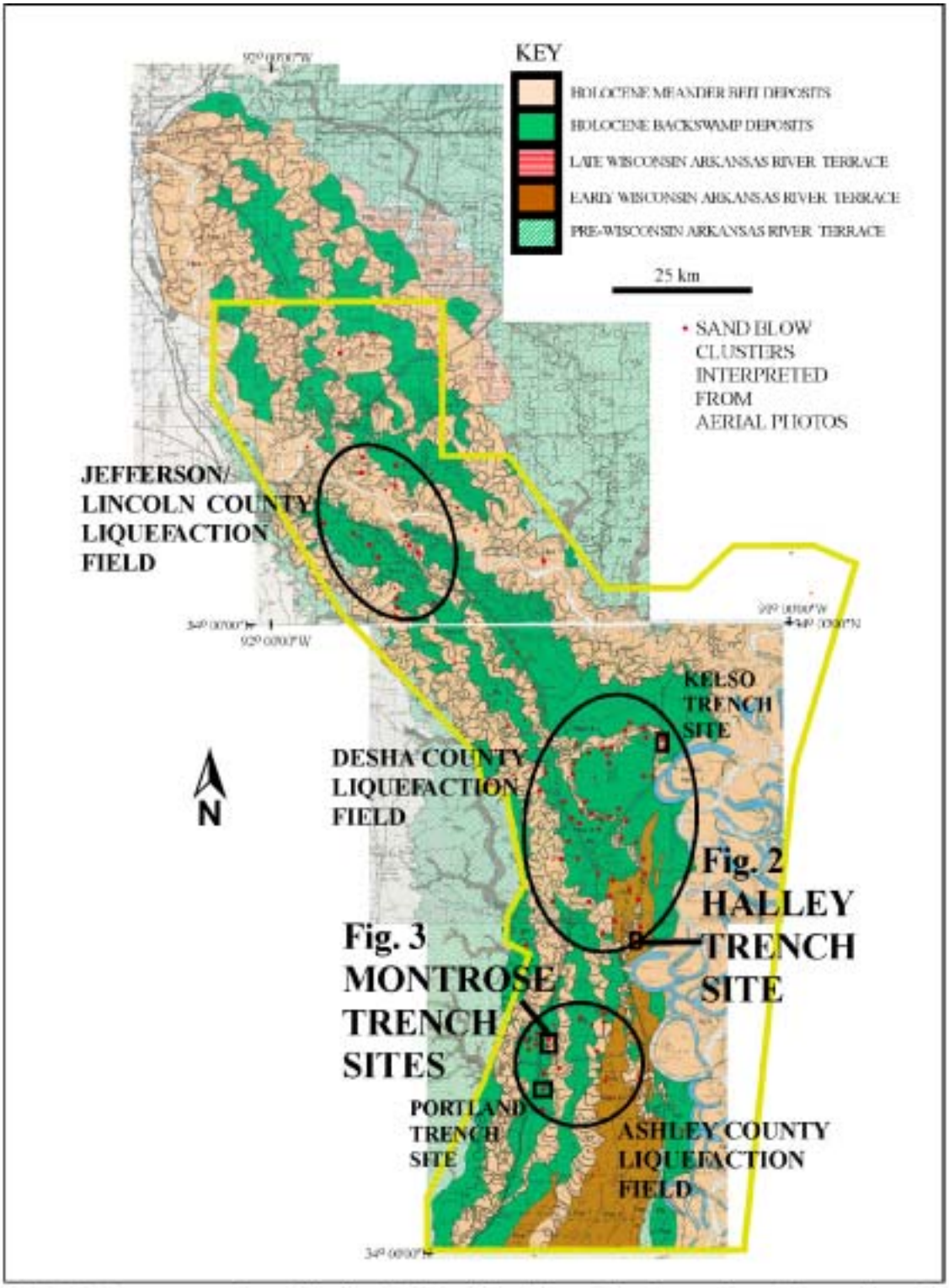

FIGURE 2. Quaternary geology of the alluvial valley of the Arkansas River in southeast Arkansas (from Saucier, 1994). Each red dots denotes a section (640 acres) that contains circular to elliptical, light tonal anomalies on aerial photography that are characteristic of sand blows (large dots denote many distinct anomalies; small dots denote few or vague anomalies). These anomalies have been shown to be liquefaction bodies of vented sand at the trench sites on the map (Cox and others, 2000; 2002; 2003; Morat and others, 2003). The Halley trench and one Montrose trench are new excavations during this phase of the project.

STUDY AREA

Field work associated with this research project was conducted in southeastern Arkansas in Desha and Ashley Counties. Specific field sites were identified based on remote sensing and geophysical data in the form of aerial photography, electrical conductivity, and confirmed with field reconnaissance. Yellow polygon in Figure 1 denotes study area.

Study areas are located near the urban areas of Memphis, TN and Little Rock, AR. Infrastructure in the region, including pipelines and highway bridges, could be impacted by local ground motion strong enough to generate the liquefaction features explored in this research. Documentation of strong Holocene ground shaking in the southern Mississippi Embayment will be important in understanding the seismic hazard in the central United States. Moreover, this study will advance understanding of seismic hazards of intraplate settings in general.

RESEARCH QUESTIONS

1. How many seismic events generated liquefaction features in the southern Mississippi Embayment?

2. What is the age of each venting event?

3. How do these ages relate to large historic and/or prehistoric NMSZ events?

INVESTIGATIONS UNDERTAKEN

Excavation of sand blows and age analysis of related deposits have been highly successful for the establishment of a chronology of strong paleoseismicity in the eastern U.S. (Talwani, 1989, 1996; Tuttle and Schweig, 1996; Tuttle et al., 1998; Tuttle, 2001). Field excavation sites were identified through remote sensing techniques to enhance the trenching results. Following evaluation of spatial extent of the blow field and prior to excavation, electrical conductivity surveys and push core samples were collected to assess the site stratigraphy.

Two trenches have been excavated during this second phase of the project, the Golden Trench (Desha County sand blow field) in August of 2003 and the Morgan Trench (Ashley County sand blow field) in October of 2003, 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 establish the stratigraphic relationships of vented liquefaction deposits to alluvial deposits and soil horizons. Organic-rich crater fill and soil units, along with wood 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 (infrared stimulated luminescence). This effort is a continuation of our investigation of liquefaction features across the southern Embayment, therefore methods and techniques used are consistent with previous work.

RESULTS

Golden Trench

Golden trench is located in the southern part of the Desha County sand blow field near Halley, Arkansas on Lester Golden Road at 33°29.199'N, 91°18.325'W. Electrical conductivity survey (Fig. 2) revealed two elliptical anomalies consistent with previously excavated sand blows. This blow, located in a fallow field, was excavated in August of 2003. A field team of University of Memphis faculty, graduate and undergraduate students logged the trench walls, collected bulk sediment samples for lab analysis, carbon samples for radiocarbon dating, luminescence samples for dating, and photography of the trench walls. Dating samples were submitted for analysis to BETA Analytic, Inc, Miami, Fl for ^{14}C dating and

to Luminescence Dating Research Laboratory, University of Illinois at Chicago for infrared stimulated luminescence (IRSL) dating. Thus far, a ^{14}C age of 510 to 290 cal. yr BP has been obtained for a lens of organic sediment post-dating venting at this site. Other dating results are expected in early 2004.

The Golden trench exposed a principal vented deposit of brecciated clay clasts suspended in a fine sand matrix (Unit C, Table 1). This blow, a champagne glass shape in cross-section (Fig. 2), was fed by several dikes (~ 5 cm wide) that extend downward through the source of the clay clasts (Unit F, Table 1) that is ~0.5 m below the blow. Unit F is brecciated around the primary feeder dikes, and we interpret Unit F as the hydraulic capping unit that ruptured during ground shaking. A network of smaller sand dikes ($\leq$0.5 to 3 cm width) and sills ($\leq$10 cm thick) is present below the flanks of the principal blow, and some of these dikes are linked to the principal blow. Spatial relationships in the Golden trench suggest the sand dikes, sills, and blows formed during a single earthquake. Alternatively, some of the "sills" may be older buried blows. Our IRSL dates should indicate if there was an older event.

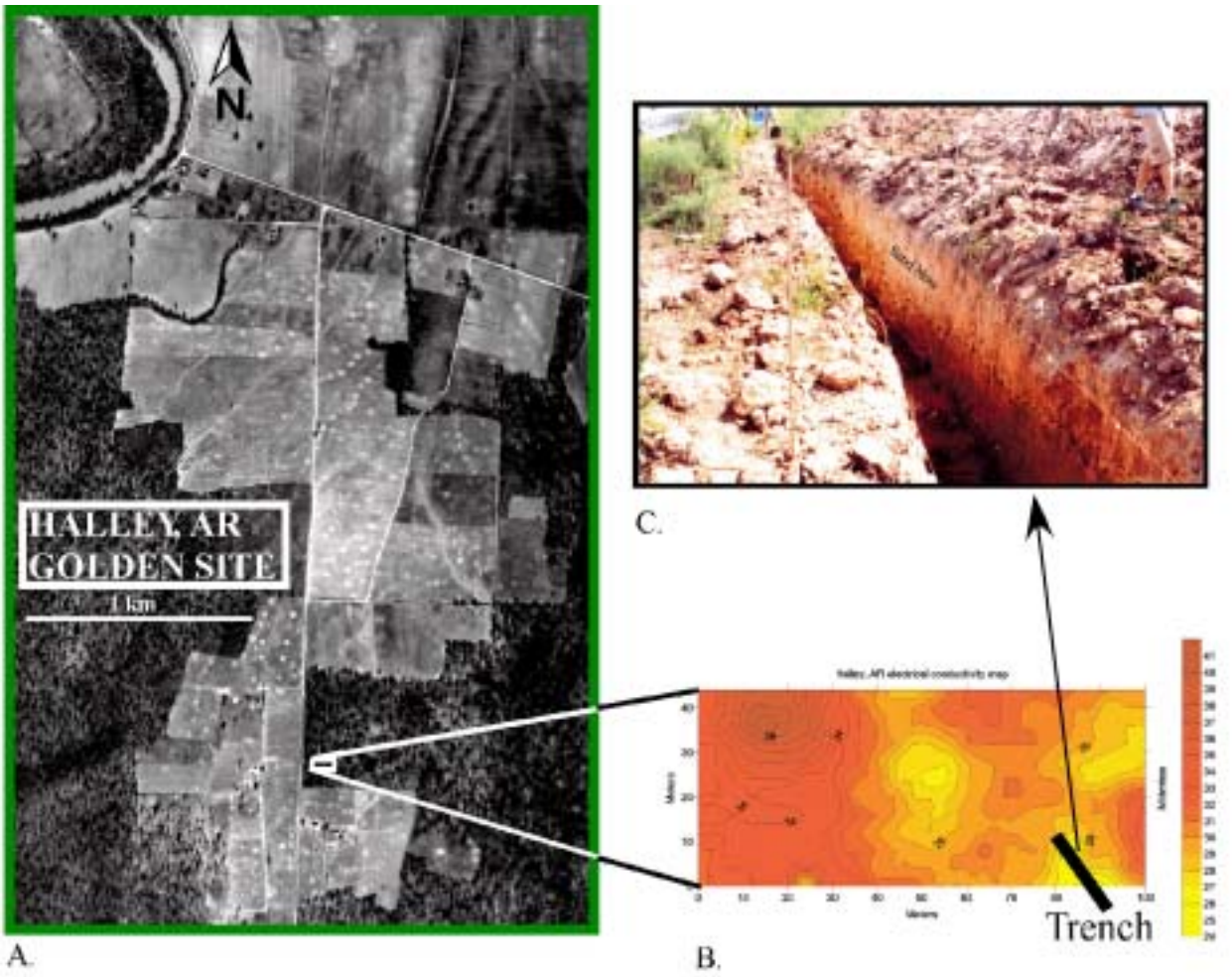

Figure 2. Golden site near Halley, AR in the southern part of the Desha County sand blow field. A) Aerial photo of the site and vicinity showing sand blows aligned along shallowly-buried crevasse splay channels. B) Electrical conductivity map of site showing low value anomalies of sand blows (this spot has been cleared of trees since aerial photo). C) photo of Golden trench showing champaign-glass shaped sand blow.

Table 1: Golden Trench Description of Stratigraphic Units.

(Only field logs of the Golden trench are available at the writing of this report. Full trench wall maps will be included in the Final Technical Report.)

Unit*/Depth	Field Description	Dating Sample
A / 0-20 cm	Plow Zone- fine sand and silt, loose, 10YR6/2 (light brownish gray)	
B / 20-40 cm	Organic fill and burrow fills-10YR4/3 (brown)	S1, S2 (^{14}C)
C / 20- 230 cm	Principal vented deposit- Sand dikes, blows, and sills. Clay breccia clasts- hard, 10YR6/4 (light yellowish brown) Fine sand matrix- soft, 10YR7/4 (very pale brown)	
D / 80-120 cm	Silty-clay- slightly hard, 7.5YR4/6 (strong brown). Lenticular body absent in vent area.	
E / 20-200 cm	Fine oxidized sand (minor clay)- soft, 7.5YR4/6 (strong brown) pervaded by fine white sand fissures and blows. Principal blow substrate	S6, S10 (IRSL)
F / 200- >230cm	Hydraulic capping unit. Clay- hard, 5YR4/3 (reddish brown) in upper 10 cm and 10YR6/4 (light yellowish brown) below to bottom of trench. Brecciated/ fractured in area at base of sand blow.	

* Field Designations.

Summary of field soil analysis in Golden Trench

The soil trench and sub-trench pit exposed approximately 280 cm of section. The upper 96 cm comprises blow sand with a weakly developed modern soil profile, the lower part of which is brecciated. Eighty cm of pedogenically-modified, brecciated alluvium (C horizons) underlies the blow sand. A very weakly developed buried soil profile, again partially brecciated, extends into underlying red and gray clay that underlies the upper horizons. Overall, the materials in this trench are sandier than those observed at the Portland trench site ~ 5 km to the south, also in the Ashley County sand blow field (Morat et al., 2003), and the red and gray clay at the base of the trench shows little pedogenic modification. No carbonate accumulation is observed in any horizons and weak clay accumulation is observed only in the surface soil and the buried soil profile overlying the red and gray clay.

Morgan Trench

Morgan trench is located near Montrose, Arkansas just off of US highway 165 at 33^{o}19.801'N, 91^{o}29.077'W ~1.3 km south of our previous Montrose trenches. As at the Golden trench site, an electrical conductivity survey of the Morgan trench site (Fig. 3) revealed elliptical anomalies consistent with previously excavated sand blows. One of these blows located in the non-planted corner of a center-pivot irrigation quarter section of cotton crops was excavated in October of 2003. A field team of University of Memphis faculty, graduate and undergraduate students logged the trench wall, collected bulk sediment samples for lab analysis, carbon samples for radiocarbon dating, luminescence samples for dating, and photography of the trench walls. Dating samples have been submitted for analysis and results are expected. The team was joined by faculty from the University of Louisiana at Monroe and members of the Arkansas Archaeological survey.

The Morgan trench exposed a principal vented deposit of loose fine sand (Unit B, Table 2) underlain by a colluvial clayey sand (Unit C, Table 2) that in turn is underlain by an older vented fine sand (Unit E, Table 2). A principal sand vent (25 cm-wide, Fig. 3 inset) and many subsidiary sand dikes ($\leq$2 cm-wide) were linked to the two sand blows and to many minor sand sills. Stratigraphy had subsided ~50 cm at the principal vent. However, 10 cm coherent blocks of Unit J (Table 2) had been transported upward ~45 cm in a matrix of fine sand in the principal vent dike (Fig. 3 inset).

Table 2: Morgan Trench Description of Stratigraphic Units.
(Only field logs of the Morgan trench are available at the writing of this report. Full trench wall maps will be included in the Final Technical Report.)

Unit*/Depth	Field Description	Dating sample
A / 0-25 cm	Plow Zone- fine sand, 10YR6/3 (pale brown)	No sample.
B / 25-80 cm	Principal vented deposit- Sand dikes, blows, and sills. Very fine quartz sand – rounded, loose, 10YR6/4 (dark yellowish brown), mottles 7.5YR 6/6 (reddish yellow)	S2, S9 (^{14}C)
C / 80-95 cm	Clayey very fine sand – slightly blocky, slightly hard, 10YR5/4 (yellow brown), mottles 7.5YR5/8 (strong brown), colluvial deposit restricted to venting area (reworked units D & E?).	S11 (IRSL)
D / 80-95 cm	Fine sandy clay – blocky, hard, 7.5YR5/6 (strong brown), absent from venting area (pre-blow surface removed during venting?)	
E / 95-105 cm	Older sand blow deposit- Very fine quartz sand – rounded, loose, 10YR6/4 (dark yellowish brown).	
F / 95-110 cm	Fine to very fine quartz sand, sub-rounded, soft, 10YR4/6 (dark yellowish brown). Only present below unit D.	S12 (IRSL)
G /105-125cm	Fine to medium fine quartz sand, sub-rounded with minor clusters of oxide nodules (<1cm), soft, 7.5YR4/6 (strong brown). Only present near main vent (older blow?)	
H /105-130cm	Fine quartz sand, sub-rounded, cross-bedded with patches of oxide nodules (<1cm), soft, 7.5YR4/6 (strong brown)	S6, S13 (IRSL)
I / 130-150cm	Fine to very fine clayey sand, cross-bedded, slightly hard, 7.5YR4/6 (strong brown), minor muscovite & opaques, clusters of oxide nodules (<1cm). Units H & I are a crevasse splay deposit.	
J /150-180cm	Very fine quartz sand, sub-angular, cross-bedded, soft, 7.5YR5/4 (brown)	S1, S3, S5, S7, S8, S10 (^{14}C)
K /180- >210 cm	Fine quartz sand, sub-angular, cross-bedded, soft, 7.5YR4/4 (brown). Units J & K are a crevasse splay deposit.	

* Field Designations.

Summary of field soil analysis in Morgan Trench

The soil trench exposed approximately 180 cm of section. The upper 67 cm is a weakly developed modern soil developed in blow sand. The underlying units comprise alternating sandy and sandy clay deposits associated with crevasse splay alluvial deposition. The clay-rich intervals are typically broken or brecciated, presumably from liquefaction processes. Three weakly to well developed buried soil profiles are present in the crevasse splay deposits. Pedogenic modification is best developed in the finer grain upper parts of the crevasse-splay alternations, whereas the sandy portions are either massive or retain depositional structures (ripple cross-lamination). In general, the trench stratigraphy reflects a dominance of alluvial processes over soil development. No carbonate accumulation is observed in any horizons and weak to strong clay accumulation is observed only in the buried soil horizons. The red and gray clay that is prominent at the base of the Golden and Portland trenches is not present in this trench.

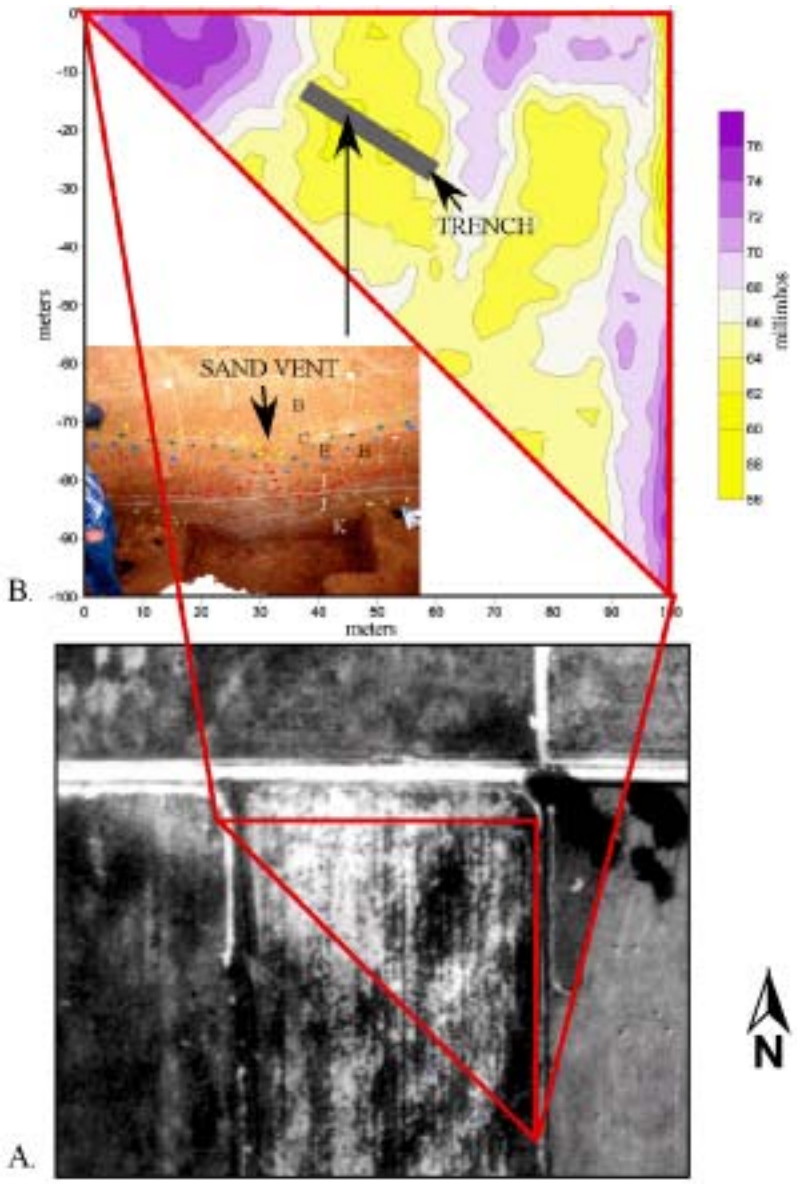

Figure 3. An aerial photograph (A) and an electrical conductivity map (B) of the Morgan site near Montrose, AR. Inset in (B) shows subsidence around the main vent in which brecciated substrate material has been trans-located upward.

ANTICIPATED PRODUCTS

The final output of this project will be a chronology of liquefaction events that will be compared to the chronology for the NMSZ. It will be constrained by ages of crater fill, soils and other organic-rich horizons that bound the sand blows, by ages of sands and silts in the base of and beneath the sand blows, and by the stratigraphic relationship of archeological materials of known antiquity to the liquefaction deposits. In addition, a map showing the distribution and age data for sand blows in the study area will be produced. These results will be presented at a suitable professional conference and published in a suitable high-profile scientific journal.

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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 southeastern Arkansas. Our goal is to document the dates of prehistoric earthquakes that produced the sand blows by collecting sediments that predate and postdate the blows and by establishing 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 at Halley, AR and at least two sand blow events in our trench at Montrose, AR. This work adds to our initial phase of work that documented at least five earthquakes in this region. Our age analyses will let us decide if any of these five earthquakes are the same as the ones recognized in our current work.

REPORTS PUBLISHED

Cox, R.T., and Gardner, C., 2003, A possible sand blow field in the central Arkansas River Valley of the southwestern Mississippi Embayment: Geol. Soc. Am. Abstracts/Programs, 35(7): 582.