ON THE SEARCH FOR PALEOLIQUEFACTION IN THE NEW MADRID SEISMIC ZONE

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ABSTRACT

The great 1811-12 New Madrid earthquakes produced extensive liquefaction in the meisoseismal zone, which is largely within the St. Francis drainage basin of Missouri and Arkansas. We examined 10's of kilometers of ditch banks within the meisoseismal zone for evidence of prehistoric liquefaction events. Radiocarbon dates indicate that the exposures studied provide a record of the last 5,000 to 10,000 years. Our search has revealed no evidence of widespread paleoliquefaction events and, hence, provides no independent support for the relatively short 550 to 1100 year return time of 1811-12 type earthquakes implied by analyses of the statistics of historical seismicity.

INTRODUCTION

The New Madrid earthquake sequence consisted of four $M_S \geq 8$ events which occurred on three separate days between December 1811 and February 1812 (Nuttli, 1973, 1979; Hopper, 1985). Understanding the recurrence characteristics of such events is fundamental to understanding both the seismic hazard and the rate of intraplate deformation in the New Madrid region. Johnston and Nava's (1985) recent analysis of the statistics of historical seismicity within the New Madrid Seismic Zone places the return time of 1811-12 type earthquake sequences at between about 550 and 1100 years. But, as pointed out by the same authors, there is also a significant uncertainty attendant to interpreting the long-term behavior of the zone based on the limited historical record. Russ' (1979) Geological study of Reelfoot scarp and Saucier's (1991) study of archaeological sites about 30 km north of New Madrid (Figure 1) also point to a return time for large earthquakes of about 450 to 600 years. However, each also notes that the estimates may reflect the recurrence of earthquakes of smaller size than occurred in 1811-12. Thus, return time estimates for 1811-12 type earthquakes remain equivocal. The 1811-12 earthquakes produced extensive liquefaction throughout a zone approximately 20-50 km wide which strikes a distance of about 150 km northeastward from near Memphis, Tennessee (Figure 1). This letter reports on a search in the area for evidence of a widespread paleoliquefaction event and, hence, more conclusive data bearing on the repeat time of 1811-12 type events. We first provide a brief review of the geologic setting and approach of the study, followed by presentation of the observations and a discussion.

GEOLOGIC SETTING AND LIQUEFACTION SUSCEPTIBILITY

Liquefaction during the 1811-12 earthquakes was concentrated within the St. Francis Drainage Basin (Figure 1), a region of low relief, loose sand at shallow depth, a high water table, and poor drainage. The basin is in large part constructed of late Wisconsinan braided stream terraces. Saucier (1977) interpreted the abandonment of the terraces to have occurred about 9500 years ago at the latitude of about Memphis. The braided stream terrace deposits generally consist of water-saturated sand overlain by clay and silt- rich strata that effectively form a topstratum of low permeability. The topstratum is generally at least 1-2m thick. This relation of the relatively thin topstratum and high water table is responsible for the tremendous liquefaction effects reported for the 1811-12 earthquakes (e.g., Fuller, 1912; Obermeier, 1988).

The occurrence of liquefaction features over a 16 km diameter resulting from the moderate m_b = 6.2 Charleston, Mo. event during the dry season of October 1895 further illustrates the conducive nature of the area to seismically induced liquefac-

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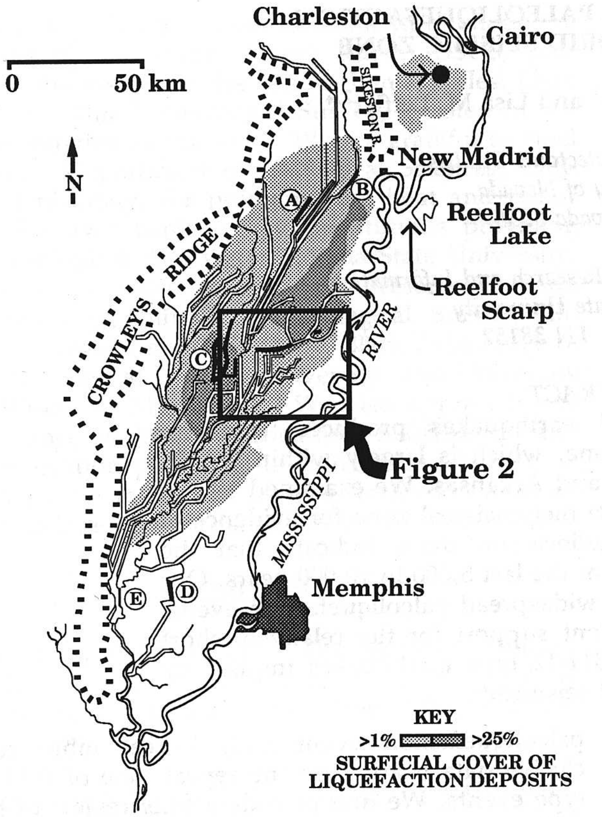

Fig. 1. Network of drainage ditches (open lines and thin solid lines) maintained by U.S. Army Corps of Engineers, showing ditches that we examined (heavy solid lines) for evidence of paleoliquefaction. Areas where 1811-12 liquefaction deposits still comprise ≥ 1% and ≥ 25% of the surface area are shaded by light and dark stippling respectively [adapted from Obermeier (1984)]. Location of Figure 2 marked by box. Circled letters A, B, C, D, and E show locations of Ditch No. 9, Little River, Honey Cypress Ditch, Blackfish Bayou and St. Francis River.

tion (Obermeier, 1988). As well, we suggest that seasonal or relatively brief climatic fluctuations should not significantly effect the liquefaction susceptibility of the region, based on our observation that, even during record low stages of the Mississippi River that occurred during the period of our study, the water table remained relatively high, as evidenced by the persistent flow in local drainage ditches that was maintained by springs along the ditch edges. Radiocarbon and pollen analysis of cores by Guccione (1987) also provides evidence that the Big Lake region (Figure 2) has been characterized by backswamp depositional processes and backswamp and bottomland arboreal vegetation through the Holocene, and by inference a relatively high water table . Thus, it seems reasonable that if 1811-12-size earthquakes occurred during the Holocene, they would have induced liquefaction that would also be recorded in the geologic record.

APPROACH

The U. S. Army Corps of Engineers maintains a network of large drainage ditches within the Basin for flood control and land reclamation (Figures 1 and 2). The banks of the ditches are generally covered with thick vegetation and outcrops are limited. However, the Corps recently reexcavated and widened a number of the existing ditches. The banks of these excavations provided a unique opportunity to examine tens of kilometers of vegetation-free exposures. We examined the length of the ditches marked by heavy solid lines indicated in Figure 1 for evidence of sand-blow deposits and sand- filled vents and fissures within the topstratum which might record evidence of prehistoric liquefaction. We limit our discussion here to observations along Ditch 12 (Figure 2), which are generally representative of the other ditches studied (Leffler, 1991; Wesnousky and Leffler, 1992).

THE OBSERVATIONS

Ditch No. 12 is located adjacent to Big Lake Wildlife Refuge in Arkansas (Figure 2). A log of about a 800m length of the Ditch is shown in Figure 3. The numerous sand dikes breaking the topstratum and vented sand deposits on the topstratum are characteristic of the pervasive effects of liquefaction we observed along many portions of the ditches. The character of liquefaction features found along the ditches studied is well illustrated by the more detailed logs of the Sites marked 2 and 3 in Figure 3.

The exposure at Site 3 (Figure 4) shows the clay topstratum is broken by the intrusion and ejection of fine grained sand. Soil development on the extruded sand is immature, composed of a thin (< ~10 cm) A-horizon and virtually no B-horizon development, consistent with an 1811- 12 origin for sand emplacement. The ejected sand lies on a surface whose antiquity is suggested by a well developed soil profile.

The lowermost meter of topstratum to the east of the ejected sand at Site 3 is loam and sand (Figure 4). Large pieces of bark-covered wood were recovered from 2 sites within the exposure (see Figure 5). Conventional radiocarbon dates place the ages of sample 1 and sample 2 at 5090 1 60 and 11,100 1 100 yr B.P., respectively (Beta Analytic Inc.; numbers Beta-38311 and Beta-41984). Thus, the topstratum reflects some 5,000 to 10,000 years of development, in general accord with the 9500 year figure cited by Saucier (1977) for abandonment of the braided stream terrace at about this latitude 9500 years ago.

At Site No. 2, the exposure is capped by about

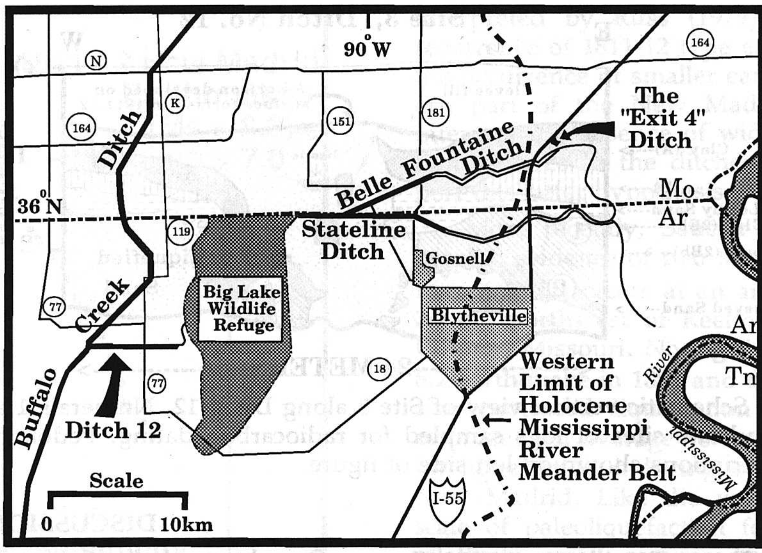

Fig. 2. Map of a portion of the 1811-12 New Madrid earthquakes meisoseismal zone showing location of ditches (heavy solid lines) we searched for evidence of paleoliquefaction. Locations discussed in text are limited to Ditch 12. Region west of the Holocene Mississippi meander belt is constructed principally of Late Wisconsinan braided stream deposits (Saucier, 1977). Location shown in Figure 1.

1 m of artificial levee fill (Figure 5). Beneath the levee fill is about 1 to 2 m of clean fine to medium sand. The sand is fed by a dike at the base of the exposure. Soil development on the sand is immature, consisting of a 5-10 cm thick A-horizon and no significant B-horizon development. The immaturity of the soil profile on the sand suggests that the deposit is very young, most likely a result of the ejection of the sand to the surface in 1811-12. In contrast, the buried surface on which the ejected sand rests is characterized by a well-developed soil profile, consisting of a 10-15 cm thick A- horizon (2Ab) and a B-horizon (2Bb), which is about 1 m thick. The maturity of the 2Ab-2Bb soil profile suggests that the surface on which the sand ejected was stable for a relatively long period of time prior to being breached and buried by liquefied sand in 1811-12. The relative lack of soil development on vented sand is present on all the sites of liquefaction we studied along the

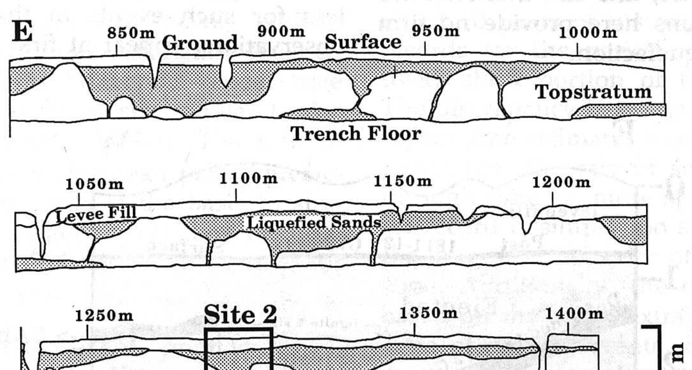

Fig. 3. Schematic vertical view of a portion of the south side of Ditch No. 12. The topstratum is broken by numerous sand dikes (stippled). The uppermost white unit is artificial levee fill resulting from excavation of the ditch. Note vertical exaggeration.

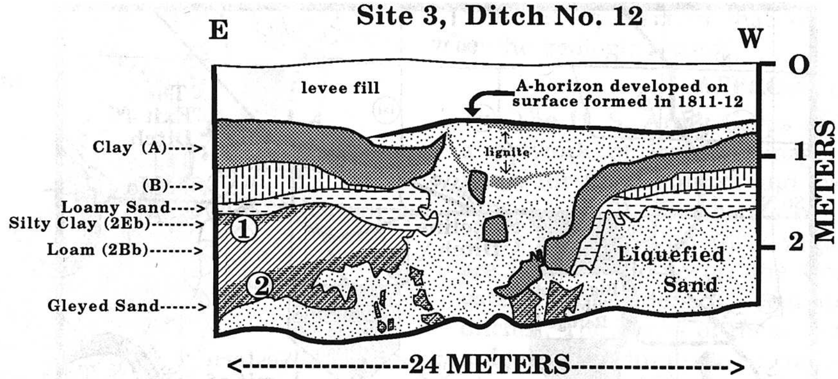

Fig. 4. Schematic vertical view of Site 3 along Ditch 12. Numerals 1 and 2 indicate sites of logs sampled for radiocarbon dating. Pedological descriptions shown on left side of figure.

ditches in Figure 1.

Unique to Site 2 (Figure 5) with respect to all other sites we examined is the observation of a buried sand unit that may have been emplaced by liquefaction. The buried 2Ab-2Bb profile grades down into clean sand. The buried sand rests in sharp contact on a buried surface on which the 3Ab- 3Bb soil-profile was developed. A possible interpretation is that the 2Ab-2Bb profile developed on sands ejected by a prehistoric earthquake. Indeed, among all of the exposures we examined (Leffler, 1991; Wesnousky and Leffler, 1992), it was only this site that left open the possible interpretation for a prehistoric liquefaction event. A sand fissure feeding the buried sand and breaking the 3Ab horizon would be evidence of a liquefaction origin for the sand. However, because no fissure was observed along the exposed sand-3Ab contact, an alluvial origin for the buried sand cannot be ruled out. Hence, like all other sites we examined, our observations here provide no firm evidence of prehistoric liquefaction.

DISCUSSION

Our observations are best discussed within the context of prior attempts to shed light on the recurrence behavior of the New Madrid seismic zone. The first reported geologic evidence for paleoearthquakes and, hence, estimate of the recurrence interval for large New Madrid earthquakes resulted from trenching of the Reelfoot fault (Russ, 1979), which is near Reelfoot Lake (Figure 1). Structural, stratigraphic, and geomorphic relationships observed within and near a trench emplaced across the fault were interpreted to indicate 2 episodes of fault movement prior to 1811-12. Coupling the geologic observations with the historical record, Russ (1979) interpreted the evidence to indicate the occurrence of 3 earthquakes of a size sufficient to produce liquefaction during the last 2000 years and, on that basis, suggested a recurrence time of 600 years or less for such events in the region. Russ' (1979) observations appear at first glance in conflict with

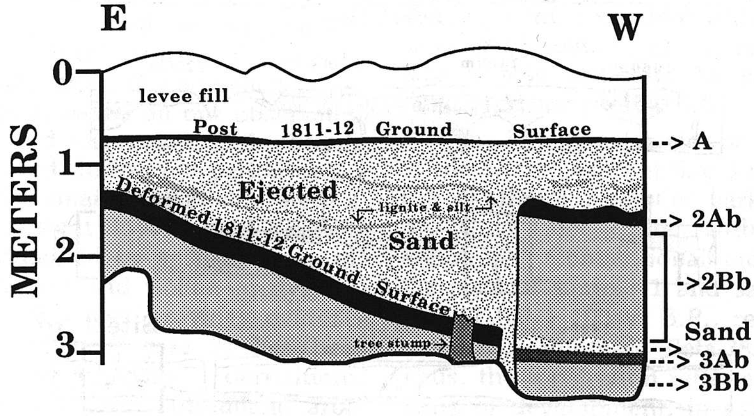

Fig. 5. Schematic vertical view of Site 2 along Ditch No. 12. Pedological descriptions shown on right side of figure. See text for further discussion.

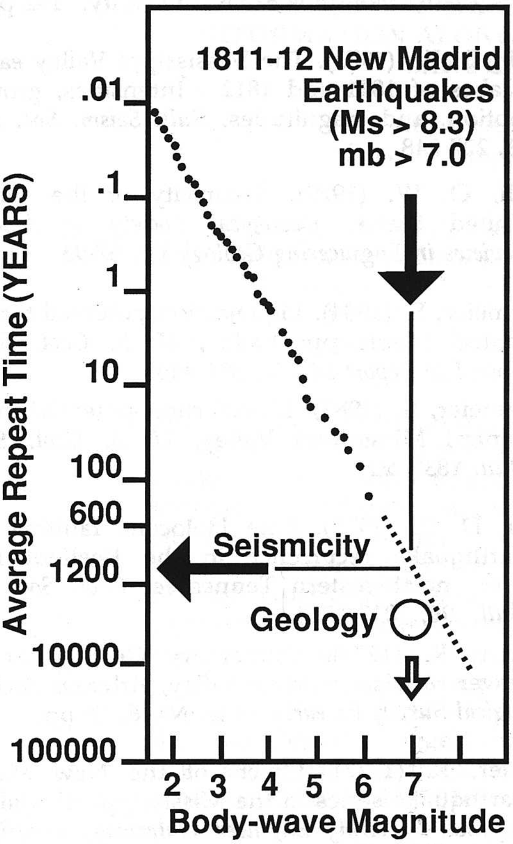

Fig. 6. Schematic diagram illustrating discrepancy in estimates of repeat time for great New Madrid earthquakes based on geological and seismological considerations, respectively. Average repeat time of earthquakes of size greater than or equal to a given body-wave magnitude is shown by solid dots for the New Madrid seismic zone for the period 1816-1983 [adapted from Johnston and Nava, (1985)]. Extrapolation of earthquake statistics (dashed line) implies a 550 to 1100 year repeat time (solid arrows) for events of size similar to the 1811-12 earthquakes (M_S > 8.3). The lack of geologic evidence for widespread paleoliquefaction observed in our study is the basis to suggest a significantly longer repeat time of 5,000 to 10,000 years or greater (circle with arrow) for such events in the region.

the absence of liquefaction events prior to 1811-12 implied by our observations. However, it should be noted that Russ (1979) found insufficient evidence to prove that any of the faults or liquefaction features in the trench were produced during the 1811-12 earthquakes. Moreover, because earthquakes as small as m_b = 6.2 can produce liquefaction at distances of 15 to 20 km from the earthquake source (e.g. Youd and Wieczorek, 1982), and our search was centered 10's of km or more to the south, one or more of the paleoearthquakes interpreted by Russ (1979) may not reflect the recurrence of 1811-12 type earthquakes but, rather, the occurrence of smaller earthquakes in the northern part of the New Madrid seismic zone. We interpret the absence of widespread paleoliquefaction features in the ditches we examined to support this latter hypothesis.

More recently, Saucier (1991) reported stratigraphic evidence of two liquefaction events during the past 1300 years at an archaeological site about 30 km northwest of Reelfoot Lake in Mississippi County, Missouri. Noting that both a nearby m_b = 6.2 earthquake in 1895 and the 1811-12 earthquakes also produced liquefaction in the area, Saucier estimated an average recurrence rate of 468 years for liquefaction inducing events in the vicinity of New Madrid. Like the work of Russ (1979), the scale of paleoliquefaction features observed were relatively small compared to those reported in 1811-12 (e.g. Fuller, 1912). Hence, as stated by Saucier (1991), any inference of the repeat time of great New Madrid earthquakes from these observations remains equivocal and, therefore, based on our field studies, we also suspect that the paleoliquefaction probably represents the recurrence of smaller magnitude events in the New Madrid seismic zone. However, it is also not likely we could distinguish differences between sand vented in 1811-12 or a few hundred years earlier on the basis of soil considerations alone. Additionally, examination of similar 500-1500 year old archaeological sites elsewhere in the New Madrid seismic zone has revealed no conclusive evidence of severe pre-1811-12 earthquakes (Saucier, 1977, 1989).

The 550 to 1100 year estimate of repeat time put forth by Johnston and Nava (1985) is based on about 10 years of instrumental data and historical records for the period after 1811. This is a relatively short portion of the expected repeat time. The discrepancy between our observations and the repeat time estimates based on seismicity may then reflect that the rate of seismicity is not stationary through time or, more specifically, that the historical record is simply too short to accurately portray the long-term behavior of the New Madrid seismic zone. Additionally, the estimate of repeat time is based on the linear extrapolation of the recurrence rates of smaller events, but earthquake frequency curves are commonly not linear through the entire magnitude range for all fault zones (e.g. Youngs and Coppersmith, 1985). Thus, it certainly seems reasonable to cast additional doubt on the accuracy of the 550 to 1100 year return time in light of the apparent absence of paleoliquefaction found in our study.

To summarize, our search revealed no evidence for any widespread paleoliquefaction during approximately the last 5,000 to 10,000 years. The observation of the buried sand overlying the buried soil profile at the base of Site 3 leaves open the possibility that we failed to recognize some evidence for paleoliquefaction. It is also difficult to rule out that geologic or pedogenic processes may have removed liquefaction features predating the 1811-12 earthquakes. However, when coupling the widespread occurrence and large sizes of liquefaction features induced by the 1811-12 earthquakes with the implication that some 5 to 20 1811-1812 type events should be recorded in the 5,000 to 10,000 years of available geologic record, it seems that evidence of paleoliquefaction should be clear and abundant, if previously reported implications of a 550 to 1100 year repeat time are correct. Hence, although negative evidence must be used with extraordinary caution to make conclusions, the lack of evidence indicating any widespread paleoliquefaction event suggests to us a repeat time of 5,000 to 10,000 years or more for events of a size equal to the great 1811-12 earthquakes (Figure 6).

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