ARKANSAS
ENERGY & ENVIRONMENT

GEOLOGICAL SURVEY

Bekki White, Director and State Geologist

GB 2021-1

EARTHQUAKE FEATURE RECOGNITION WORKSHOP/FIELD TRIP II

Compiled by Martha Kopper, Geohazards Supervisor

Sponsors

United States Geological Survey

State Farm Insurance

Regional Induced Seismicity Collaborative (RISC) through funding from the Groundwater Protection Council and Department of Energy

Arkansas Oil and Gas Commission

North Little Rock, Arkansas

2021

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Introduction

The Geological Survey (GS) held the Earthquake Feature Recognition Workshop and Field Trip II, the second of two opportunities offered by the GS to study paleoliquefaction features in eastern Arkansas.

This workshop and field trip focused on the use of geophysical surveys to locate features and documentation of paleoliquefaction. Feature identification may include soft sediment deformation structures present in the excavated trenches such as sand blows, dikes, sill, diapirs, foundered clasts, convolute bedding, pseudonodules, load casts, fissures, subsided, and tilted ground. The majority of the information within this publication has been prepared by the field trip leaders.

This event started at the Holiday Inn Express & Suites on the afternoon of Tuesday, November 5, 2020, with early morning briefings Wednesday. The field trip began mid-morning, Wednesday, November 6, 2019 near Marianna, Arkansas. Presenters and field trip leaders were a select group of subject matter experts in their fields including Dr. Haydar Al-Shukri and Dr. Martitia Tuttle. Pre-departure briefings preceded field trip activities. The field trip leaders presented information on the presence, manifestation, appearance, and characteristics of earthquake features in eastern Arkansas.

New Madrid Seismic Zone

The New Madrid seismic zone (NMSZ) lies within the Mississippi Embayment, a large synclinal sedimentary basin formed during the Cretaceous due to reactivation of the northeast trending Cambrian-age Reelfoot Rift System (Figure 1) (Ervin and McGinnis, 1975). The embayment is filled with unconsolidated Upper Cretaceous and Cenozoic sediments, with thickness increasing from north to south. Modern microseismicity is spatially associated with several faults as follows (Figure 1): (1) the NE-SE trending zone located along the central axis of the Reelfoot Rift, also known as the Cottonwood Grove-Blytheville Arch or Axial Fault; (2) the NW-SE trending zone along the Reelfoot Fault; (3) the NNE-SSW trending zone along the North New Madrid Fault; and (4) the E-W trending zone along the Risco Fault. These faults are oriented favorably relative to the present east-northeast regional compressive stress field for right-lateral strike slip displacement to occur along northeast oriented faults and for reverse displacement to occur along northwest oriented faults (e.g., Zoback and Zoback, 1989).

The New Madrid earthquakes of 1811-1812 are the largest earthquakes to have struck the conterminous United States in recorded history (Figure 1, stars). The first main shock occurred at 2:15 a.m., December 16, 1811. The two other large earthquakes occurred on January 23 and February 7, 1812. All three mainshocks have estimated moment magnitudes in the mid-magnitude 7 to 8 range (Johnston, 1996; Johnston and Schweig, 1996; Hough et al., 2000; Bakun and Hooper, 2004). Epicentral Modified Mercalli Intensities (MMI) ranged from X to XII (Street and Nuttli, 1984). Because of the low attenuation of seismic waves in the central United States, these three earthquakes had large (5,000,000 km^2) felt areas (Nuttli, 1982; Nuttli and Herrmann, 1984) and were felt as far away as Boston, Massachusetts (distance of 1,690 km). In addition to the mainshocks, thousands of aftershocks were associated with the New Madrid earthquake sequence, many of which caused damage and were felt along the eastern seaboard (Street and Nuttli, 1984; Johnston, 1996). Since 1812 at least 28 damaging earthquakes having estimated moment magnitudes between 4.2 and 6.4 have struck the region (Nuttli, 1983; Hamilton and Johnston, 1990; Johnston, 1996).

Although the exact locations of the 1811-1812 New Madrid earthquakes are unknown, their relationship to the NMSZ is strongly suggested by the isoseismal maps compiled from historical accounts (Nuttli, 1973) and the distribution of ground failures, particularly those related to liquefaction (Fuller, 1912; Saucier, 1977; Obermeier, 1984; Tuttle et al., 2002), and earthquake-induced landslides (Jibson and Keefer, 1988; 1989; 1992). Liquefaction of subsurface sand layers resulted in the ejection of sand-bearing water through ground fissures, forming sand blow deposits typically tens of meters in width, hundreds of meters in length, and up to 2 meters in thickness (Fuller, 1912; Obermeier, 1988; Tuttle and Barstow, 1996). The Mississippi River was reported to have been choked with trees and the wreckage of boats in certain locations and massive bank failures (Penick, 1981). The Reelfoot Fault and associated back thrusting probably displaced the bed of the Mississippi River at four locations (Purser and Van Arsdale, 1998). At two locations, one upstream and one downstream from New Madrid, waterfalls or rapids formed in the Mississippi River channel (Penick, 1981; Purser and Van Arsdale, 1998). These displacements in the soft sediments in the river channel were apparently eroded and rapidly destroyed.

Landslides along the bluffs bordering the Mississippi River valley happened from about Cairo, Illinois, to Memphis, Tennessee (Fuller, 1912; Jibson and Keefer, 1988). Eyewitnesses describe the land surface following the earthquakes as being disrupted and in many places, uninhabitable (Penick, 1981).

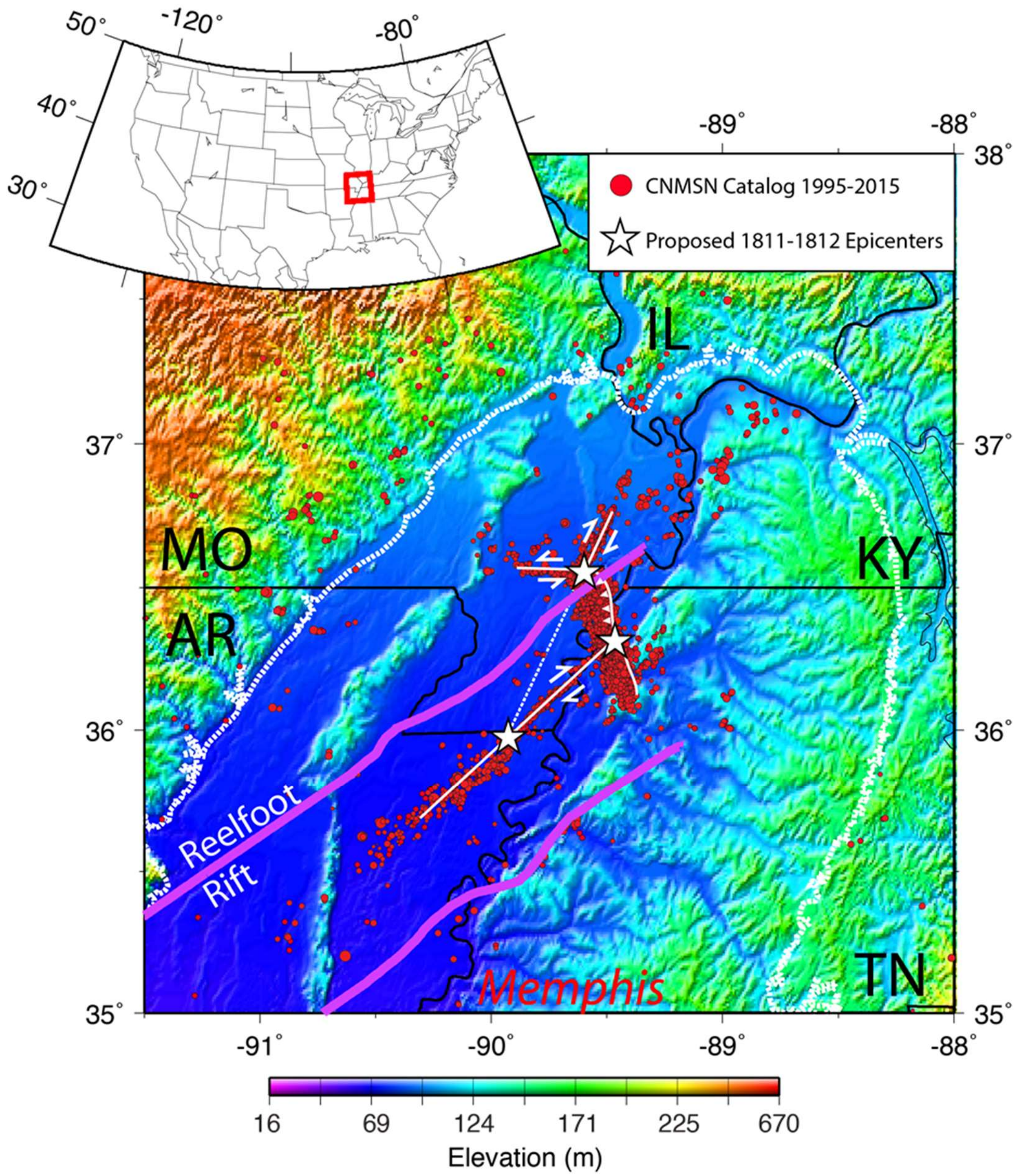

Figure 1. Overview map of the NMSZ, showing locations of 1811-1812 mainshocks (white stars), seismicity from 1995-2015 (red dots), and Reelfoot Rift margins (purple lines), and local faults (thin white lines) (from DeShon, 2016, ADAMS ML 16221A590).

Earthquake Potential of the New Madrid Seismic Zone

In order to understand the hazards that the NMSZ may pose in the future, earth scientists have studied the geological and geophysical record of past earthquakes in the region. These studies have focused on paleoliquefaction features, active faults associated with the Reelfoot Rift Fault system, and the sedimentological record of uplift, subsidence, and abrupt changes in the morphology of the Mississippi River. These independent studies have reached similar conclusions that the NMSZ has repeatedly produced large magnitude earthquakes during, at least, the past 4 kyr. Paleoseismic evidence indicates that the NMSZ produced 1811-1812-type events in about A.D. 900 and A.D. 1450 suggesting an average recurrence time of 500 years (Kelson et al., 1996; Tuttle et al., 2002; Guccione, 2005). Although less well understood, two earlier New Madrid events have been proposed to have occurred in 1000 B.C. (Holbrooke et al., 2004) and 2350 B.C. (Tuttle et al., 2005). Holbrooke et al. (2004) suggested that the NMSZ is characterized by active and inactive periods, with inactive periods lasting about 1700 years. Alternatively, the paleoearthquake record may be incomplete prior to A.D. 800.

Earthquake-induced liquefaction features, including sand blows and sand dikes, have been studied at more than two hundred sites across the New Madrid region (Figure 2; e.g., Saucier, 1991, Vaughn, 1994; Li et al., 1998; Tuttle, 1999; Broughton et al., 2001; Tuttle et al., 2002 and 2005; Tuttle et al., 2018 and 2019). During these investigations, the locations, sizes, and sedimentary characteristics of historic and prehistoric liquefaction features were documented, and organic samples collected for radiocarbon dating of the liquefaction features, and thus the earthquakes that formed them. Both historic and prehistoric sand blows are compound structures composed of multiple fining upward units, suggesting they were formed during earthquake sequences that included several very large earthquakes (Saucier, 1989; Tuttle et al., 2002). The age estimates of sand blows across the region cluster around three dates which include A.D. 1810 ± 130 years, A.D. 1450 ± 150 years, A.D. 900 ± 100 years. These time periods were interpreted as dates of New Madrid earthquakes (Figure 3). At several sites in northeastern Arkansas and southeastern Missouri, large sand blows were found which were estimated to be formed in 2350 B.C. ± 200 years, possibly during an earlier New Madrid event (Tuttle et al., 2005).

There is a close spatial correlation of both historic and prehistoric sand blows with the NMSZ, which was interpreted as the source of earthquakes responsible for most of the liquefaction features (Tuttle, 1999; Tuttle et al, 2002). Also, the size and spatial distributions of historic and prehistoric sand blows were found to be strikingly similar, suggesting that the prehistoric earthquakes were similar in location and magnitude to the 1811-1812 mainshocks (Figure 2). The Ambraseys (1988) relation between moment magnitude and epicentral distance to farthest surface manifestation of liquefaction (~240 km to farthest sand blows) suggests that the largest of the 1811-1812 earthquakes was of $M \geqslant 7.6$. Although the extent of the paleoliquefaction fields have not yet been determined, the similarity in the size and spatial distribution of prehistoric sand blows with historic sand blows suggests that the A.D. 900 and A.D. 1450 events are likely to have included at least one earthquake of M $\geqslant$ 7.6 (Tuttle, 2001). Geotechnical testing and analysis of liquefaction potential carried out at several liquefaction sites near Blytheville, Arkansas; and Steele, Missouri, found that sediments are not especially susceptible to liquefaction and that an earthquake of M $\geqslant$ 7.5 would be required to induce liquefaction at all of the sites (e.g., Schneider and Mayne, 2000). Overall, the liquefaction data indicate that the NMSZ generated sequences including very large, M7-8, earthquakes every 500 years on average during the past 1,200 years. The estimated uncertainties on the timing of each New Madrid event allow for the recurrence time of New Madrid events to be as short as 160 years and as long as 1200 years (Cramer, 2001).

Tuttle, et al., (2017) has used other geotechnical studies to estimate the magnitude of New Madrid events. Overall, the results are consistent with interpretations of the locations and magnitudes of historic and prehistoric earthquakes. Geotechnical studies including cone penetration techniques in northeastern Arkansas, southeastern Missouri, and western Tennessee generally shows that magnitudes in the range of M7.4 to 8.4 were likely to cause liquefaction the New Madrid region (Schneider and Mayne, 2000; Liao et al., 2002; Schneider et al., 2001; Stark, 2002; Tuttle, 2004; Bakun and Hopper, 2004).

Liquefaction studies contribute to comprehension of seismic hazard by providing information about the timing, locations, magnitudes, and recurrence rates of paleoearthquakes. There are uncertainties related to the derived earthquake parameters as many regions have not had any paleoliquefaction studies. More paleoliquefaction studies are essential to refine the uncertainties. Future studies should include instrumentation of liquefaction-prone sites, pre- and post-event of measurement of geotechnical properties. Other techniques include mapping using remotely sensed data, dating paleoliquefaction features, radiocarbon and optically-stimulated luminescence (OSL), dendrochronology, and geophysical surveys of soil properties.

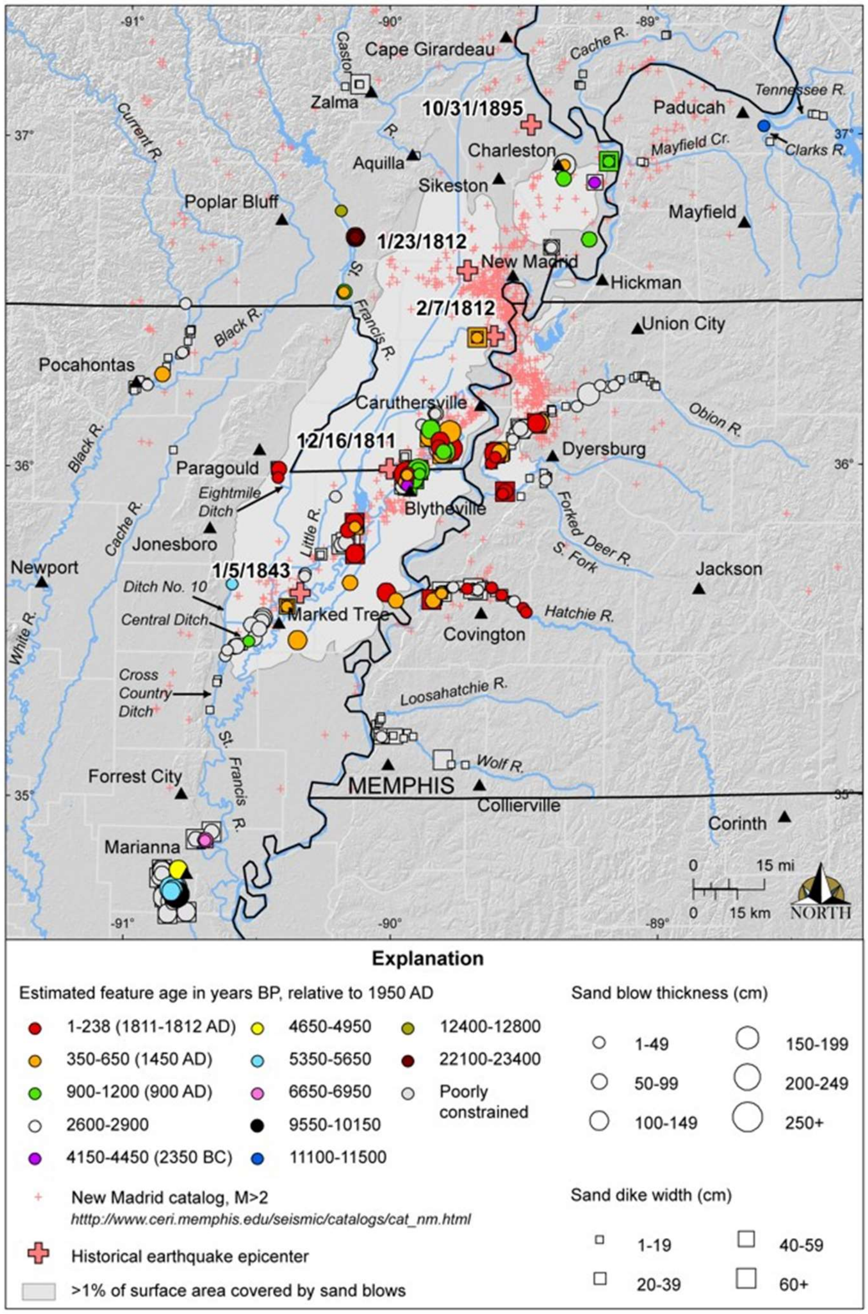

Figure 2. Shaded relief map of the NMSZ and surrounding region showing ages and measured sizes of earthquake-induced liquefaction features, previously recognized liquefaction field, inferred locations of historic earthquakes and instrumental located earthquakes (from Tuttle, 2010). Note the location of Marianna, Ar., about 80 km southwest of the southern end of the NMSZ.

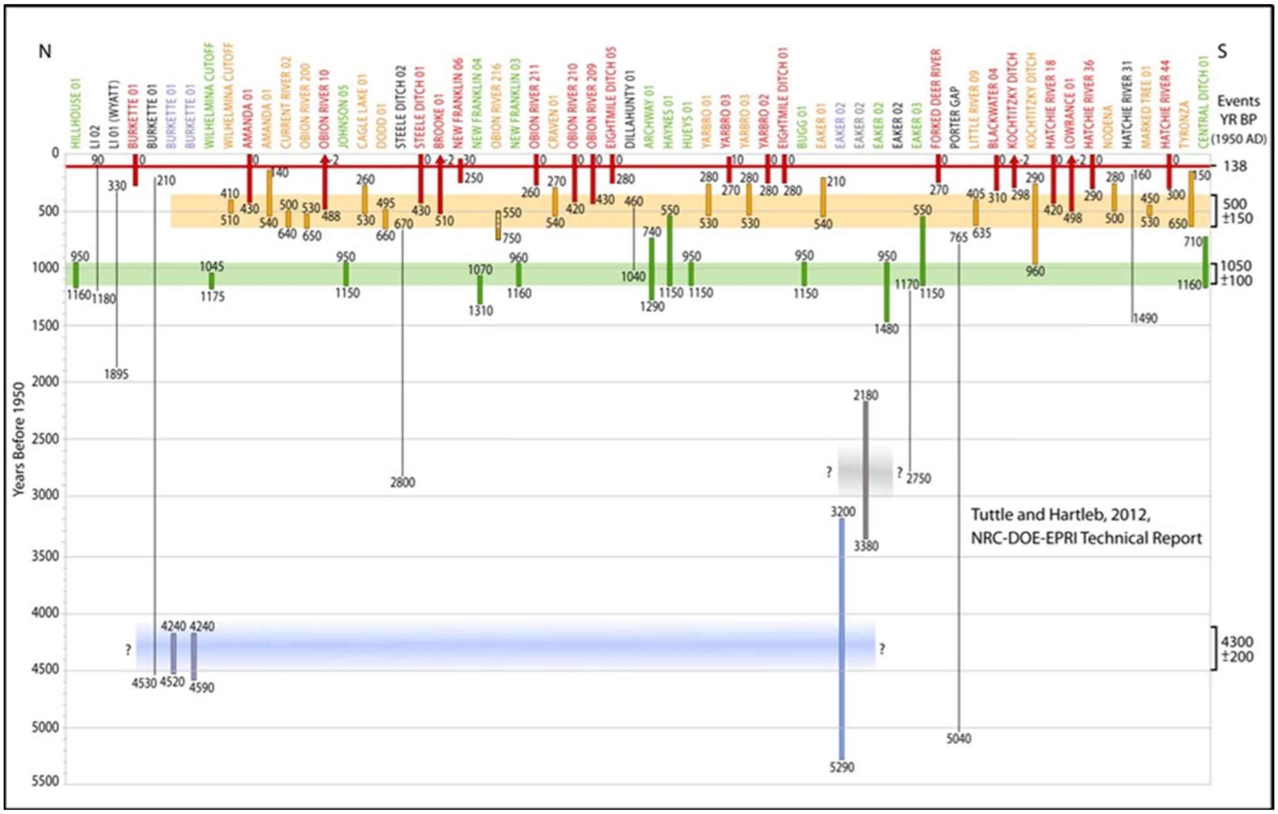

Figure 3. Diagram illustrating earthquake chronology for the New Madrid seismic zone for past 5,500 years based on dating and correlation of liquefaction features at sites (listed at top) across region from north to south. Vertical bars represent age estimates of individual sand blows, and horizontal bars represent event times of 138 yr. B.P. (A.D. 1811-1812); 500 yr. B.P. ± 150 yr. (A.D. 1450); 1,050 B.P. ± 100 yr. (A.D. 900); and 4,300 yr. B.P. ± 200 yr. (2,350 B.C.) (Tuttle and Hartleb, 2012).

Recent Studies Pertinent to Workshop and Field Trip

Tuttle (2001) discussed the use of liquefaction features in paleoseismology and offered lessons learned from the New Madrid seismic zone. She noted that to estimate the timing, source areas, and magnitudes of paleoearthquakes from liquefaction features, it is necessary to document many liquefaction features across a region and to constrain the ages of those features as closely as possible. This is achieved by conducting regional and detailed studies. It is critical to examine many sites in the area to determine the best sites for dating these features and to define the size and spatial distribution of the liquefaction features produced by each event. Detailed studies provide necessary data to limit the age estimates of liquefaction features. Given the current methodology of dating organic material in horizons that bound sand blows and the uncertainty in age estimates that results, Tuttle recommends that it would be desirable to develop high-precision methods for dating liquefaction features directly.

In the 2018 U.S. Nuclear Regulatory Agency report (Tuttle, et al., 2011, NUREG/CR-7238), the authors provide guidance on protocols for conducting paleoliquefaction studies for earthquake source characterization. These protocols are critical for the siting of nuclear power plants and other critical structures. This document provides detailed guidance for conducting paleoliquefaction studies that will generate high-quality paleoliquefaction data for use in seismic source characterization and seismic hazard assessment. It includes: 1) background information on earthquake-induced liquefaction, ground failures, and soft-sediment deformation features preserved in the geologic record, 2) relevant information derived from the disciplines of geology, geophysics, and geotechnical engineering, 3) extensive bibliography, and 4) recommendations for future research.

An investigation conducted on an archeological site in the NMSZ yielded important information regarding earthquake liquefaction and ground failure, (Tuttle et al., 2011). The study revealed compound sand blows (up to 1 m thick) and dikes (up to 12 cm wide) which formed during four closely timed earthquakes probably during the NMSZ earthquake sequence of A.D. 1450 + 150 years. Liquefaction ground failure resulted in the tilting of to 22º of cultural horizons, and subsidence/burial of archeological components below the sand blow. The study concluded that by determining the style and amount of ground failure associated with the earthquake liquefaction, the study facilitated the identification of cultural features and horizons and interpretation of the archeological data.

Paleoliquefaction studies facilitated the development of a paleoearthquake chronology of the NMSZ and better understanding of its earthquake potential, (Tuttle et al., 2002, 2005, and 2019). The findings have been interpreted to indicate the age estimates of the liquefaction features and the causative earthquake clusters happened around A.D. 1810 + 130 years, A.D 1450 + 150 years, A.D. 900 + 100 years, A.D. 0 + 200 years, 1050 B.C. + 250 years, and 2350 B.C. + 200 years. Sand blows in this study suggest that faults associated with the central branch of the seismic zone were responsible for the M > 7.6 earthquakes during the A.D. 900 and A.D. 1450 and 1811-1812. Liquefaction data indicated that NMSZ events have occurred on average every ~500 years during the past 1200 years and every ~1100 years during the previous 3300 years. This recurrence rate for very large events is not easily reconciled with small amount of crustal deformation observed in the region, suggesting that the NMSZ became active during the Late Holocene and that the NMSZ events may be temporally clustered in the intraplate region. The authors proposed that sequences of very large earthquakes will continue to happen at a rate similar to that of the recent past or every 500 years.

A study of ground failures related to earthquake-induced liquefaction in the St. Francis River Basin focused on large curvilinear en-echelon sand blows and related feeder dikes that formed along abandoned channel margins, (Tuttle and Barstow, 1996). USACE borehole data were used to characterize the geologic relationships and properties of the depositional units at the study site. The findings supported the mechanisms of ground failure which are consistent with results of centrifuge modeling of liquefaction in layers sediments (Dobry and Liu, 1992; Fiegel and Kutter, 1994). Sand dikes indicate water flowed up through the profile, fluidizing host sediment along the way. Sand sills exhibited ripple cross-bedding and silt laminations, emplaced along the base of the clayey overbank deposits suggests that water flowed and accumulated below the overbank deposits. Other features reveal foundering of clasts of the overlying channel-fill deposit into the underlying channel deposits in which a water-interlayer had likely formed. Further, low Standard Penetration Tests (SPT) counts in the upper part of the channel deposits also suggested the formation of water rich zone and loosening of the deposit. Spatial relations of sedimentary deposits and their permeability and thickness appear to influence the location and mode of ground failure. The authors note that a better understanding of factors contributing to liquefaction-related ground failures can help to identify sites that may be prone to large ground displacements and mitigate the hazard posed by earthquakes in the region.

Ground penetrating radar (GPR) studies focused on imaging sand blow deposits and underlying feeder dikes in the vicinity of Marianna, Arkansas. Al-Shukri et al., (2006, 2015) used high resolution 3-D and profile surveys at several of these Marianna sites. The GPR surveys imaged the contact between the sand blows and buried paleosurface, defining their morphology in order to optimize the siting of paleoseismic trenches. Due to field conditions, a 400 MHz antenna was necessary to provide high resolution images of the upper 5 m of soil. Data acquisition was along parallel profiles oriented normal to the long axes of the sand deposits. Data reduction and analytical procedures included the removal of direct and ground surface effects, frequency filtration, gain control, profile migration, and three-dimensional visualization. The geophysical surveys were followed by paleoliquefaction studies that verified the presence of sand blows and dikes, characterized the liquefaction features, and estimated the ages of their formation (Al-Shukri et al., 2005, 2006 and 2015; Tuttle et al., 2006). According to those studies, large sand blows formed as the result of large earthquakes around 4.8, 5.5, 6.8, 9.9 k.a, and possibly other events between 11-41 k.a. The sand blows were concentrated along a northwest-southeast oriented zone and likely delineate faulting at depth. In addition, liquefaction potential analysis suggested that a M > 6 generated by the fault zone may have been responsible for the large sand blows in the area, (Al-Shukri et al., 2015).

Odum, et al., (2016) discussed preliminary assessments of a previously unknown fault zone beneath the Daytona Beach Sand Blow Cluster near Marianna. In their paper, the authors identify what appears to be a northwest-southeast trending zone of fault(s) beneath the cluster of sand blows. They suggest that the fault zone is a possible source of the Late Quaternary earthquakes responsible for the Marianna sand blows.

A comparison study between the liquefaction induced during the 2010-2011 Canterbury earthquake sequence in New Zealand and the NMSZ earthquake events (Tuttle, et al., 2017) included these lessons learned: 1) liquefaction features are important indicators of fault ruptures are difficult to recognize or do not propagate to the surface, 2) site conditions such as susceptibility of sediment to liquefaction and water table depth influence sand blow distribution, and 3) the sequence of closely-timed earthquakes produced compound sand blows composed of several sand-silt couplets, corroborating previous interpretations of compound sand blows in the NMSZ in the central United States and elsewhere; characteristics of sand blows including internal stratigraphy have important implications for interpretation of number, locations and magnitudes of paleoearthquakes.

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Al-Shukri, H. J., Lemmer, R. E., Mahdi, H. H., and Connelly, J.B., 2005, Spatial and temporal characteristics of paleoseismic features in the southern terminus of the New Madrid seismic zone in eastern Arkansas: Seismological Research Letters, v. 76, no. 4, p. 502-511. https://doi.org/10.1785/gssrl.76.4.502.

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Workshop & Field Trip Abstracts and Activities

Dr. Roy Van Arsdale will give a dinnertime presentation titled "Pliocene and Quaternary Geologic History of the Northern Mississippi Embayment and its Implications for the New Madrid Earthquakes"; at the Crazy Donkey Grill in Palestine, Arkansas Tuesday evening, November 5.

The November 6 field trip will be focused on a region (Figure 1) of paleoliquefaction features located southwest of Marianna, Arkansas. Figure 2 shows four sandblows (DBNW2, DBNW3, DBNW4 and DBNW5) which have been identified for purposes of this field trip. Not all will be observable due to the poor field conditions.

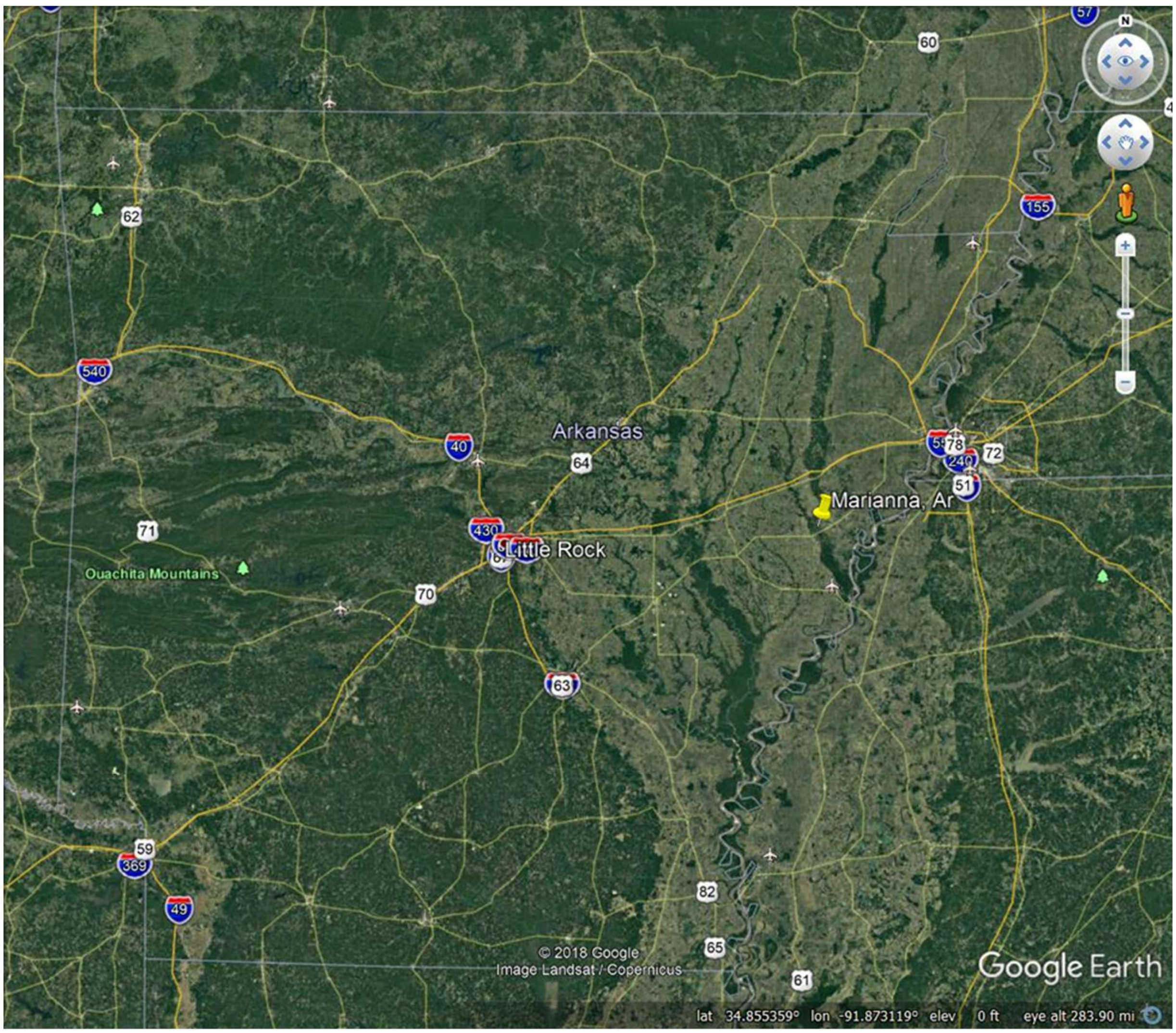

Figure 4. Google Earth image. General map showing Marianna, Arkansas and location of Paleoseismology field trip.

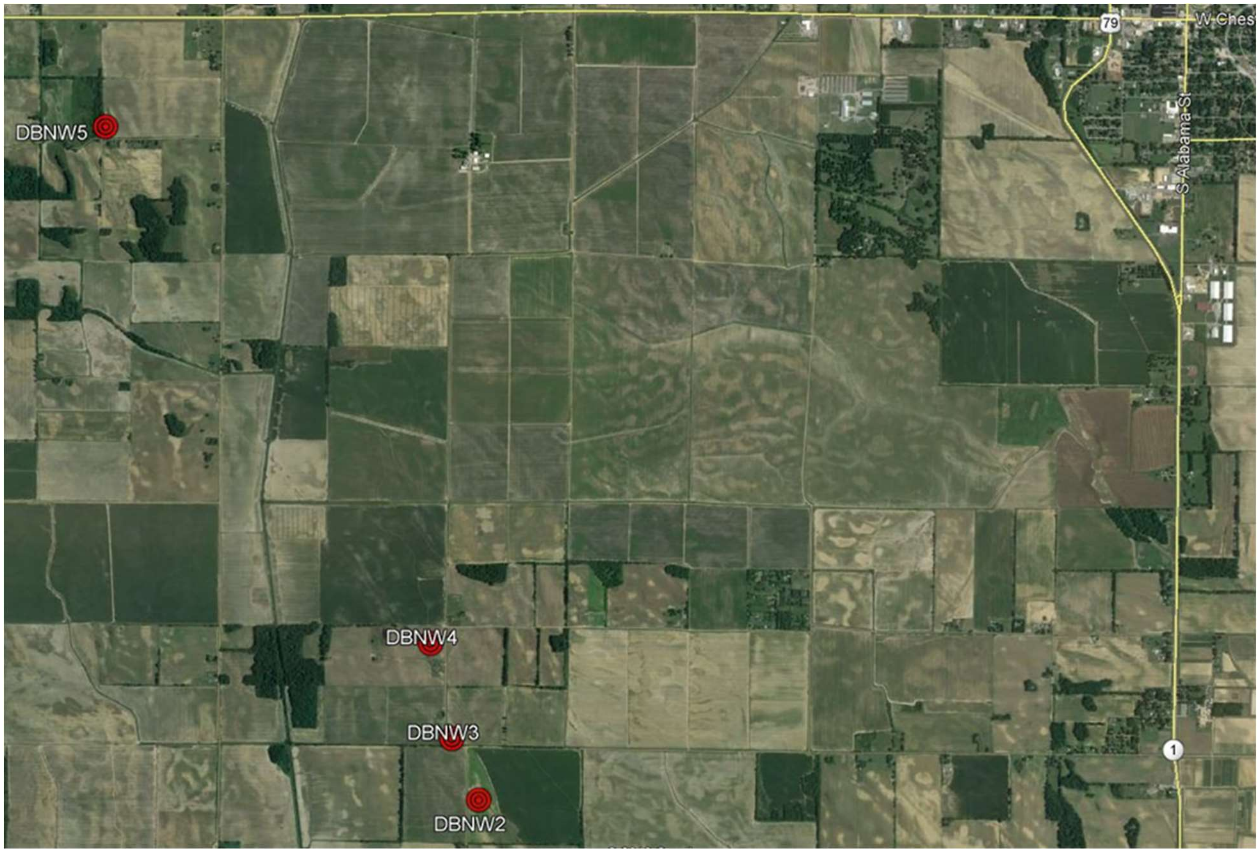

Figure 5. Google Earth image of paleoliquefaction sites to be visited (DBNW2, DBNW3, DBNW4). The trench site DBNW3 will be studied in detail. North is at the top of the page.

Holiday Inn Express & Suites, Forrest City, AR
Time: 0700-0715
Use of Scanning Total Station to Document Trenches

James Evans, P.E., Geotechnical Regional Technical Specialist for the Mississippi Valley Division in the Memphis District-Geotechnical Engineering Branch, United States Army Corps of Engineers (USACE)

We will evaluate the potential useful benefits of mapping paleoliquefaction trench walls using a scanning total station. The scans of the trench walls performed by this equipment include both geo-referenced photo images and very high resolution, multi-beam laser scanning of the trench walls. The photos and scans are integrated together to provide a colored survey scan of the trench walls. We are also evaluating the potential to distinguish varying soil type based on the intensity of the reflected laser.

Time: 0715-0745
Studies of Earthquake Related Features using Ground Penetrating Radar

Dr. Haydar Al-Shukri, Professor, Department of Physics, Director of the Arkansas Earthquake Center, Dr. Hanan Mahdi, Research Professor, and Rauf Hussein, Ph.D. candidate, University of Arkansas, Little Rock.

Ground Penetrating Radar (GPR) is a powerful tool to study earthquake-related features such as sand blows and faults. The primary goal of using GPR is to locate feeder dikes of sand blows and to image the contact between sand blows and the buried paleo-surface in order to optimize the location of trenches. A secondary goal is to image the sand blows in three dimensions to define their sizes and morphology. Trenching large sand blows is costly and provides a limited view of the overall structure. GPR helps to identify possible locations for the venting dikes and to visualize the subsurface features. It also helps to map the locations of tree stumps in the sand blows that are useful for dating.

In the GPR surveys of large elliptical sand deposits near Marianna, Arkansas, we imaged sharp contacts in near-surface sediments that were confirmed in trenches to represent boundaries between sand blows and buried soils. One survey in particular showed a sharp discontinuity in the boundary related to a large feeder dike. Because sand thickness was no more than 4 meters, a 400-MHz antenna was used. This antenna is designed to provide high-resolution images of the upper 5 meters of soil. Data acquisition was along parallel profiles oriented normal to the long axes of the sand deposits at all sites. Data reduction and analysis procedures included removal of direct and ground surface effects, frequency filtration, gain control, profile migration, and three-dimensional visualization. We will run GPR surveys near open trenches to demonstrate the correlation between GPR profiles and the actual trench features. This will also validate the effectiveness of GPR in such studies.

Time: 0745-0815
Paleoliquefaction Studies

Dr. Martitia Tuttle, Director and Principal Investigator, M. Tuttle & Associates

The study of paleoliquefaction is a geo-forensic science that documents, dates, and analyzes soft-sediment deformation features and related ground failures that resulted from liquefaction induced by large earthquakes in the past. Evidence of these paleoearthquakes may be preserved in the geologic record for tens of thousands of years in the form of sand blows, dikes, and other soft-sediment deformations features. Paleoliquefaction studies provide information about the timing, location, magnitude, and recurrence times of large paleoearthquakes. This information is used to identify potential sources of future earthquakes, to characterize the earthquake potential of those sources, and to estimate seismic hazard. Paleoliquefaction studies are especially helpful in regions where recurrence times of large earthquakes are longer than the historical record of earthquakes and where seismogenic faults may not rupture to the ground surface. Examples of earthquake-induced liquefaction features and their use in seismic hazard assessment will be drawn primarily from paleoliquefaction studies in the New Madrid seismic zone and the Marianna area.

Field Trip, Marianna, AR
Time: 0915-0945
Assessment of Cyclic Behavior of Mississippi Embayment Sand Based on Cyclic Triaxial Tests

Hamed Tohidi, Graduate Research Assistant, Department of Civil Engineering, The University of Memphis, Memphis, TN 38152 and David Arellano, Associate Professor, Department of Civil Engineering, The University of Memphis, Memphis, TN 38152

The simplified procedure for evaluating the soil liquefaction potential of cohesionless soils is based on estimating the cyclic stress ratio (CSR) from an empirical relationship that is based on the cyclic triaxial test results of Sacramento River, California sand. Grain size analysis results indicate that the grain size distribution of Mississippi Embayment sand from Vicksburg, Mississippi is different than Sacramento River sand.

Soil properties that influence liquefaction potential and cyclic behavior include grain size distribution, grain shape, mineral composition, and age. Therefore, the hypothesis that this study will evaluate is that the cyclic behavior of Mississippi Embayment sand is different than Sacramento River sand and, consequently, the CSR based on cyclic triaxial tests of Mississippi Embayment sand will be different than the current simplified method of determining CSR that is based on cyclic triaxial tests on Sacramento River sand. For this study, it has proposed to obtain sand samples from various locations in the MS Embayment and from trenches displaying remnants of liquefied sand to perform cyclic triaxial tests and to evaluate CSR.

Time: 0945-1200
Studies of Earthquake Related Features using Ground Penetrating Radar

Dr. Haydar Al-Shukri, Professor, Department of Physics, Director of the Arkansas Earthquake Center, Dr. Hanan Mahdi, Research Professor, and Rauf Hussein, Ph.D. candidate, University of Arkansas, 2801 S. University Ave., Little Rock, Arkansas, .72204.

Ground Penetrating Radar (GPR) is a powerful tool to study earthquake-related features such as sand blows and faults. The primary goal of using GPR is to locate feeder dikes of sand blows and to image the contact between sand blows and the buried paleo-surface in order to optimize the location of trenches. A secondary goal is to image the sand blows in three dimensions to define their sizes and morphology. Trenching large sand blows is costly and provides a limited view of the overall structure. GPR helps to identify possible locations for the venting dikes and to visualize the subsurface features. It also helps to map the locations of tree stumps in the sand blows that are useful for dating.

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Time: 1300-1700
Paleoliquefaction Studies

Dr. Martitia Tuttle, Director and Principal Investigator, M. Tuttle & Associates

The study of paleoliquefaction is a geo-forensic science that documents, dates, and analyzes soft-sediment deformation features and related ground failures that resulted from liquefaction induced by large earthquakes in the past. Evidence of these paleoearthquakes may be preserved in the geologic record for tens of thousands of years in the form of sand blows, dikes, and other soft-sediment deformations features. Paleoliquefaction studies provide information about the timing, location, magnitude, and recurrence times of large paleoearthquakes. This information is used to identify potential sources of future earthquakes, to characterize the earthquake potential of those sources, and to estimate seismic hazard. Paleoliquefaction studies are especially helpful in regions where recurrence times of large earthquakes are longer than the historical record of earthquakes and where seismogenic faults may not rupture to the ground surface. Examples of earthquake-induced liquefaction features and their use in seismic hazard assessment will be drawn primarily from paleoliquefaction studies in the New Madrid seismic zone and the Marianna area.

Appendices

Biographical Summaries

Dr. Al-Shukri received his B.S. and M.S. degrees in geophysics from the University of Baghdad, Iraq and his Ph.D. from St. Louis University in St. Louis, Missouri. He is a professor with the Department of Physics and Director of the Arkansas Earthquake Center. His research interests include seismology, applied geophysics, 3-dimensional topography, digital signal processing, infrasonic studies, nuclear monitoring, fault monitoring, earthquake awareness and education.

Mr. James Evans, P.E., is the Regional Technical Specialist within the USACE, Mississippi Valley Division Memphis District Office. Mr. Evans has worked for the Memphis District USACE Geotechnical Engineering Branch since October 2006. Mr. Evans is a registered Professional Engineer in Tennessee, Arkansas, and Mississippi and holds a Bachelor of Science and Master of Science in Civil Engineering from The University of Memphis. Before accepting his current position with the Memphis District in 2006, Mr. Evans worked 7 years as a geotechnical consulting engineer for Professional Service Industries, Inc. in Memphis, Tennessee. His areas of proficiency include evaluations of slope stability, seepage, consolidation, deep and shallow foundations, lateral earth retaining structures, dewatering, liquefaction, and site-specific seismic studies. He is the technical lead of the effort to develop a Seismic Center of Excellence in the Memphis District to serve the Corps and other Federal Agencies with seismic and geophysical services. He has served as the Geotechnical Advisor for the flood fight teams for multiple flood events on the Mississippi and White Rivers. He currently serves as a Geotechnical Regional Technical Specialist for the Mississippi Valley Division in the Memphis District-Geotechnical Engineering Branch.

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For more detailed information on paleoseismology, the reader is encouraged to refer to the researchers below.

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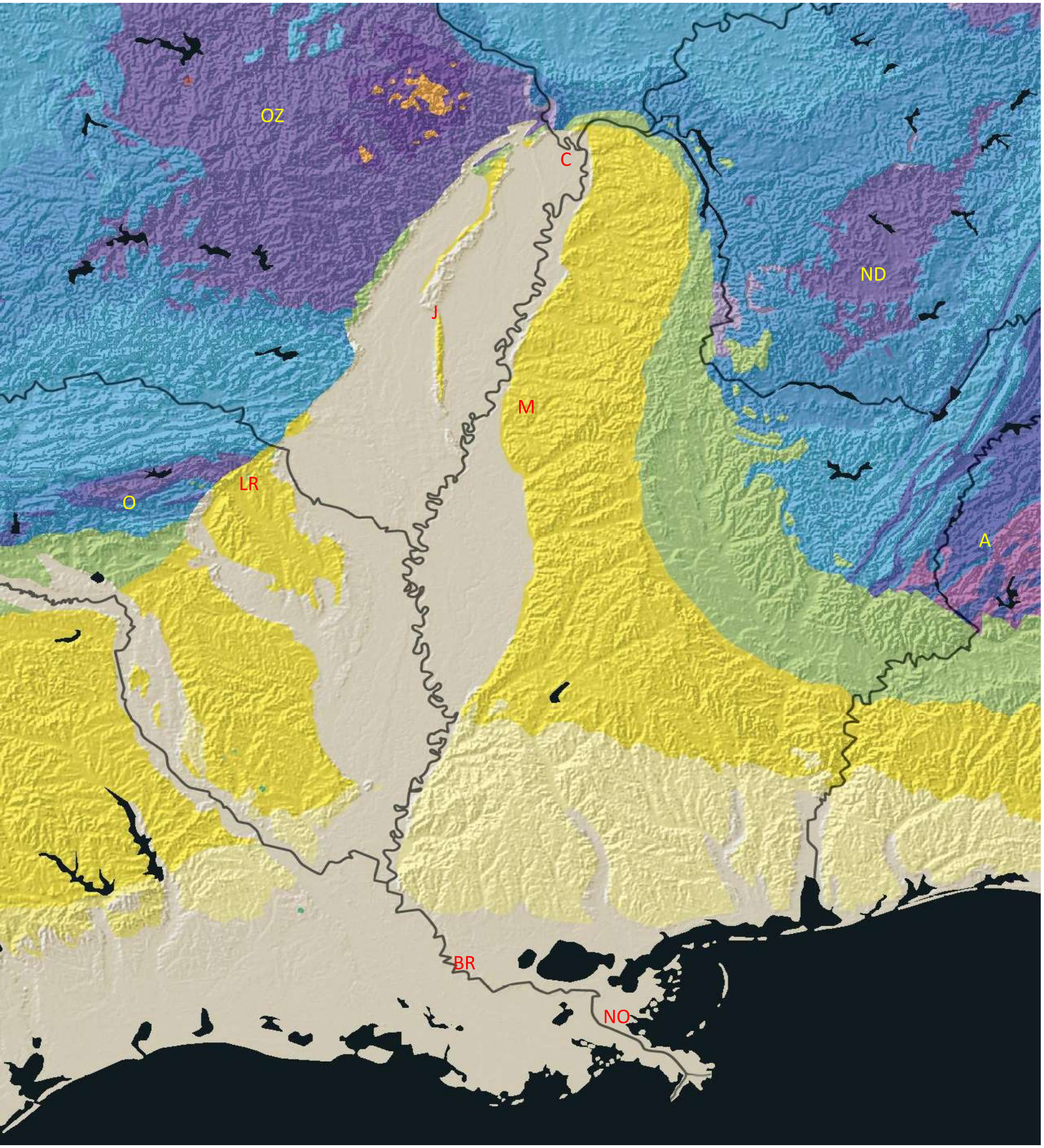
Post Workshop/Field Trip Supplemental Materials

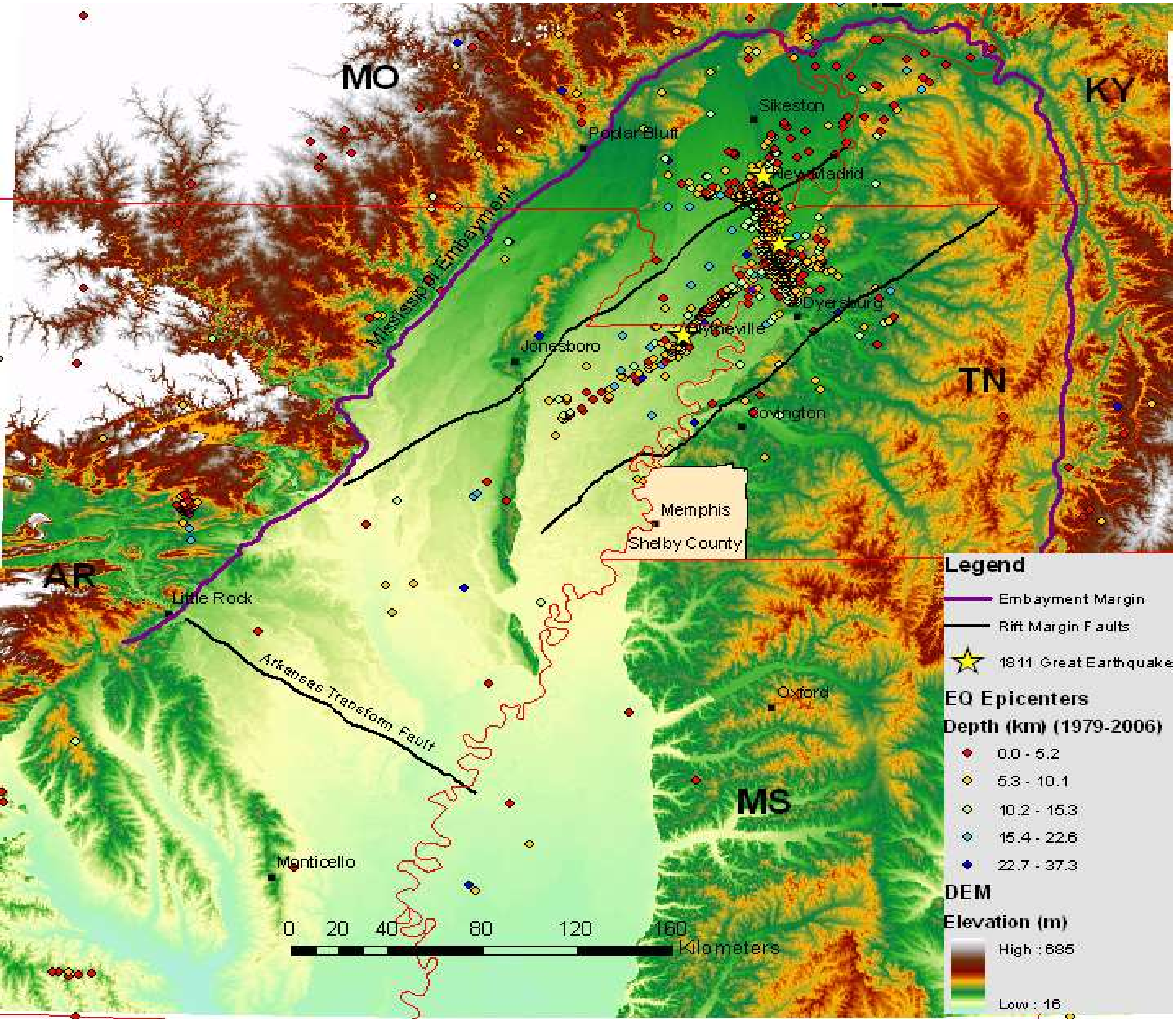
Two categories of supplemental materials from this workshop have been incorporated into this publication: 1) PowerPoint presentations, 2) Documentary. The PowerPoint presentations are attached below. James Evans presentation consisted of a movie (attached as a separate file). Through the assistance of funding from the RISC grant, and generosity of Historical Attractions, the GS and Historical Attractions developed a documentary designed to focus on public earthquake emergency preparedness and awareness. The documentary is provided as separate digital attachment/file to this report.

Pliocene and Quaternary Geologic History of the Northern Mississippi Embayment and its Implications for the New Madrid Earthquakes

Roy Van Arsdale
Department of Earth Sciences
The University of Memphis

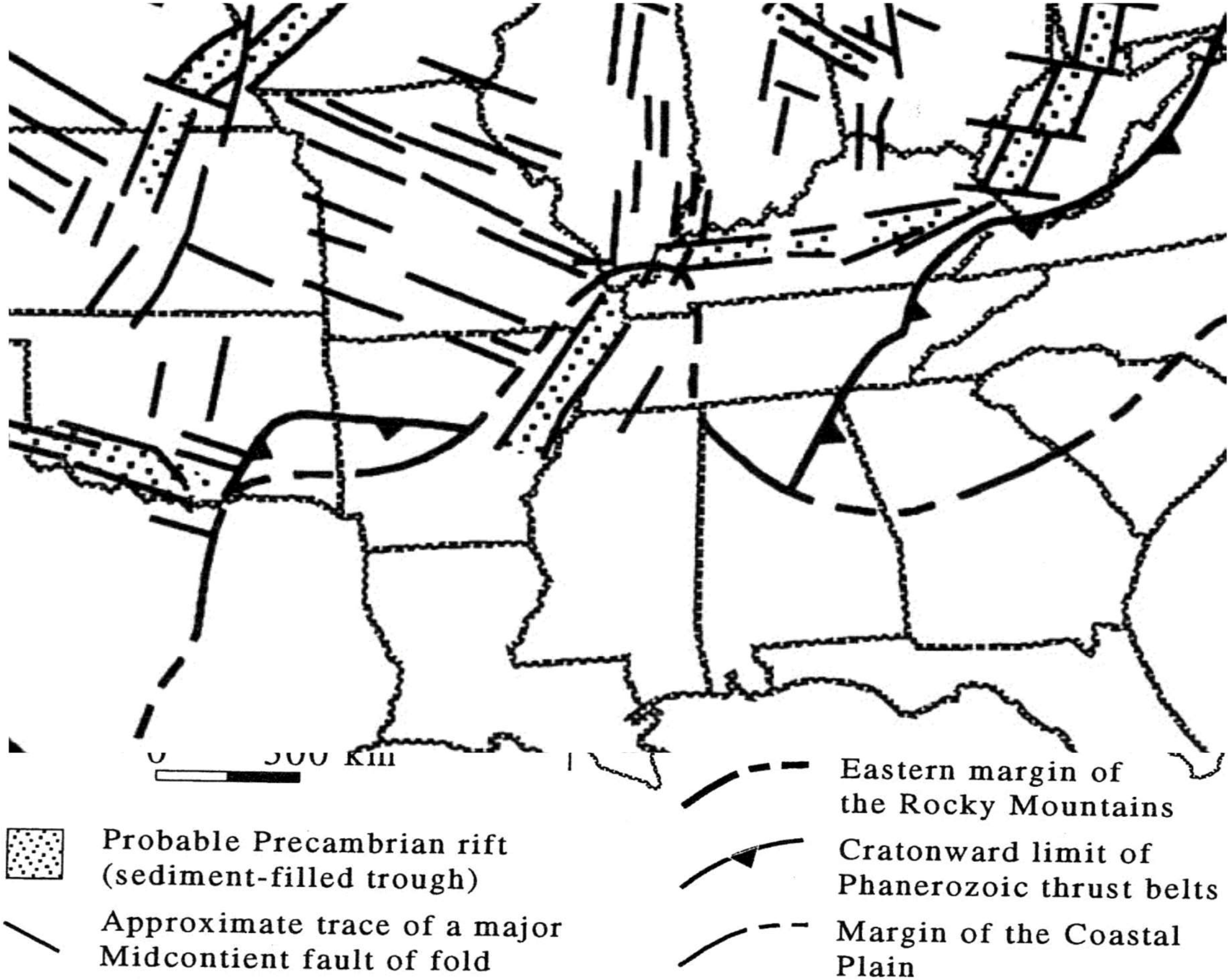


The Mississippi embayment

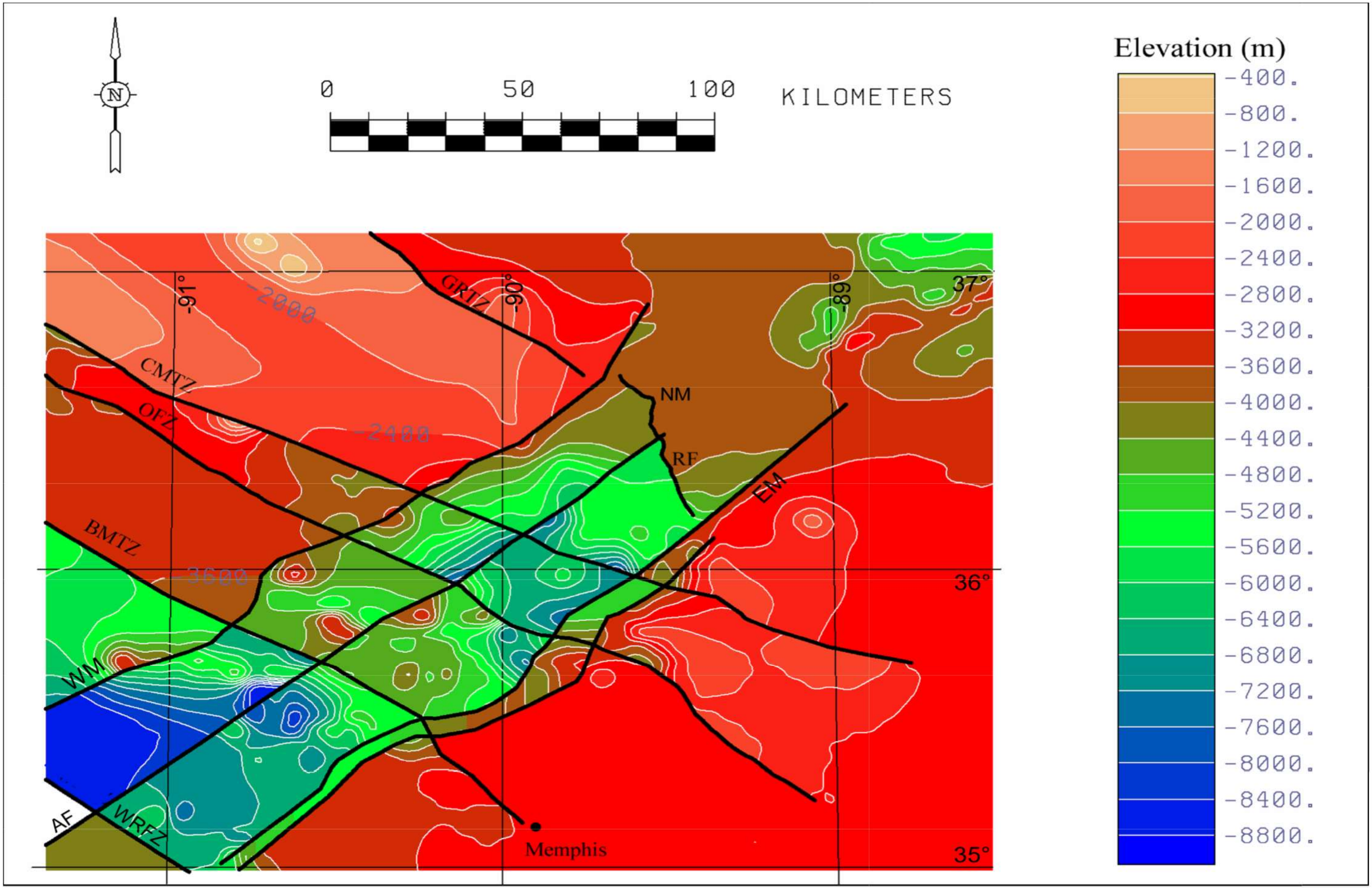


New Madrid seismic zone in northern Mississippi embayment. Stars are large earthquakes of 1811-1812.

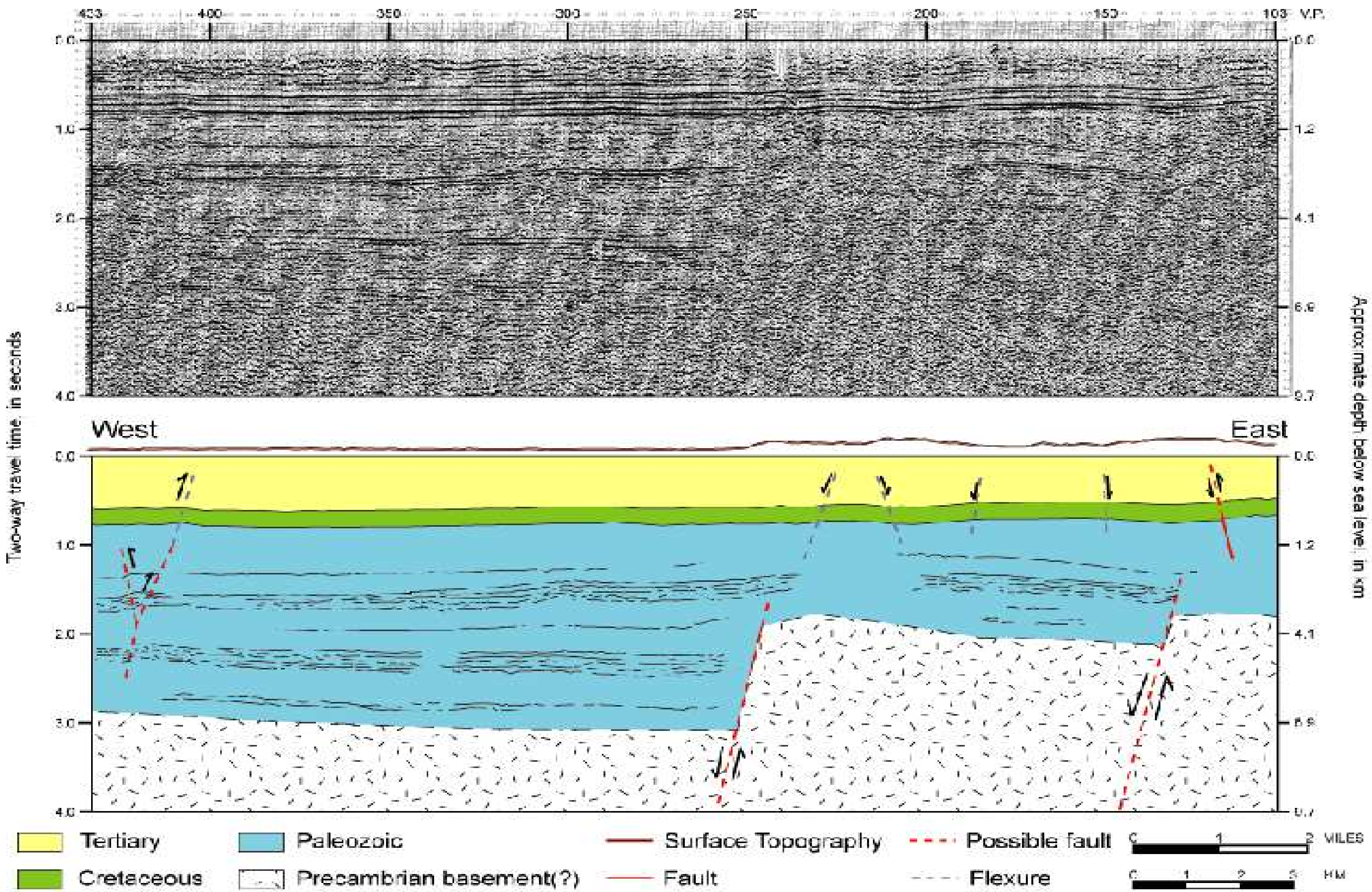
Basement Structure.



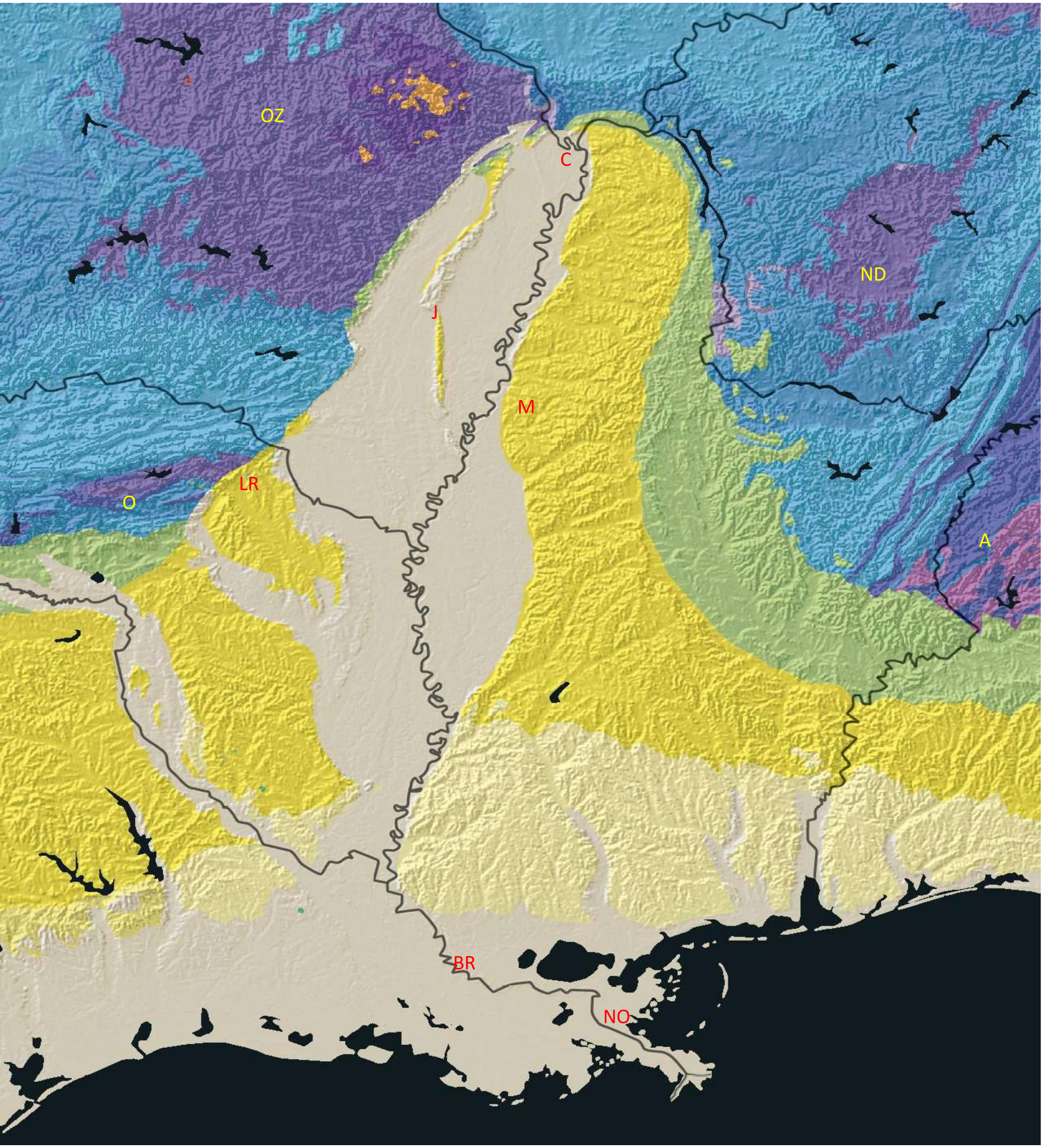
Cambrian formation of the Reelfoot Rift, Rough Creek Graben, and Rome Trough.



NW trending Proterozoic faults and NE trending Cambrian Reelfoot rift faults.

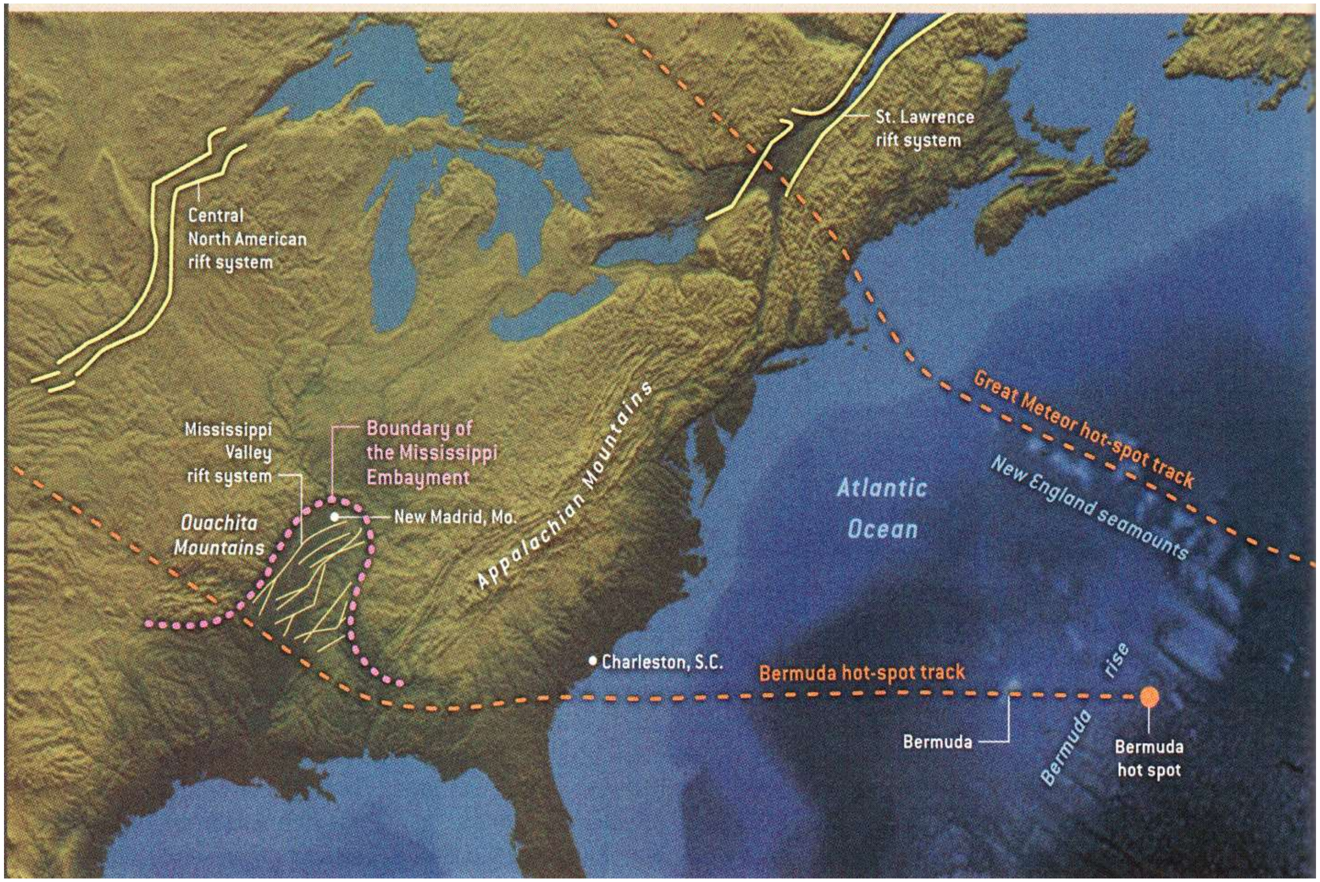


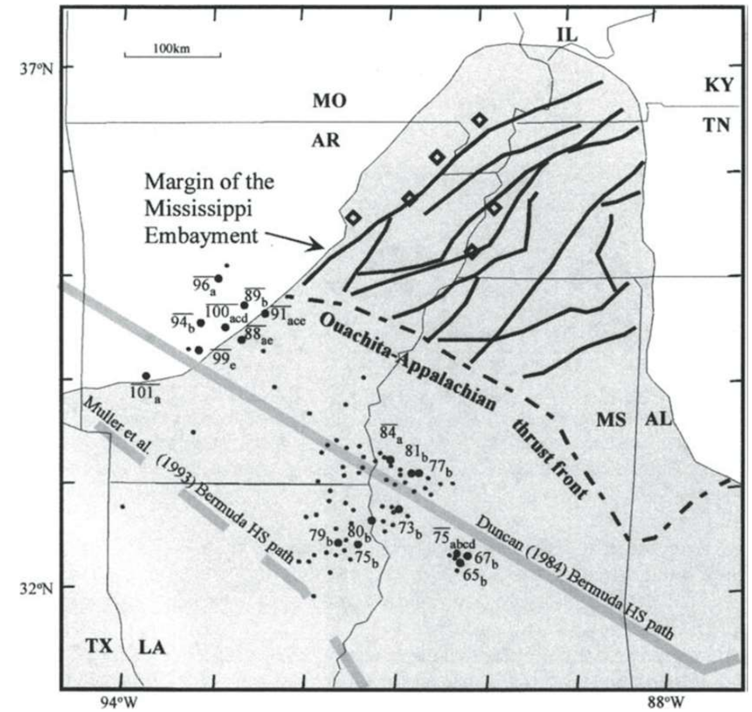
Dow seismic reflection line 143E across eastern Reelfoot rift margin faults north of Memphis.

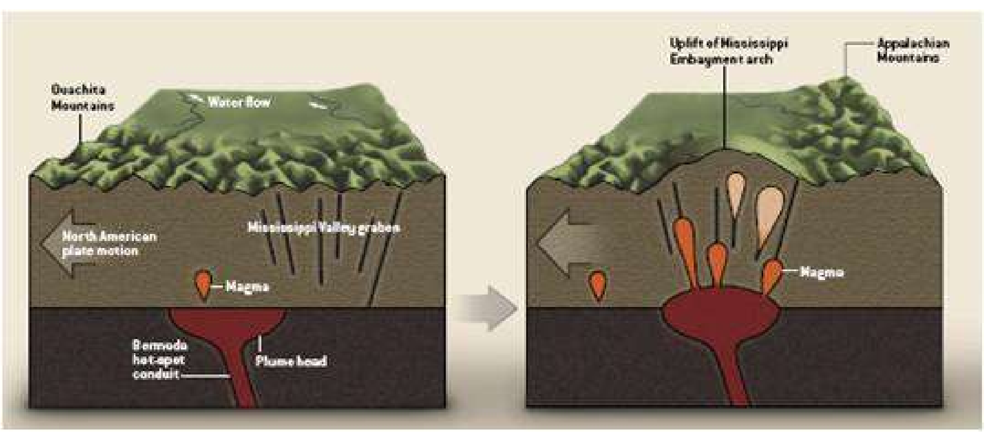


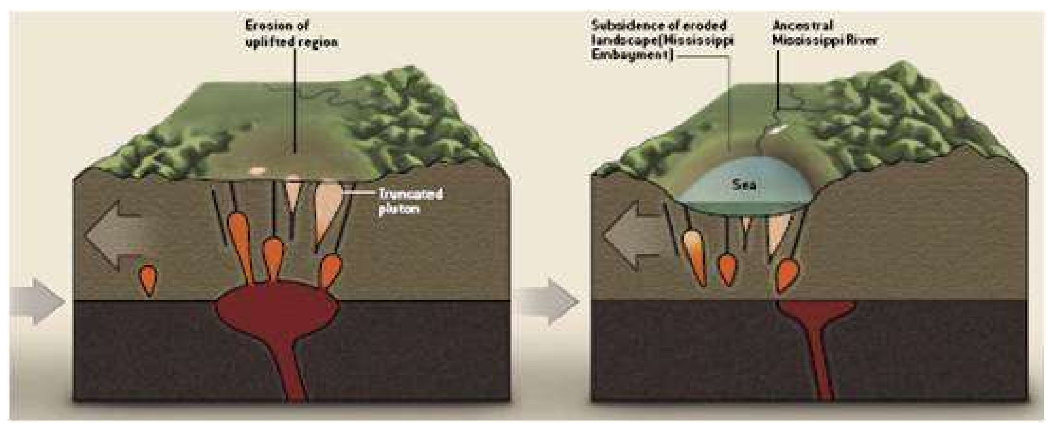
Formation of the Mississippi embayment

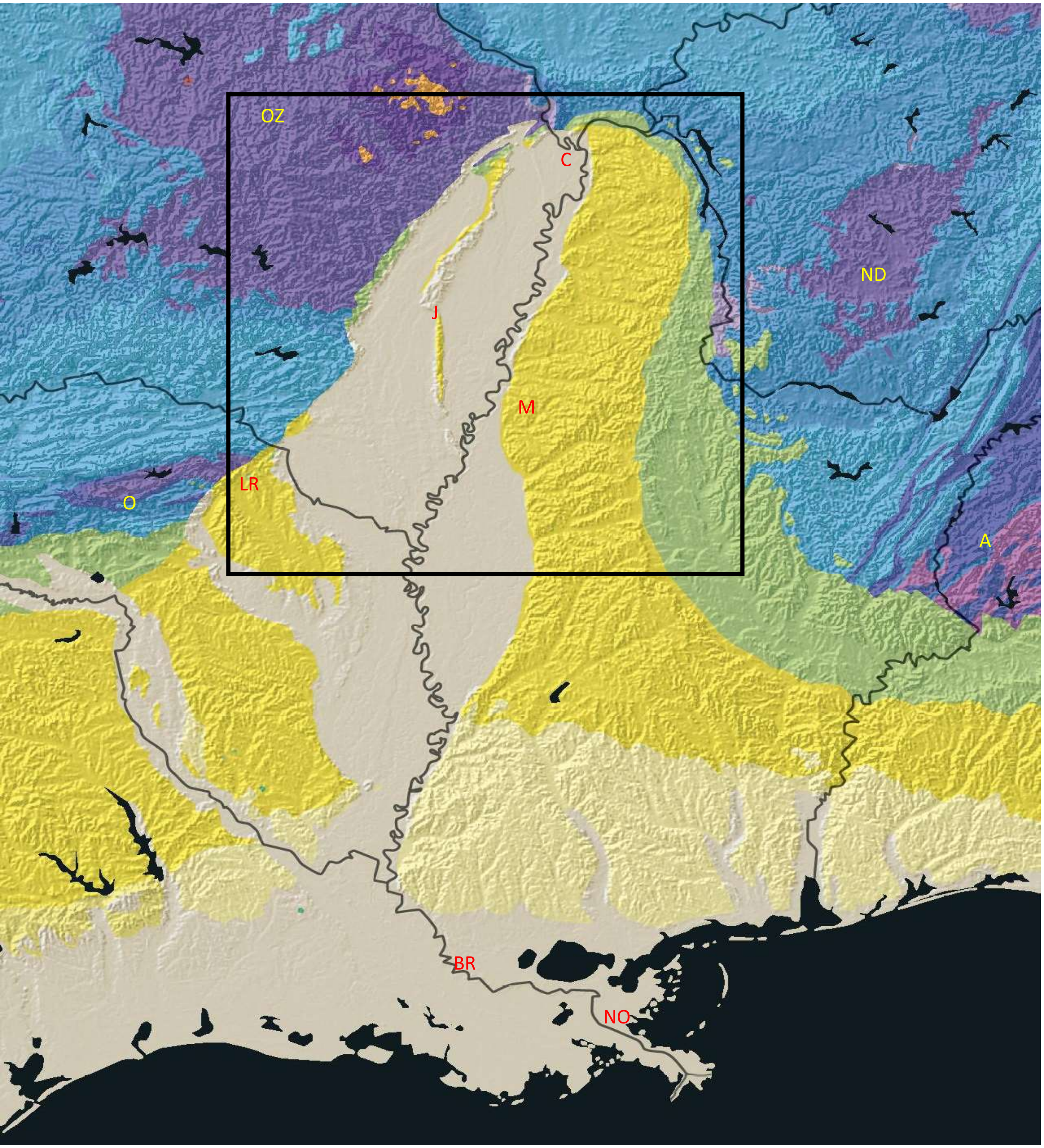
Formation of the Mississippi Embayment by the Bermuda hotspot

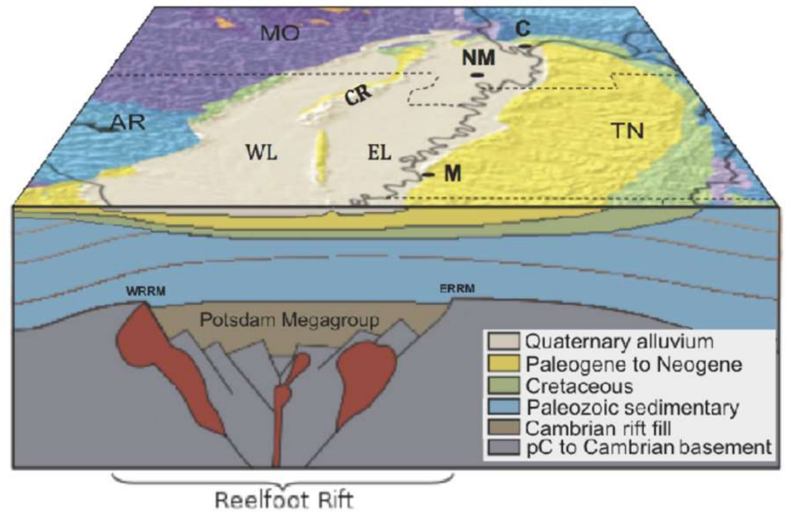






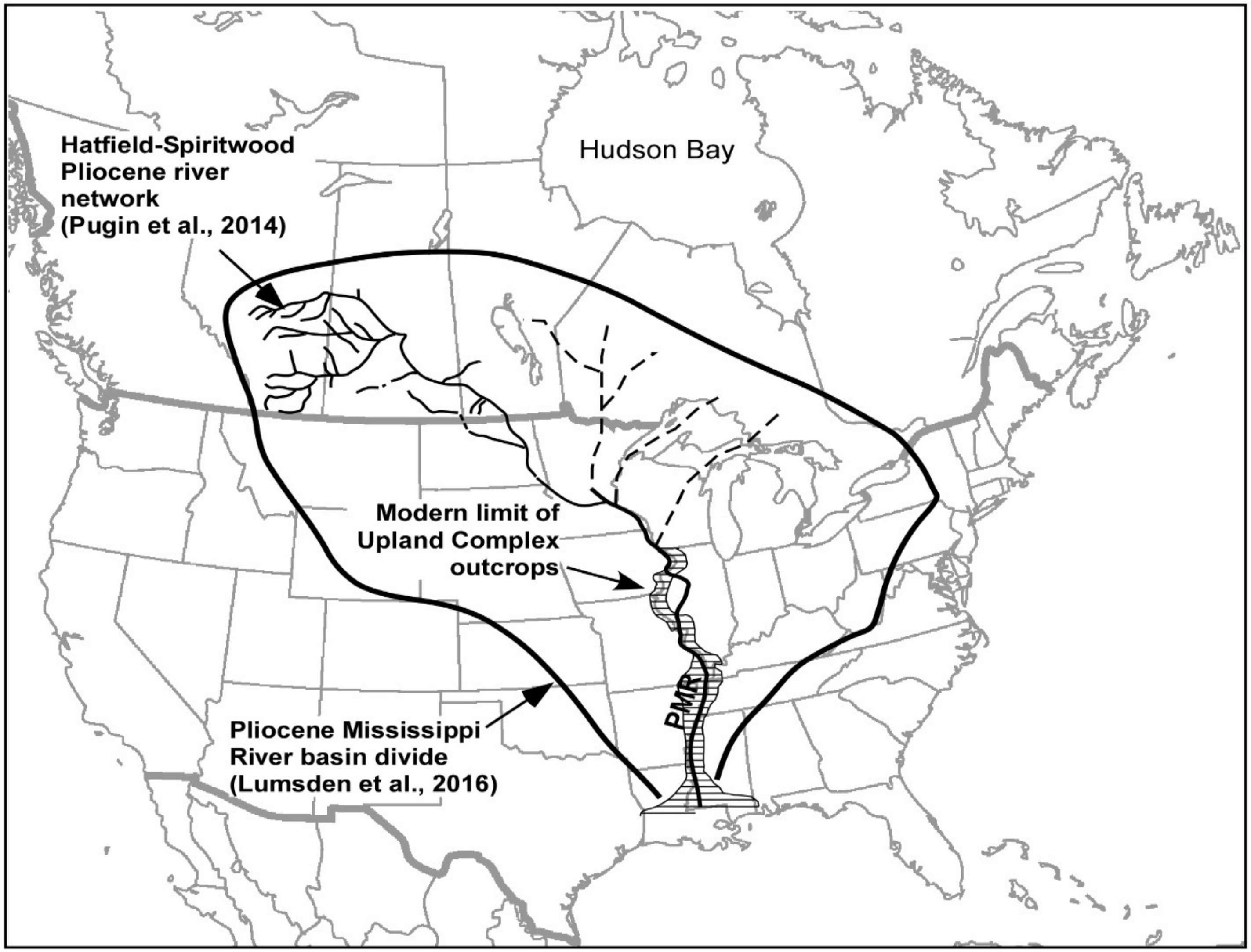


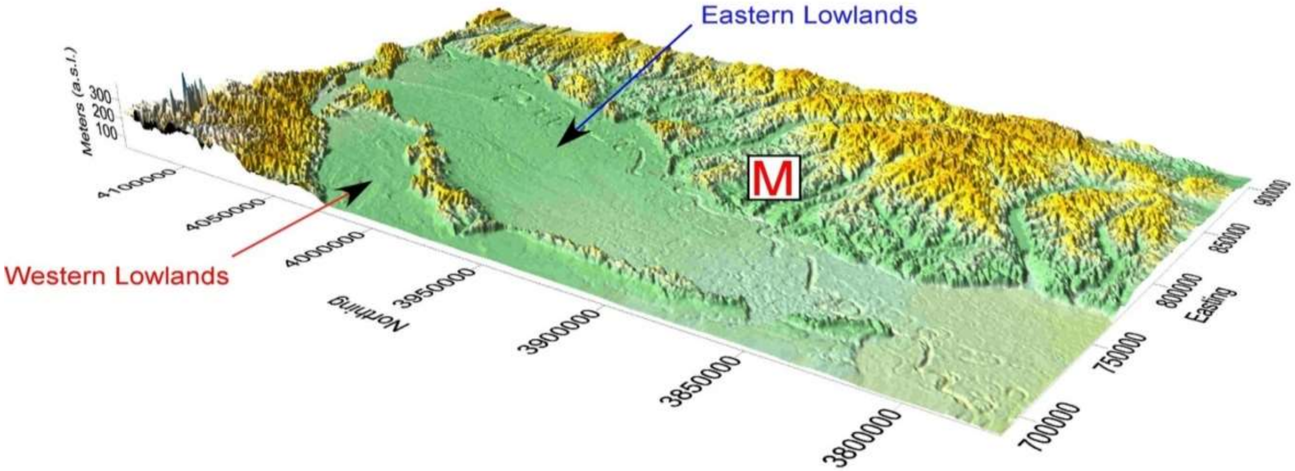




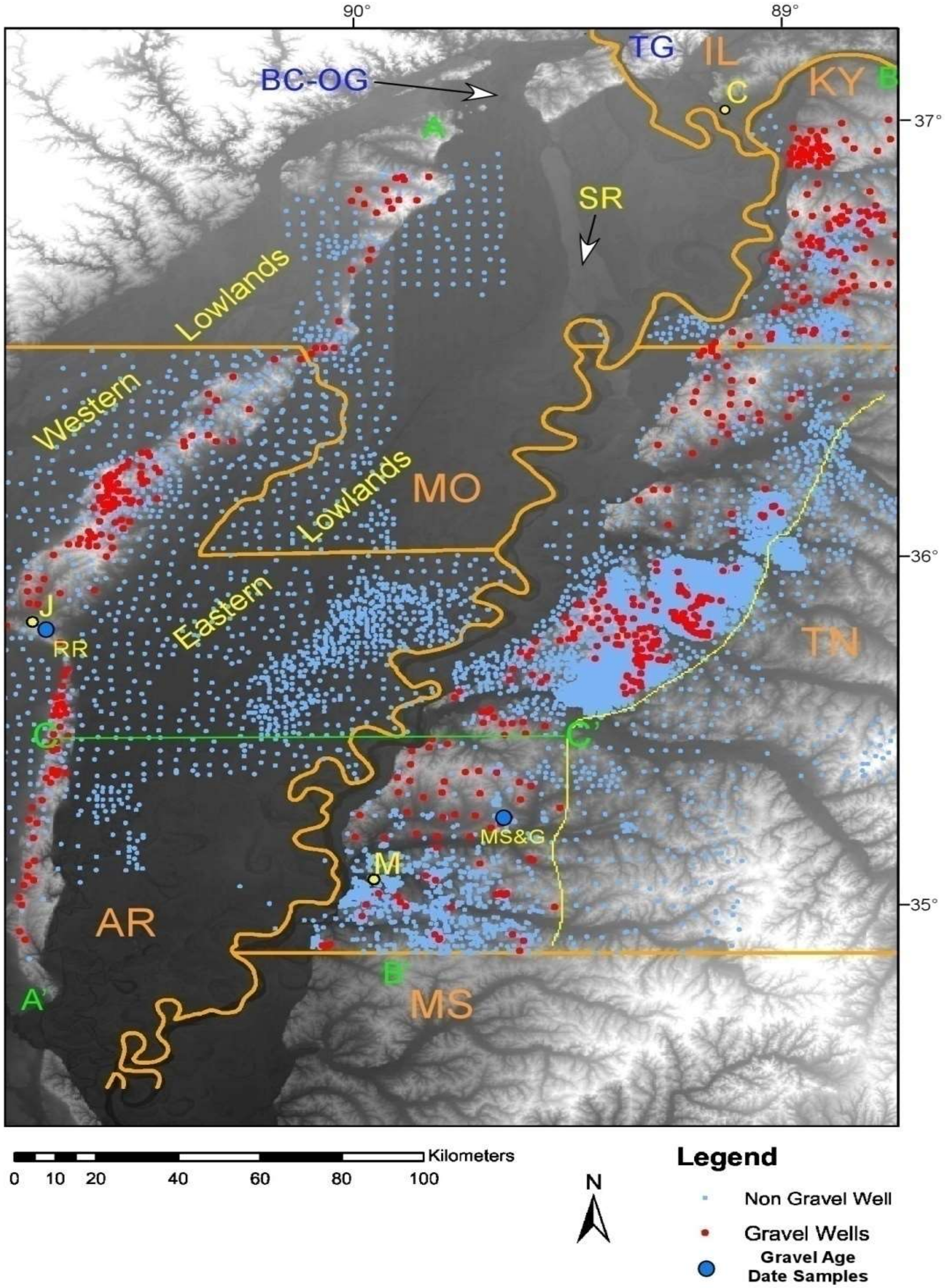
The Mississippi embayment is a south-plunging erosional trough inset into and anticline in the Paleozoic strata. Limbs dip less than 1 degree and plunge is ~ 1 degree. It is flat as a board and not a structural syncline.

Pliocene Mississippi River Drainage Basin





Pliocene ancestral Mississippi River system preserved as ~ 3.2 Ma Upland Complex alluvium.



Exhumed Pliocene ancestral Mississippi River meander bends. Meanders are much larger in radius than modern Mississippi River meanders.

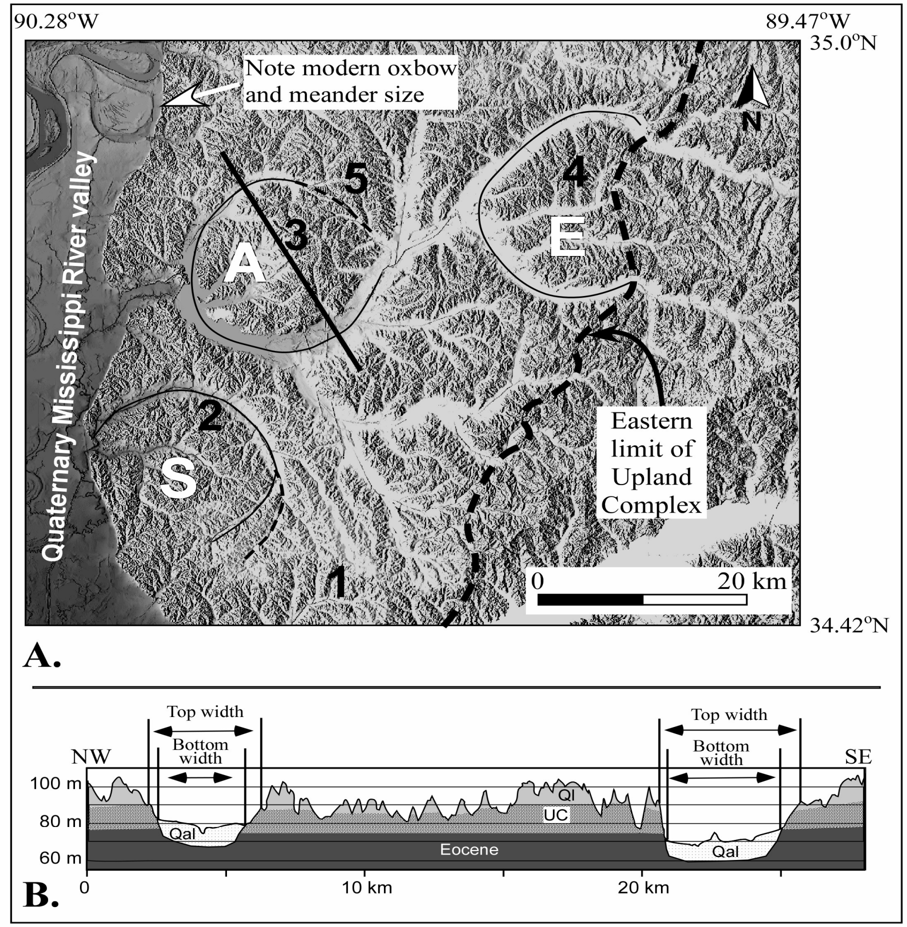
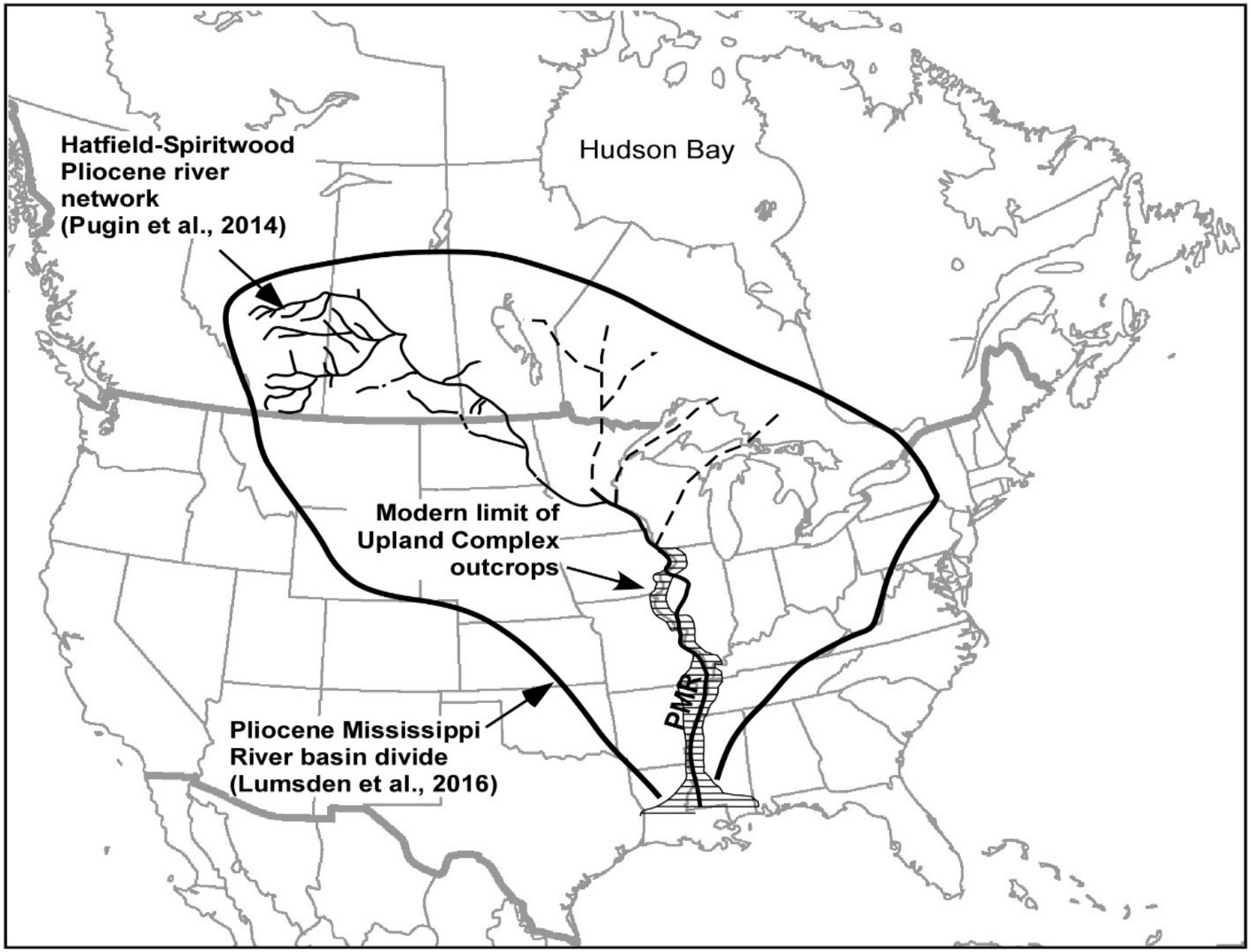


Figure 2 Cox et al.

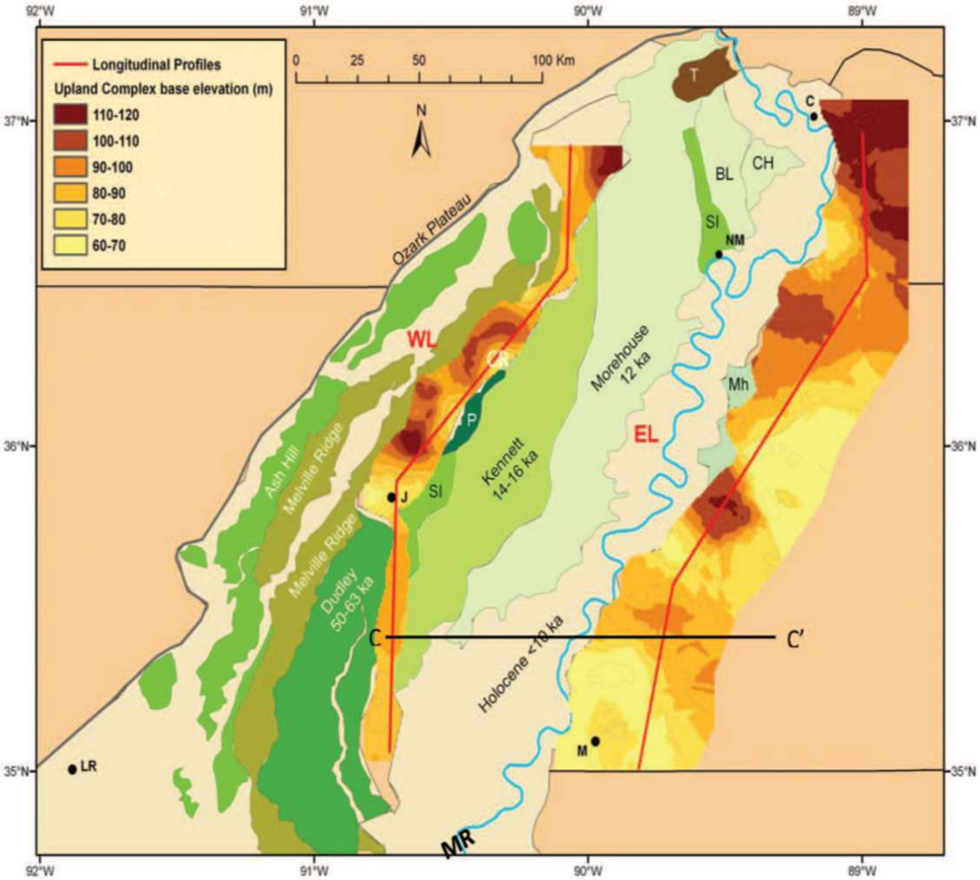
Pliocene terrace alluvium (Upland Complex) of the ancestral Mississippi River beneath Pleistocene loess.

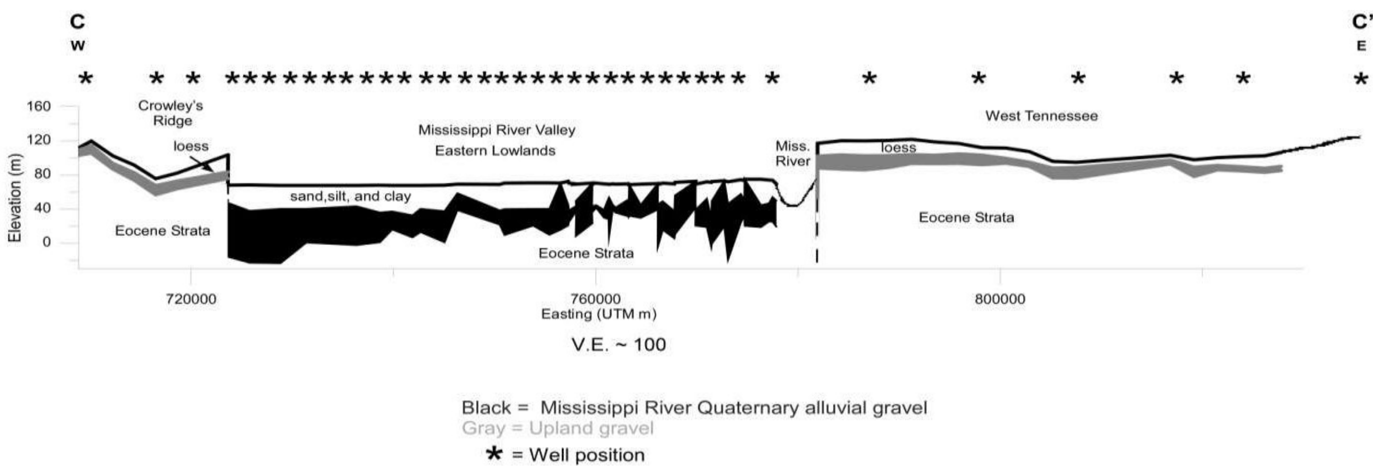
Pliocene Mississippi River drainage basin greatly modified by Pleistocene glaciation

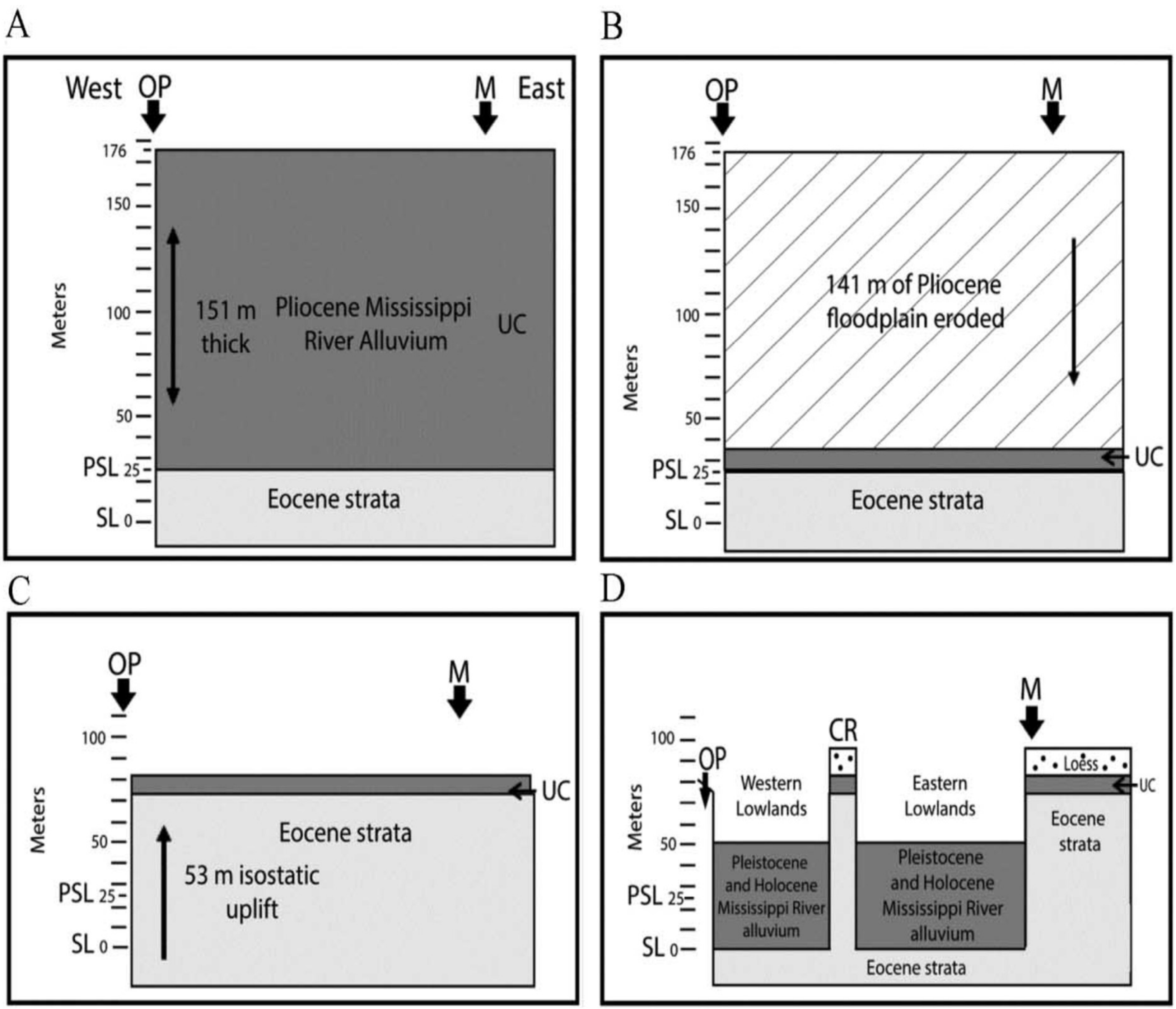


Growth of continental ice sheets in Antarctica and Greenland lowered sea level 3.5 Ma and growth of continental ice sheets multiple times during the last 2.5 Ma lowered sea level even more.

Upland Complex is the basal facies of a much thicker (~ 150 m) Pliocene Mississippi River floodplain.





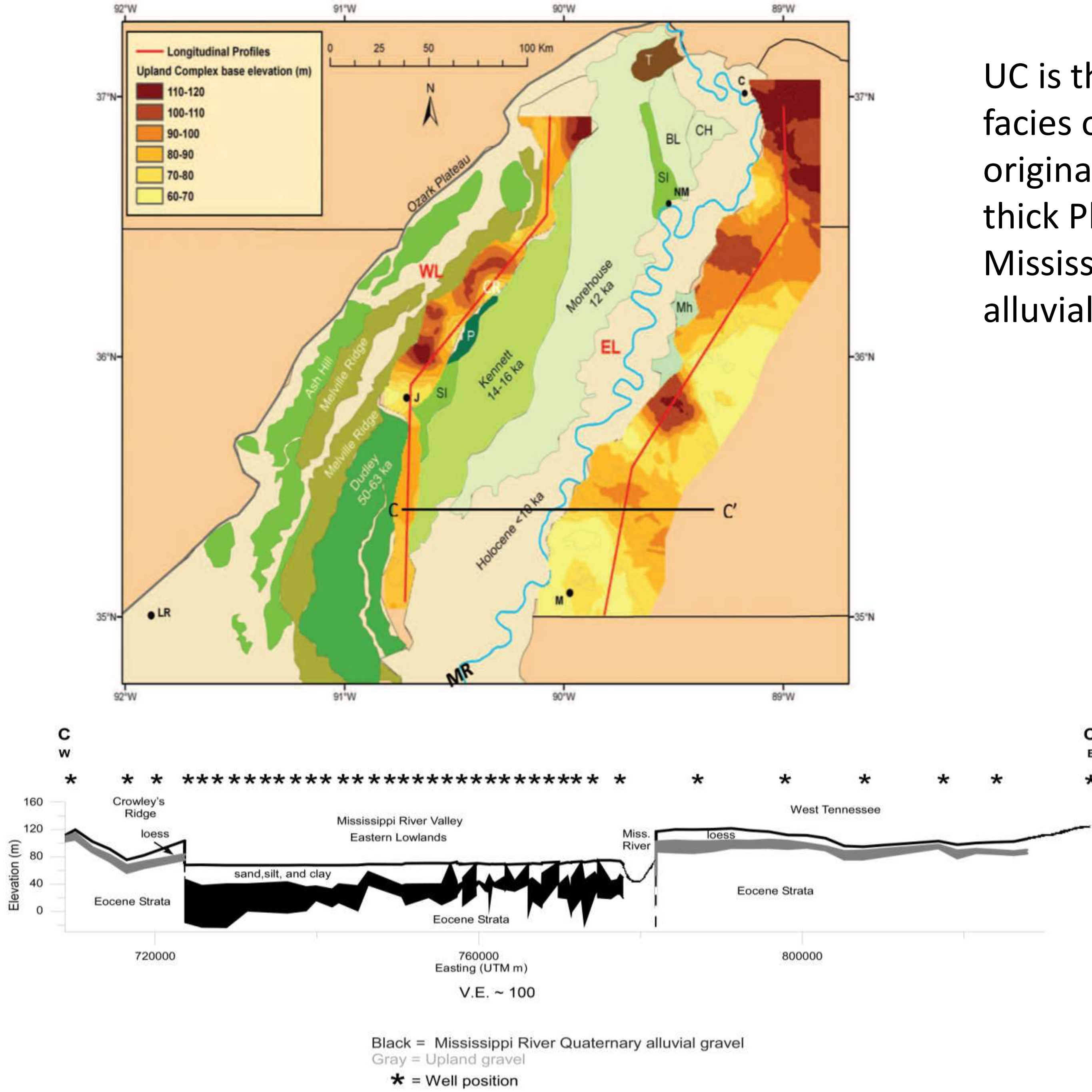


A. Upland Complex formation

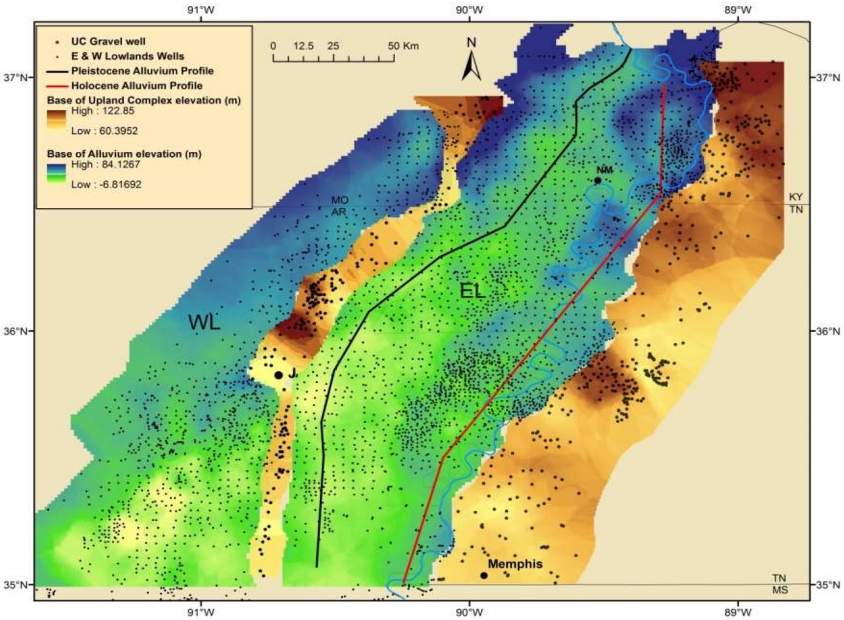
B. Pleistocene erosion of UC

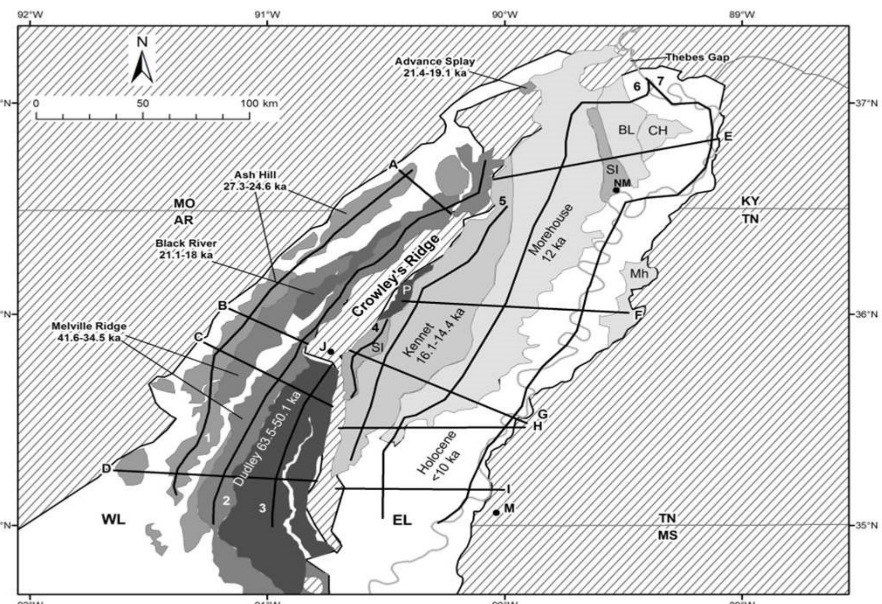
C. Isostatic uplift of Mississippi Valley

D. Erosion of the Eastern and Western Lowlands and loess load isostatic adjustment

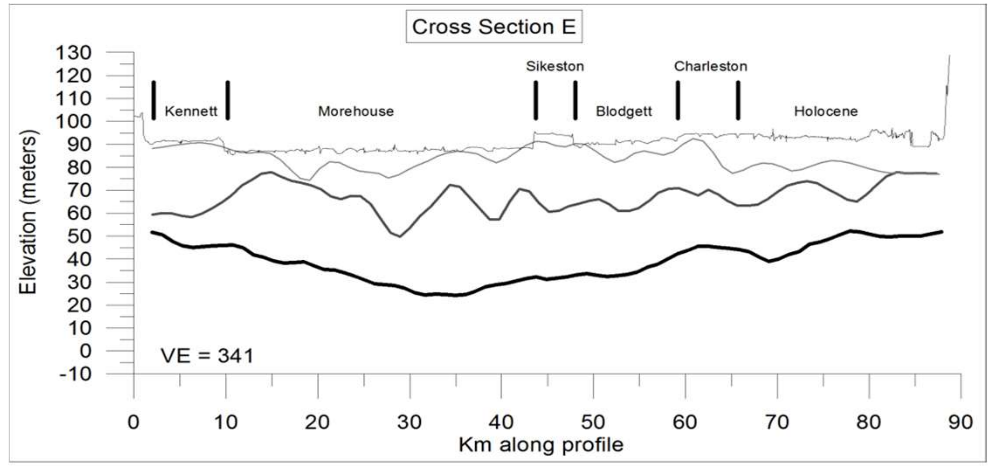


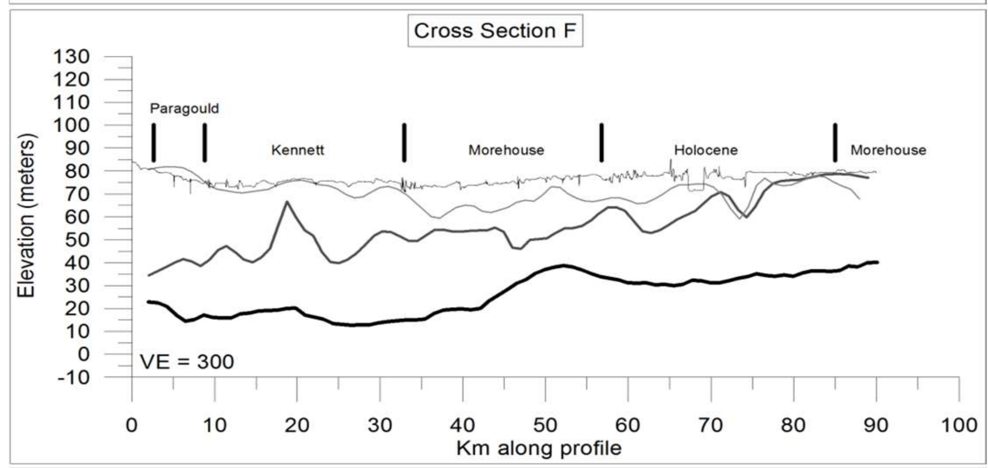
UC is the basal facies of an originally ~ 150 m thick Pliocene Mississippi River alluvial section.

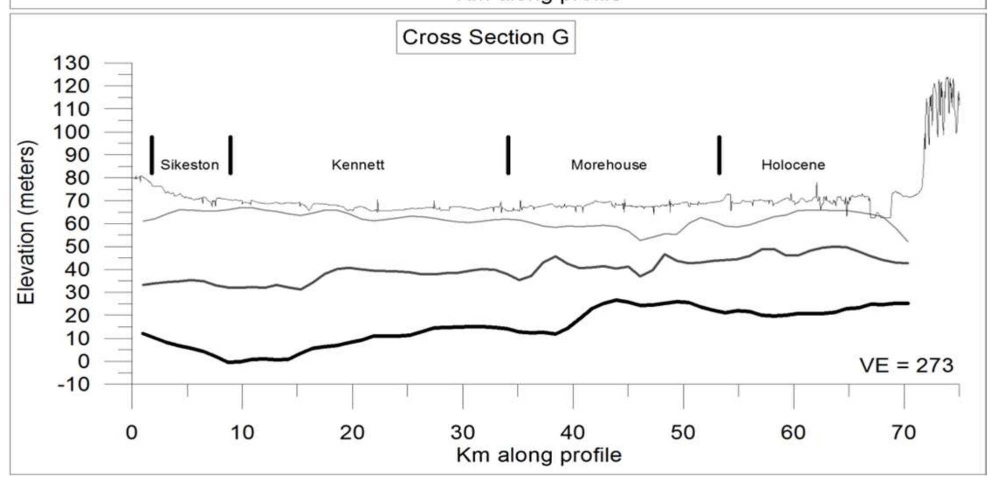




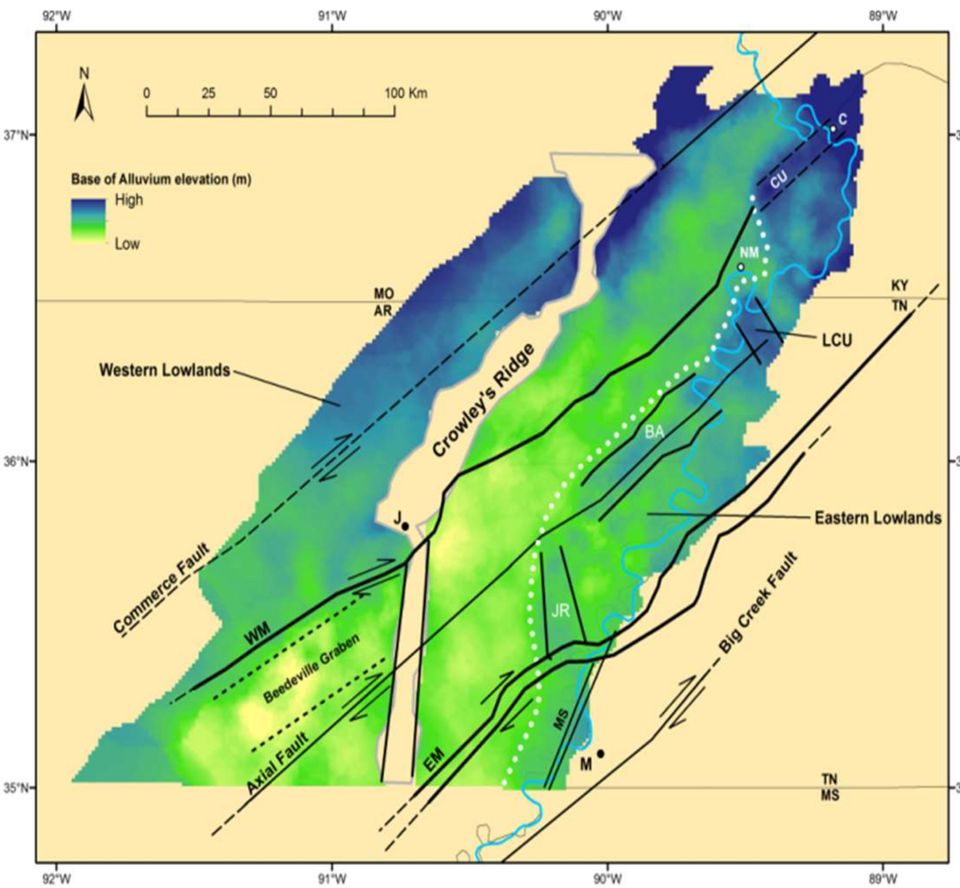
Deepest Pleistocene river incision immediately east of Crowley's Ridge with source from Cache Valley in IL. Note up-to-east step on valley floor in eastern lowlands.

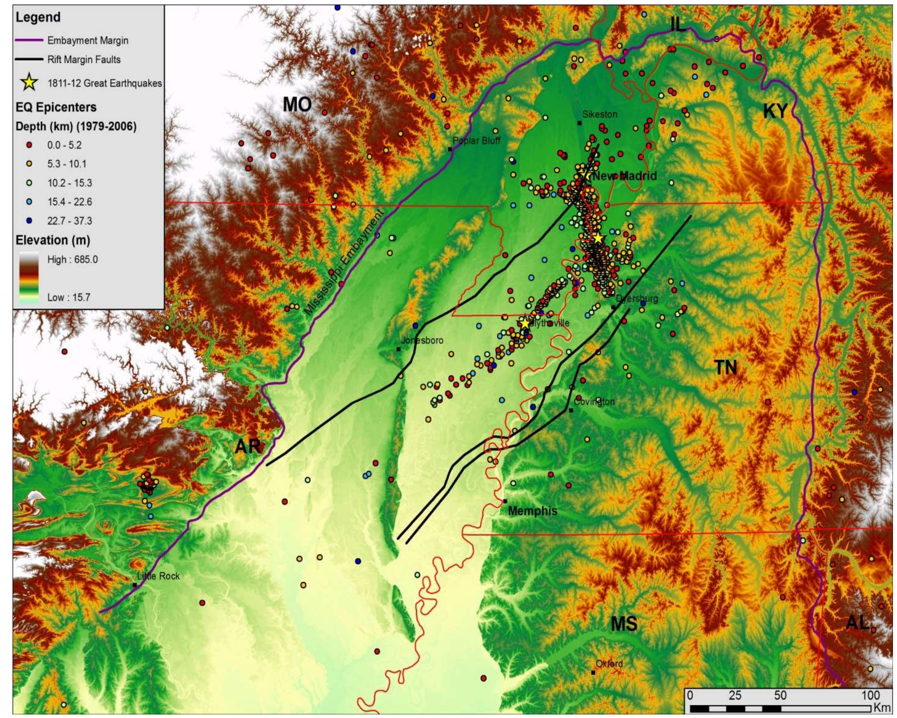






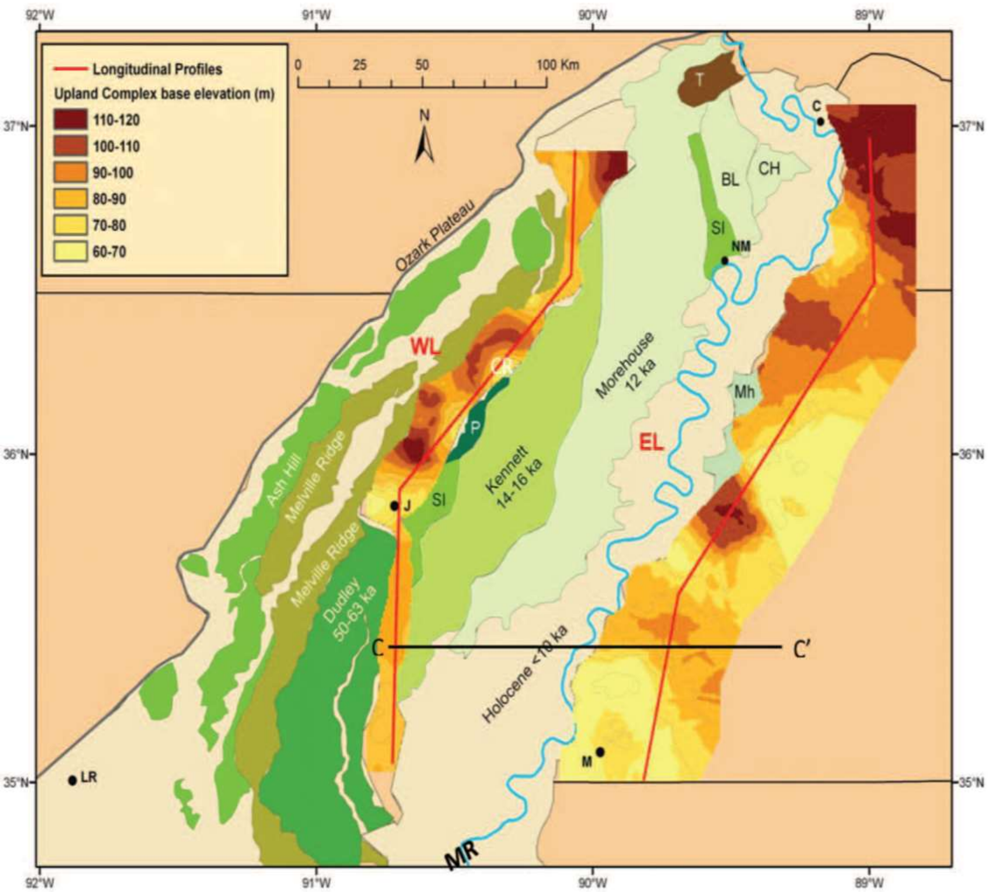
Recent research indicates that 30 m of sediment was removed from above the NMSZ within last 20 ka (Van Arsdale et al., 2014).



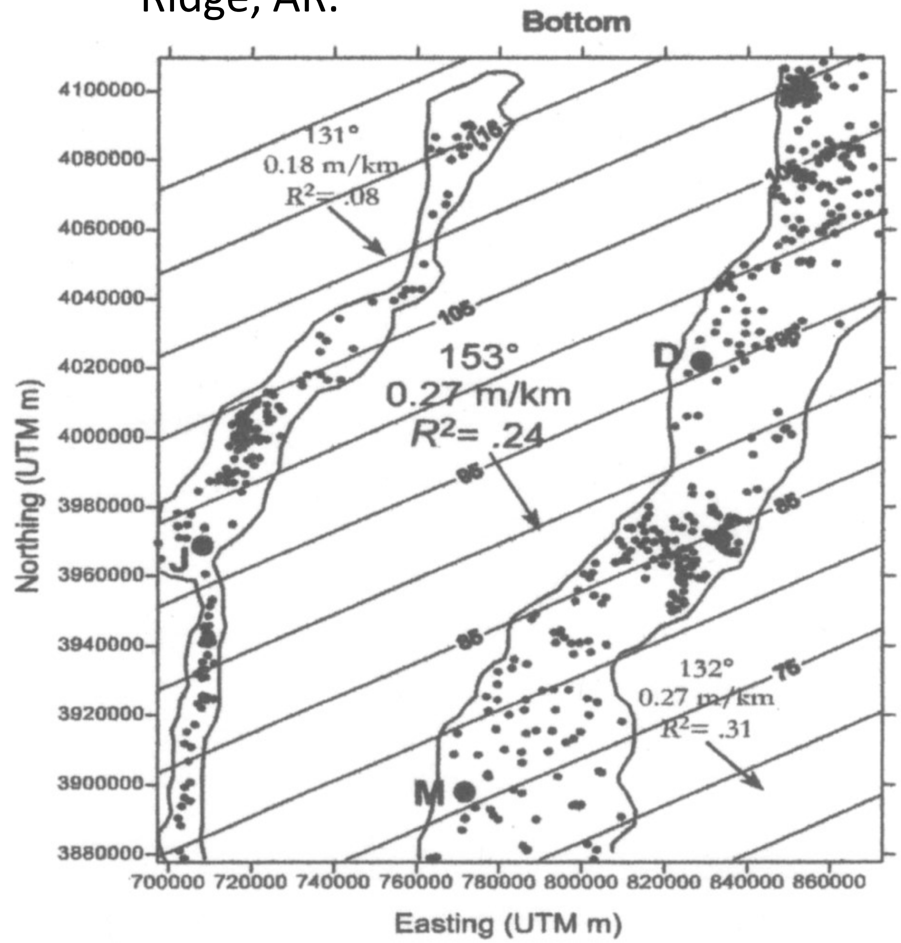


Quaternary Mississippi River Valley is Rising

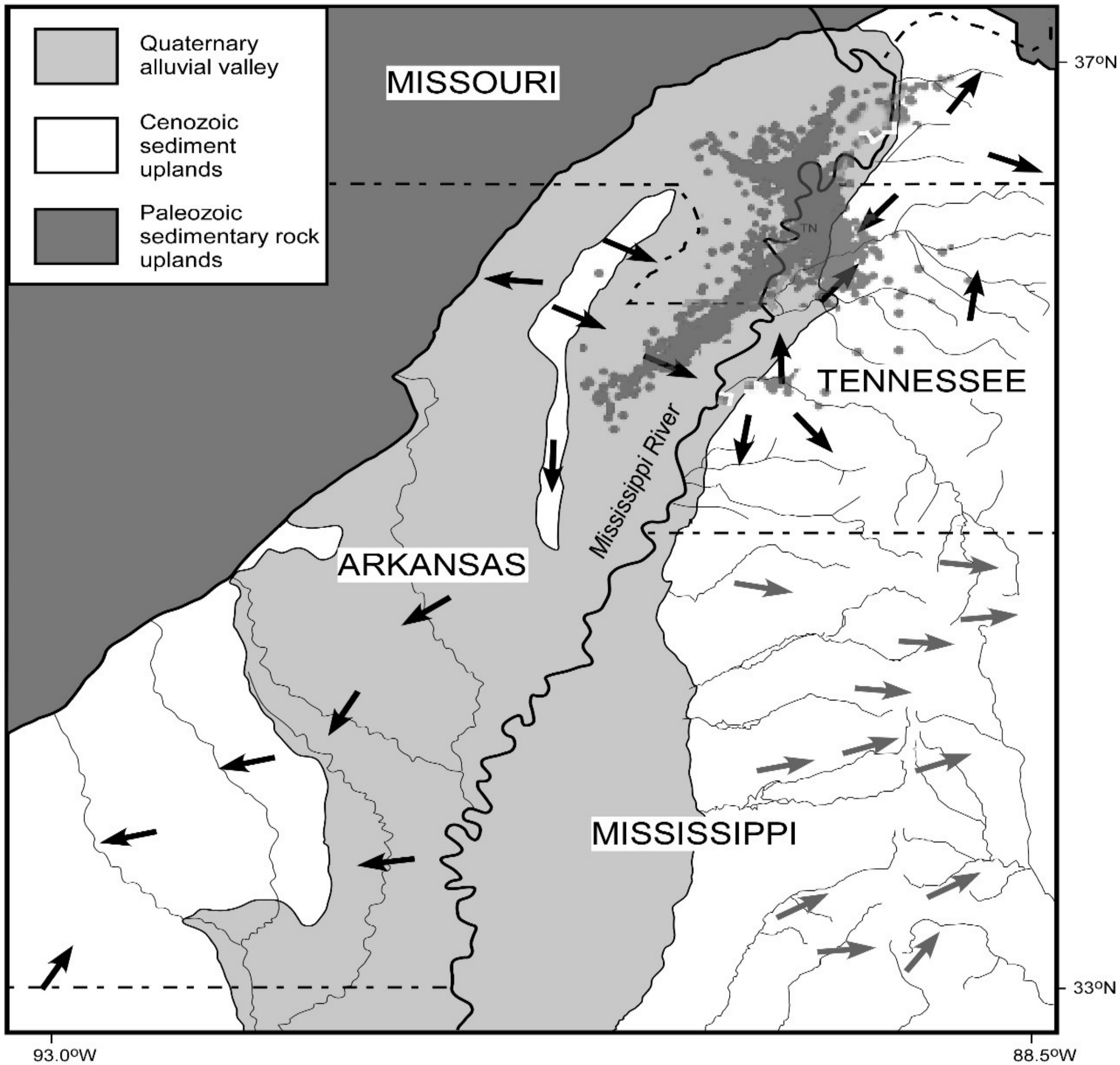
Terrace ages diminish away from Crowley's Ridge

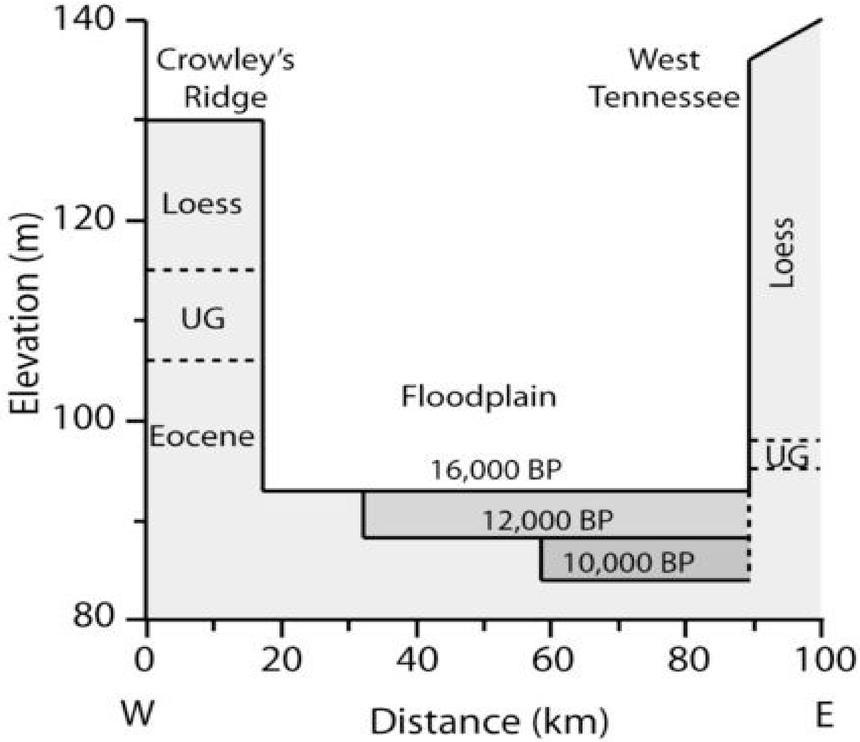


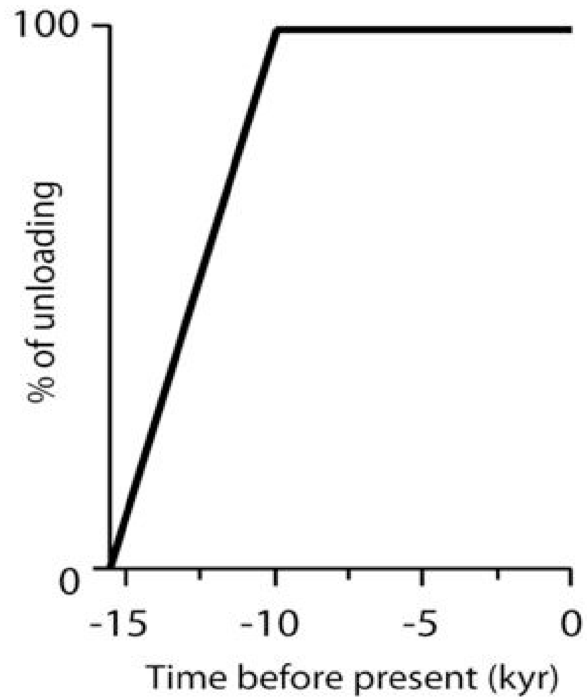
Planar trend surface of the base of the Pliocene (3.2 Ma) Mississippi River floodplain (Upland Complex) in western KY and TN and Crowley's Ridge, AR.

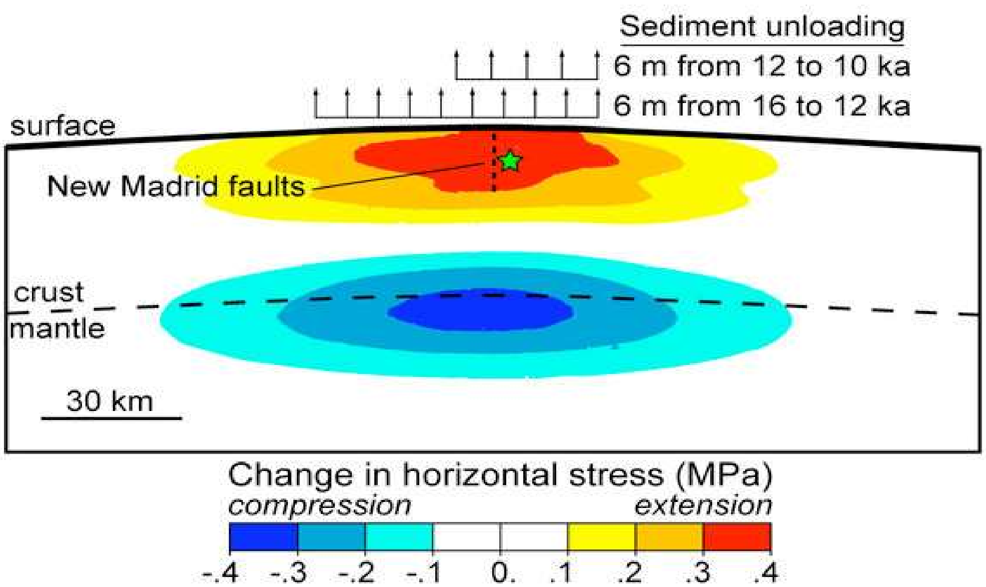


Quaternary stream migrations. Arrows denote averaged migration directions. Gray dots denote New Madrid seismic zone epicenters



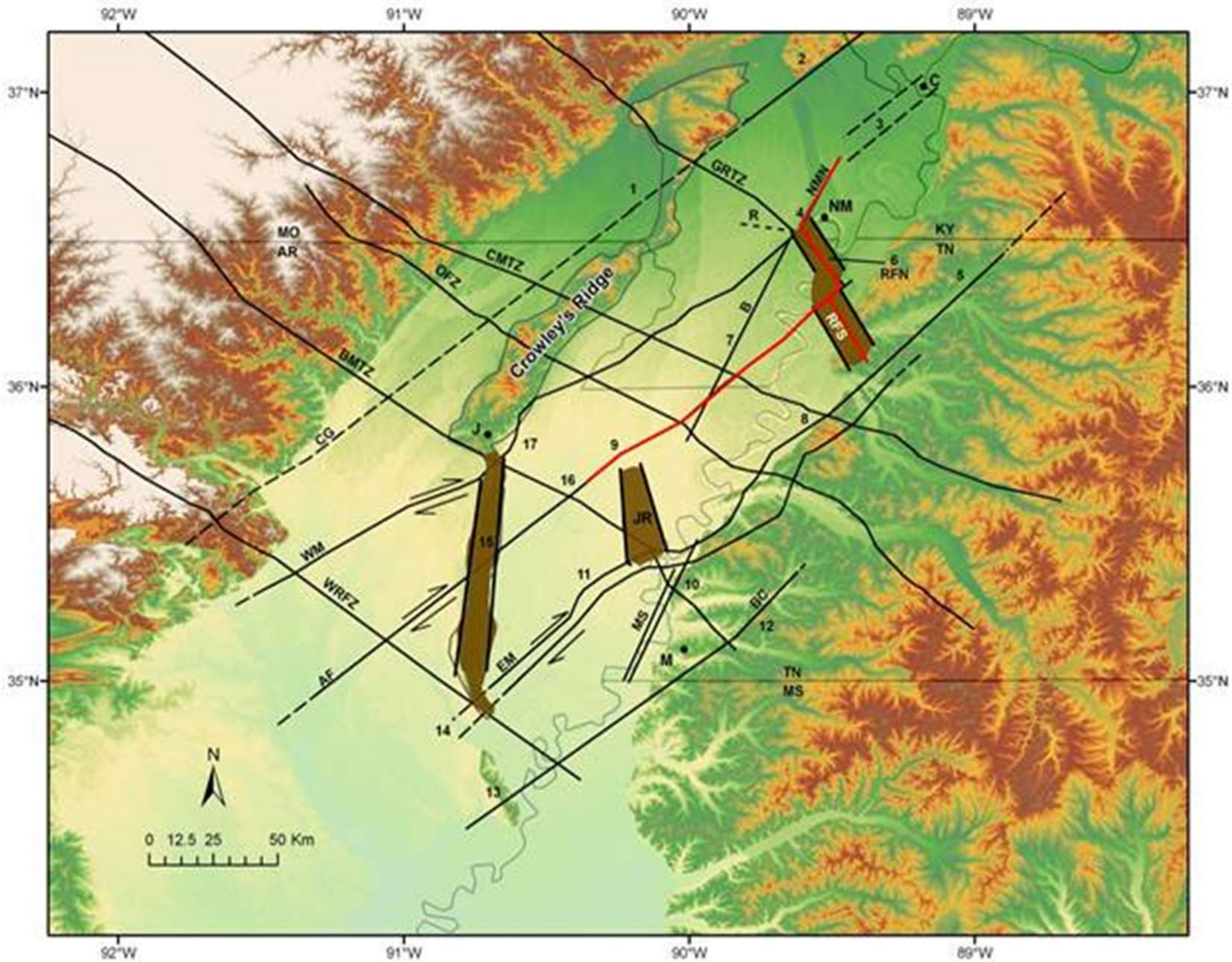




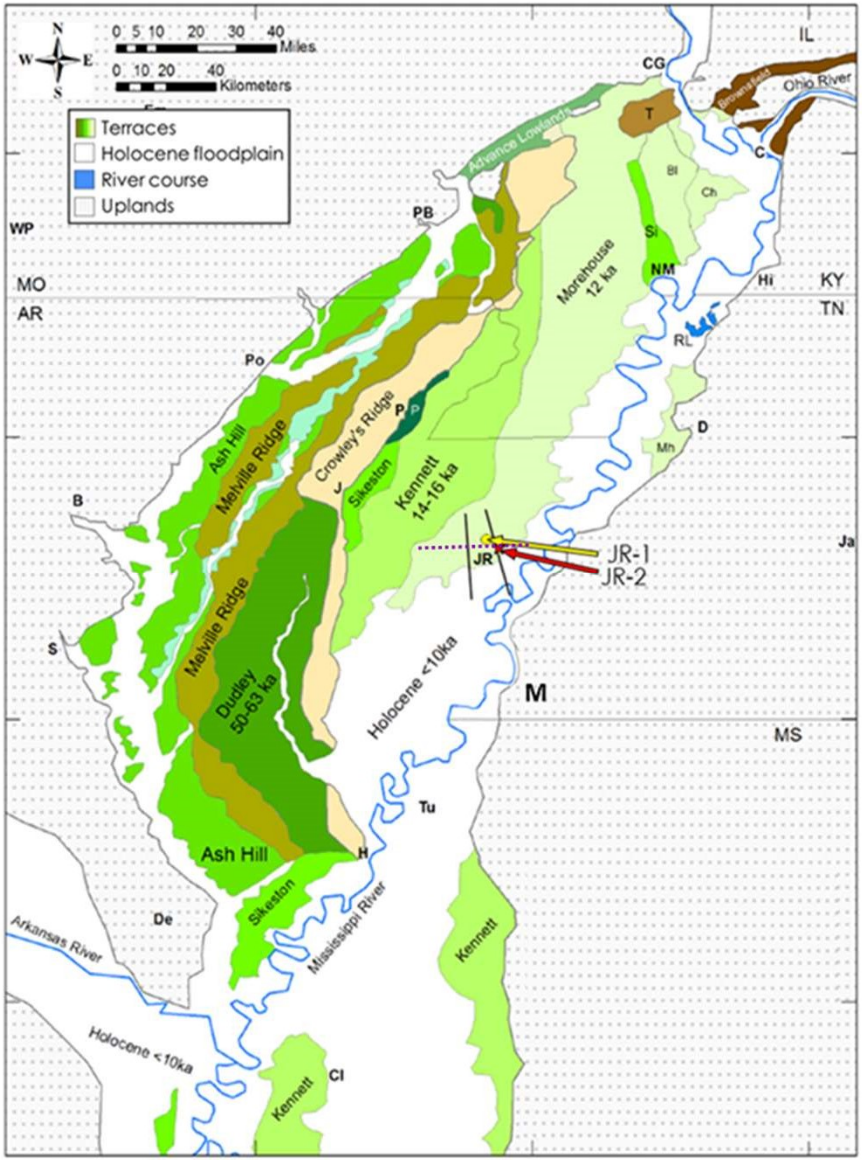


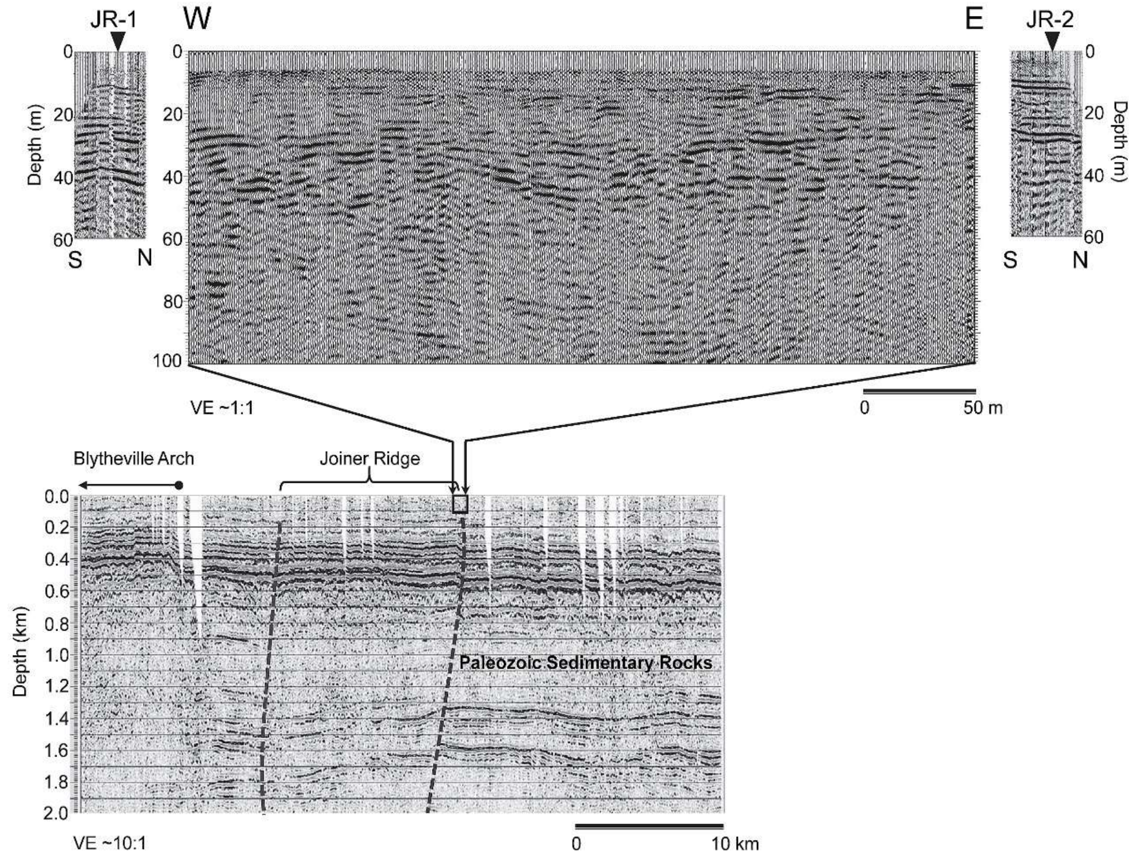
Calais et al argue that Mississippi River incision during the late Wisconsin would have reduced the horizontal compression across the NE trending Reelfoot Rift faults thereby activating them in the Holocene. I now think there was 30 m of denudation within the last 20 ka.

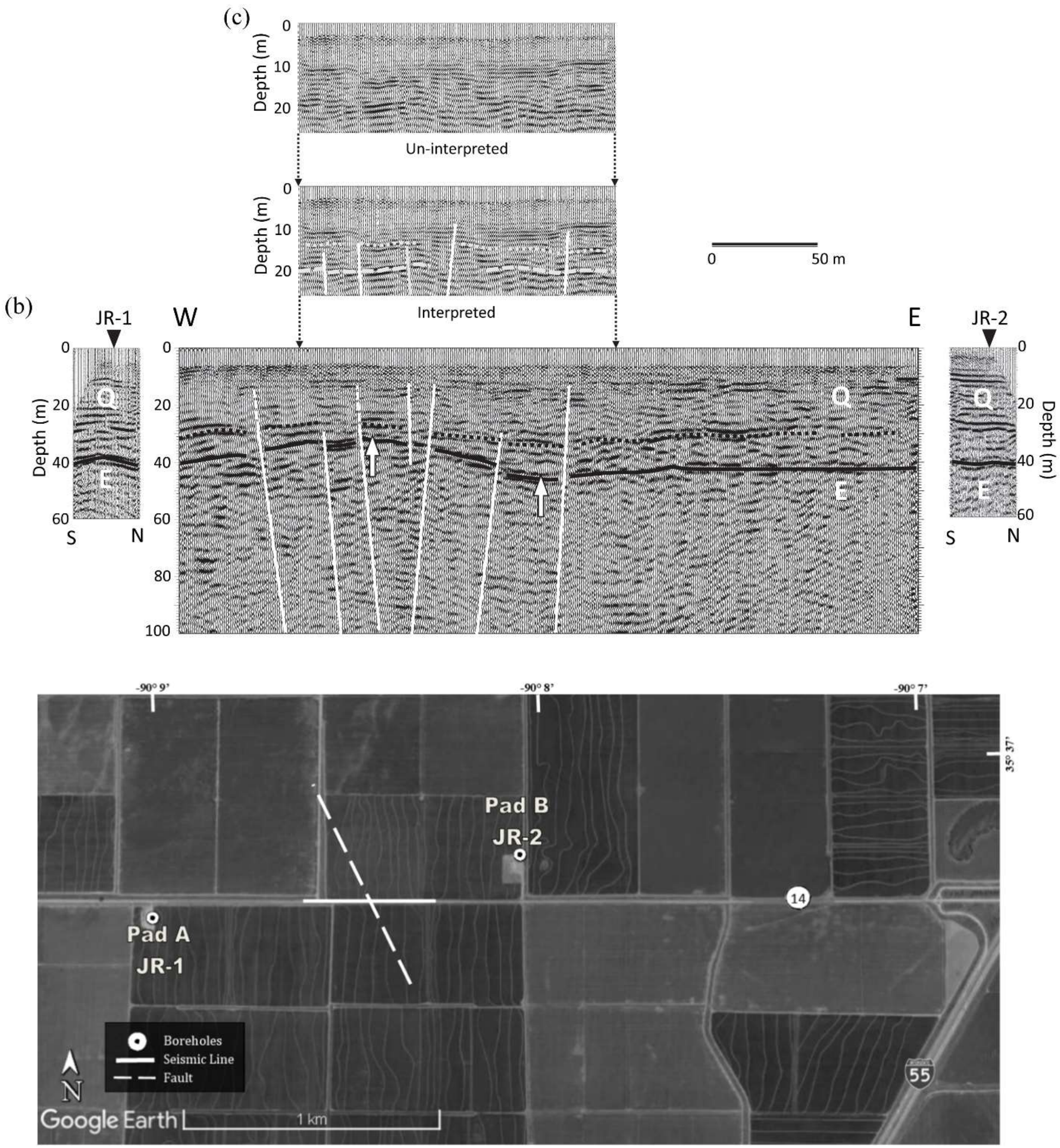
Published sites of Quaternary Faulting and/or Liquefaction

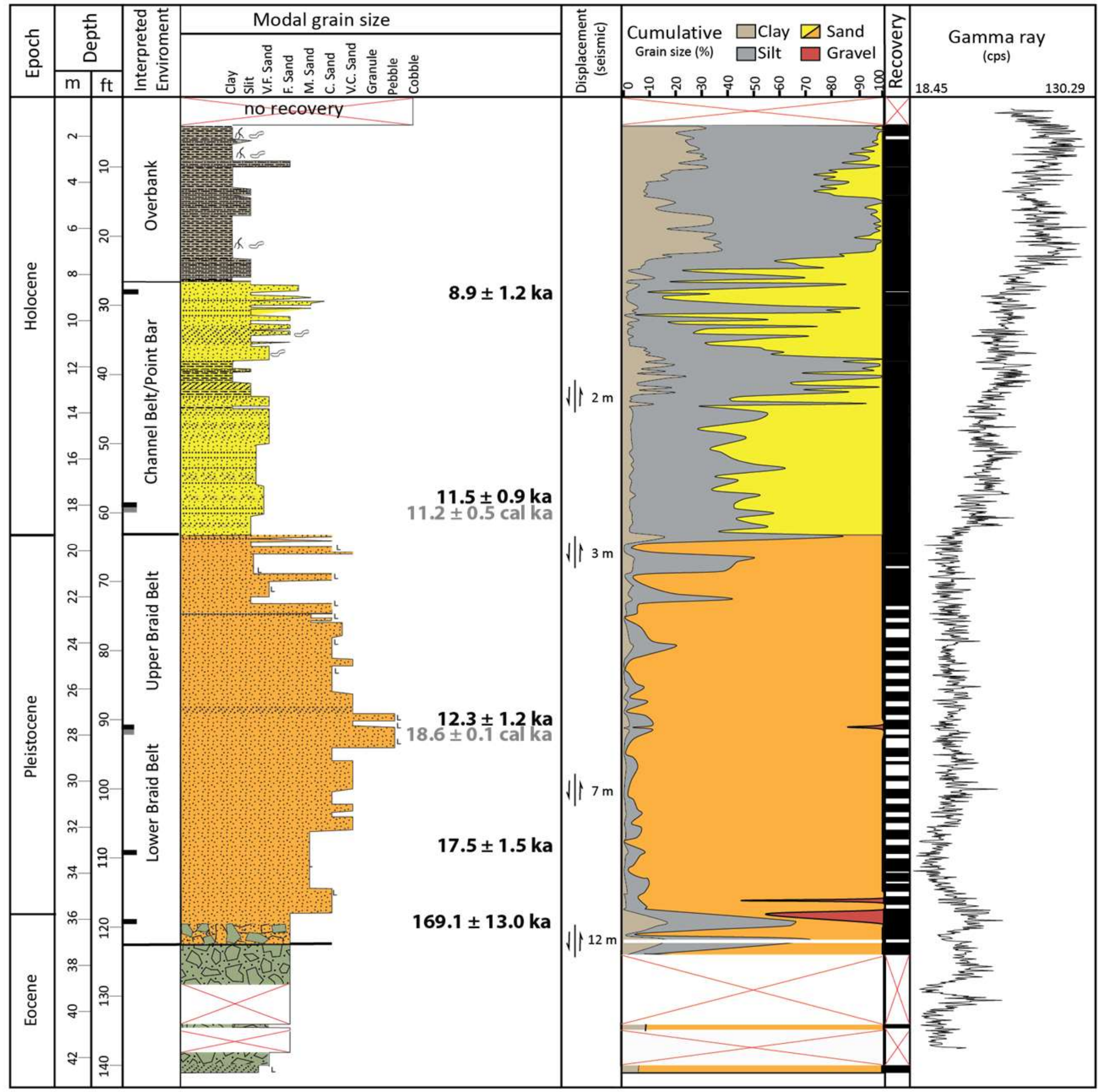


Joiner Ridge faulting (current SRL)

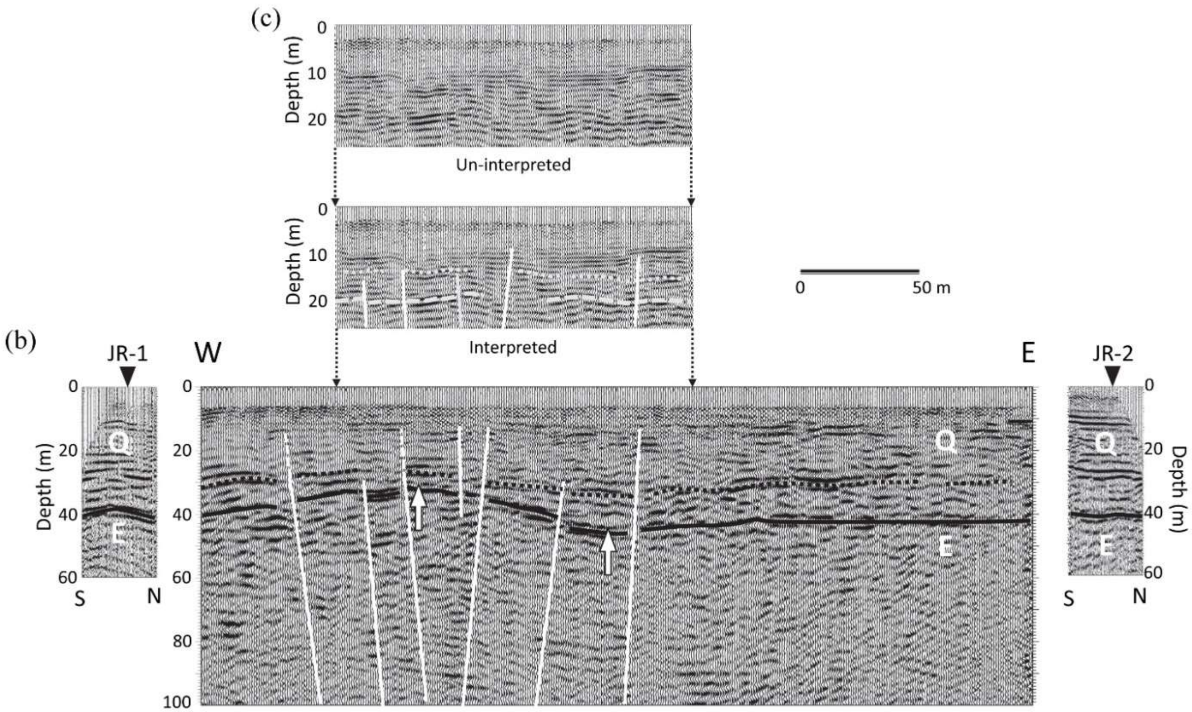




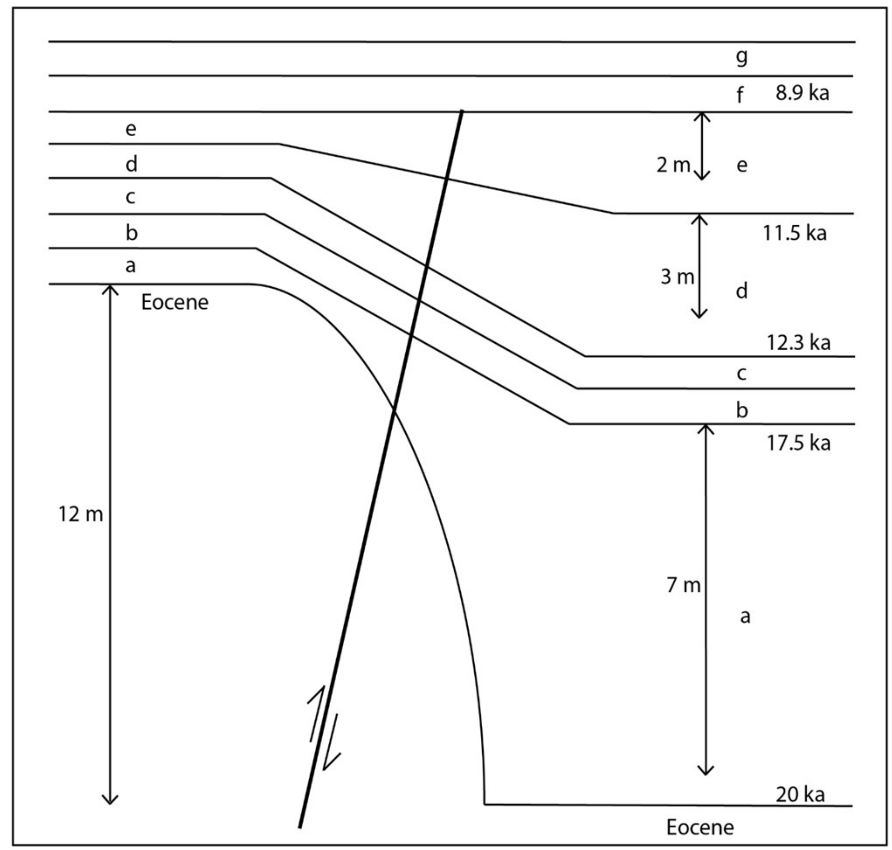

(c)
Depth (m)
Un-interpreted
Interpreted
0
50 m
(b)
JR-1
JR-2
W
E
Q
E
Depth (m)
S
N
-90° 9'
-90° 8'
-90° 7'
35° 37'
Pad B
JR-2
Pad A
JR-1
14
55
Boreholes
Seismic Line
Fault
N
Google Earth
1 km



Epoch
Depth
m
ft
Interpreted Enviroment
Modal grain size
Clay
Silt
V.F. Sand
F. Sand
M. Sand
C. Sand
V.C. Sand
Granule
Pebble
Cobble
Displacement (seismic)
Cumulative
Grain size (%)
Clay
Silt
Sand
Gravel
Recovery
Gamma ray
(cps)
18.45
130.29
no recovery
Holocene
Pleistocene
Eocene
Overbank
Channel Belt/Point Bar
Upper Braid Belt
Lower Braid Belt
8.9 ± 1.2 ka
11.5 ± 0.9 ka
11.2 ± 0.5 cal ka
12.3 ± 1.2 ka
18.6 ± 0.1 cal ka
17.5 ± 1.5 ka
169.1 ± 13.0 ka
2 m
3 m
7 m
12 m

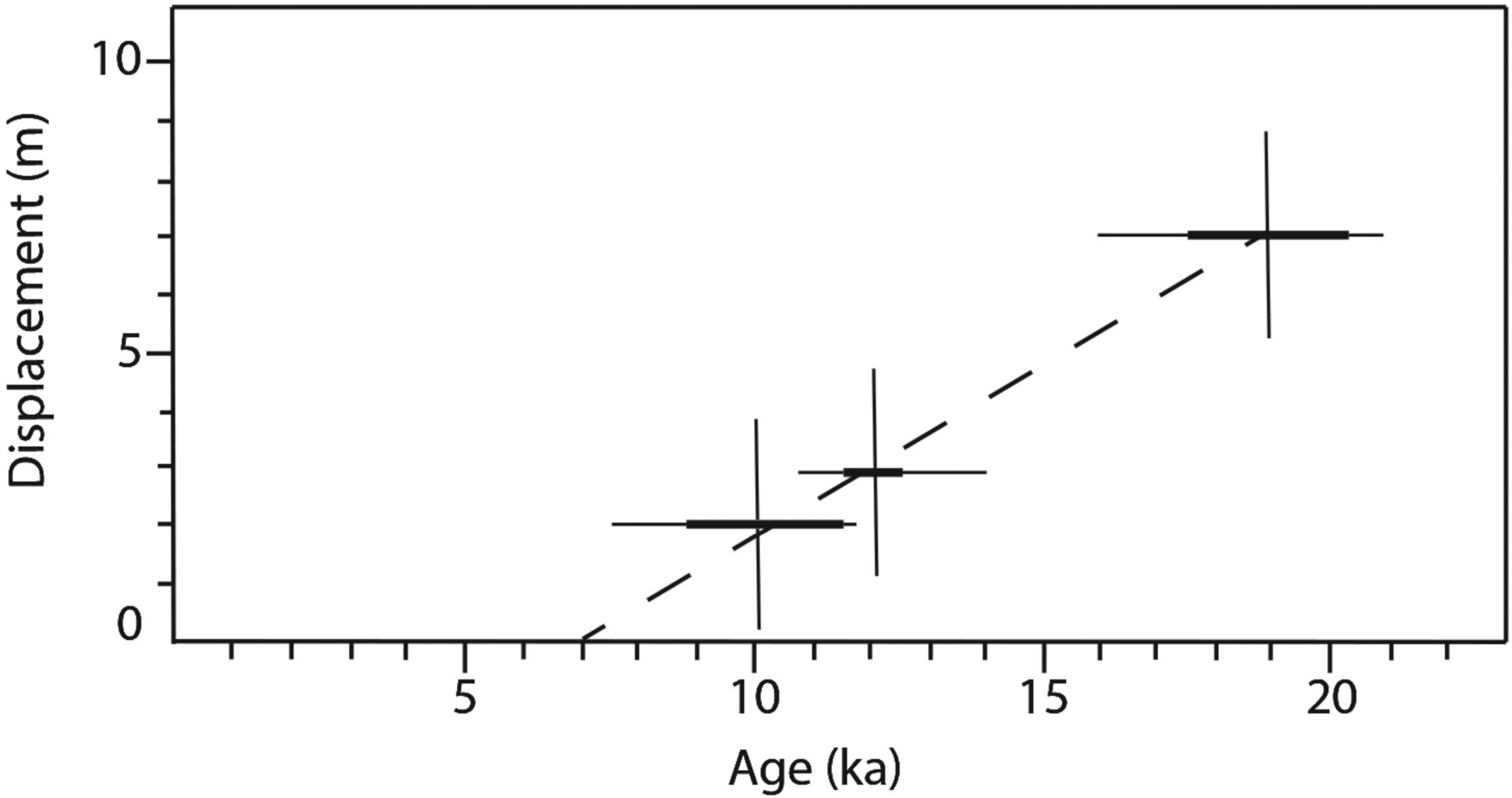


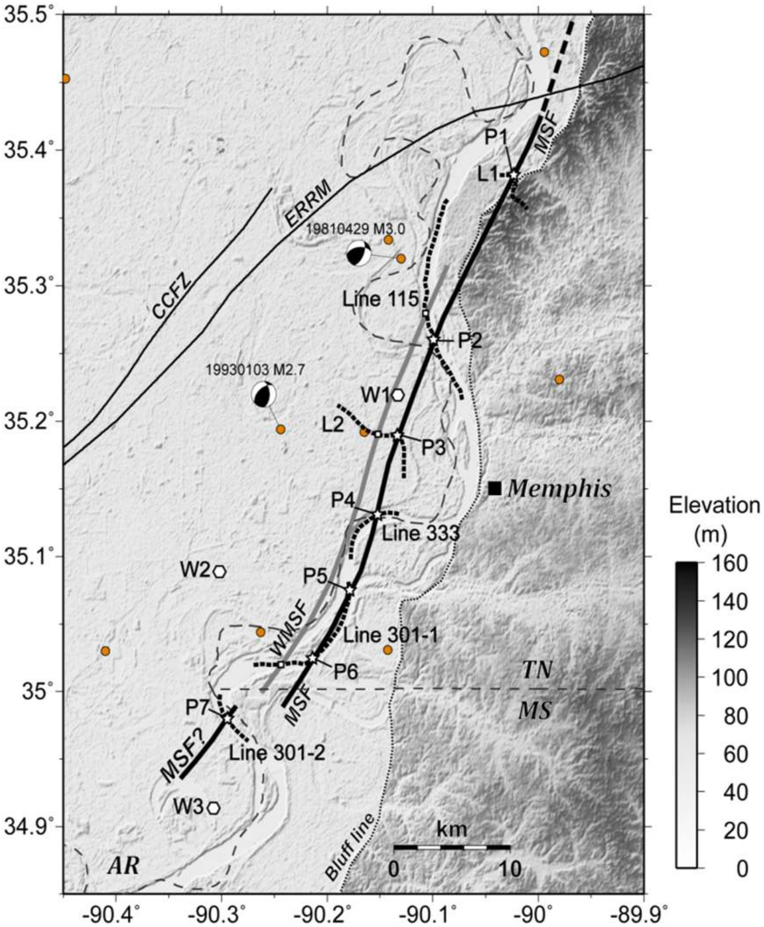
(c)
Depth (m)
0
10
20
Un-interpreted
Interpreted
0
50 m
(b)
JR-1
W
E
JR-2
Q
E
S
N
Depth (m)
20
40
60
80
100



g
f
8.9 ka
e
2 m
11.5 ka
d
3 m
12.3 ka
c
b
17.5 ka
a
Eocene
12 m
7 m
20 ka
Eocene

Joiner Ridge faulting started ~ 19 ka and ceased ~ 7 ka.





Coring through the Mississippi River alluvium to collect samples for OSL dating and age determination of the alluvium. Project objective is to document Quaternary displacement history on the Meeman-Shelby fault.

Figures in this presentation by Roy Van Arsdale are from the following publications.

Cox, R.T. and Van Arsdale, R.B., 2002, The Mississippi Embayment, North America: a first order continental structure generated by the Cretaceous superplume mantle event. Journal of Geodynamics, v. 34, p. 163-176.

Parrish, S., and Van Arsdale, R., 2004, Faulting along the southeastern margin of the Reelfoot rift in northwestern Tennessee revealed in deep seismic reflection profiles. Seismological Research Letters, v. 75, p. 782-791.

Van Arsdale, R., and Cox, R., 2007, The Mississippi's Curious origins. Scientific American, v. 296, n. 1, p. 76-82.

Van Arsdale, R.B., Bresnahan, R.P., McCallister, N.S., and Waldron, B., 2007, The Upland Complex of the central Mississippi River valley: its origin, denudation, and possible role in reactivation of the New Madrid seismic zone. In Continental Intraplate Earthquakes: Science, Hazard, and Policy Issues, S. Stein and S. Mazzotti (eds.), Geological Society of America Special Paper 425, p. 177-192.

Csontos, R., Van Arsdale, R., Cox, R., and Waldron, B., 2008, The Reelfoot Rift and its impact on Quaternary deformation in the central Mississippi River Valley. Geosphere, v. 4, n. 1, p. 145-158.

Csontos, R., and Van Arsdale, R., 2008, New Madrid seismic zone fault geometry. Geosphere, v. 4, p. 802-813.

Calais, E., Freed, A.M., Van Arsdale, R., and Stein, S., 2010, Triggering of New Madrid seismicity by late-Pleistocene erosion. Nature, v. 466, p. 608-611.

Van Arsdale, R., and Cupples, W., 2013, Late Pliocene and Quaternary deformation of the Reelfoot rift. Geosphere, v. 9, n. 6, p.p1819–1831.

Van Arsdale, R., Cupples, W., and Csontos, R., 2014, Pleistocene–Holocene transition in the central Mississippi River valley. Geomorphology, v. 214c, p. 270-282.

Cox, R.T., Lumsden, D.N., and Van Arsdale, R.B., 2014, Possible relict meanders of the Pliocene Mississippi River and their implications. Journal of Geology, v. 122, p. 609-622.

VanArsdale, R.B., Cox, R.T., and Lumsden, D.N., 2019, Quaternary Isostatic Uplift in the Northern Mississippi Embayment, Journal of Geology, v. 127, no. 1, p. 1-13.

Price, A.C., Woolery, E.W., Counts, R.C., Van Arsdale, R.B., Larsen, D., Mahan, S.A., and Beck, E.G., 2019, Quaternary Displacement on the Joiner Ridge Fault, Eastern Arkansas. Seismological Research Letters, v. 90, n. 6, p. 2250-2261.

PALEOLIQUEFACTION TRENCHING INVESTIGATION USING SCANNING TOTAL STATION RESULTS

Jamie Evans, PE
Geotech RTS, MVM

17 June 2020

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US Army Corps of Engineers®

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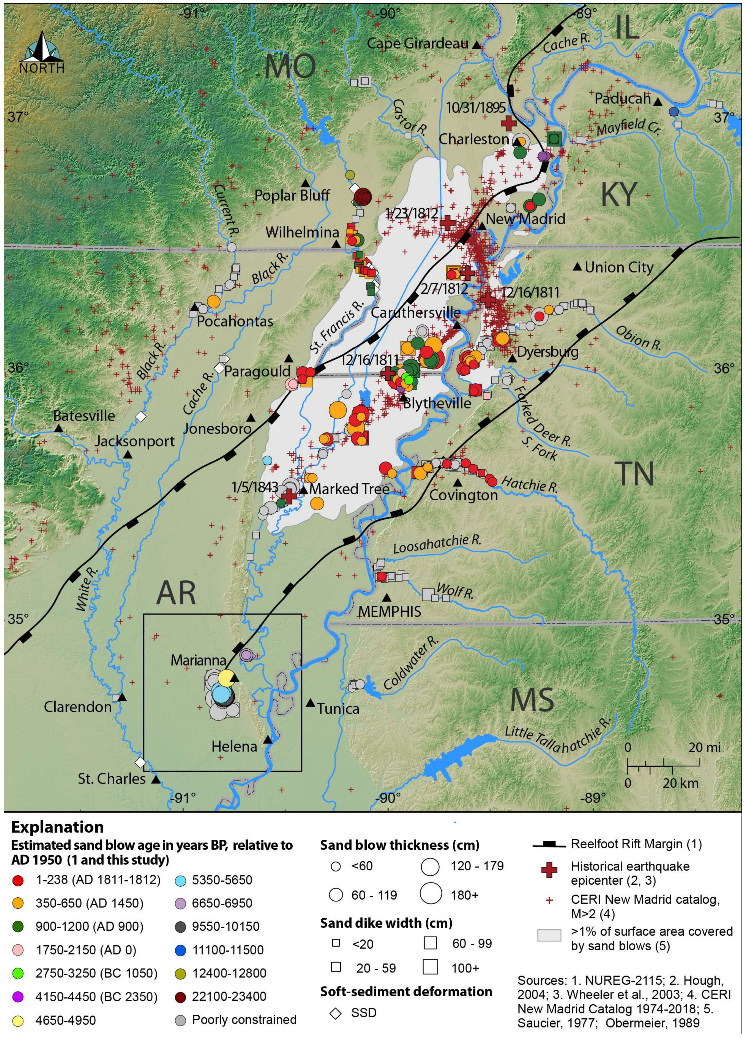
INTRODUCTION

- The Memphis District Geotech Branch has collaboration on several liquefaction related research projects in Arkansas in recent years with the Arkansas Geological Survey (AGS).
- Over the last decade, the AGS has funded and overseen the excavations of several paleoliquefaction trenches near Marianna, Arkansas (southwest of Memphis) in conjunction with the University of Arkansas-Little Rock.
- The Memphis District had recently procured a Trimble SX10 scanning total station, and we were interested in utilizing its capabilities in various ways beyond general surveys.
- In order to experiment with the capability of the SX10, we offered our survey services to scan the trench wall with the intent of providing a 3D high resolution image with associated survey as a potential means of replacing or minimizing manual logging of the trench stratigraphy.
- We performed preliminary field testing on 05Nov2019 for two trenches that had been previously excavated.

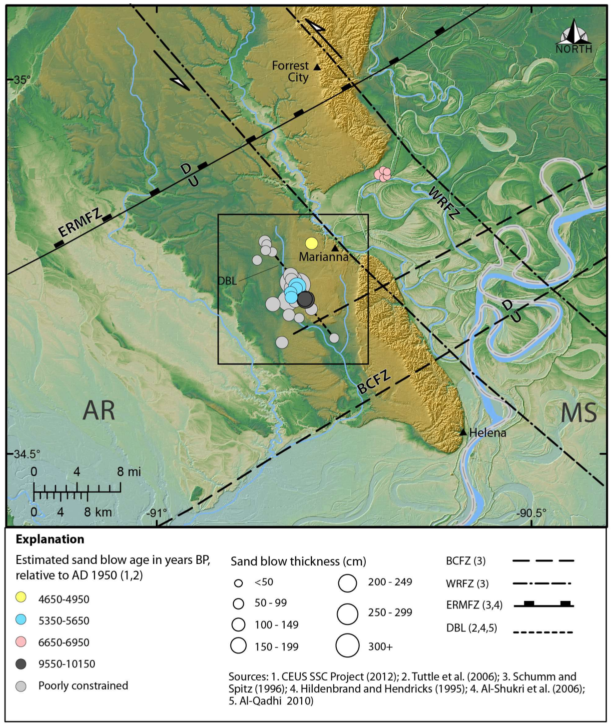
GENERAL SEISMIC SETTING

- Wide spread liquefaction features are prevalent throughout the New Madrid Seismic Zone (NMSZ) predominately located in southeast Missouri, northeast Arkansas, and northwest Tennessee. The extent of these features generally ranges from approximately New Madrid, Missouri to Marked Tree, Arkansas.
- These liquefaction features are generally concentrated along the areas associated with faulting in the NMSZ as defined by recorded and historical seismic events.
- Most of the NMSZ liquefaction features have been dated to be associated with earthquakes that have occurred within the last 2,000 years at intervals of about 500 years.
- Multiple liquefaction features have also been discovered in the Marianna, Arkansas area, which are more than 100 km from the majority of liquefaction features in the currently active portions of the NMSZ.

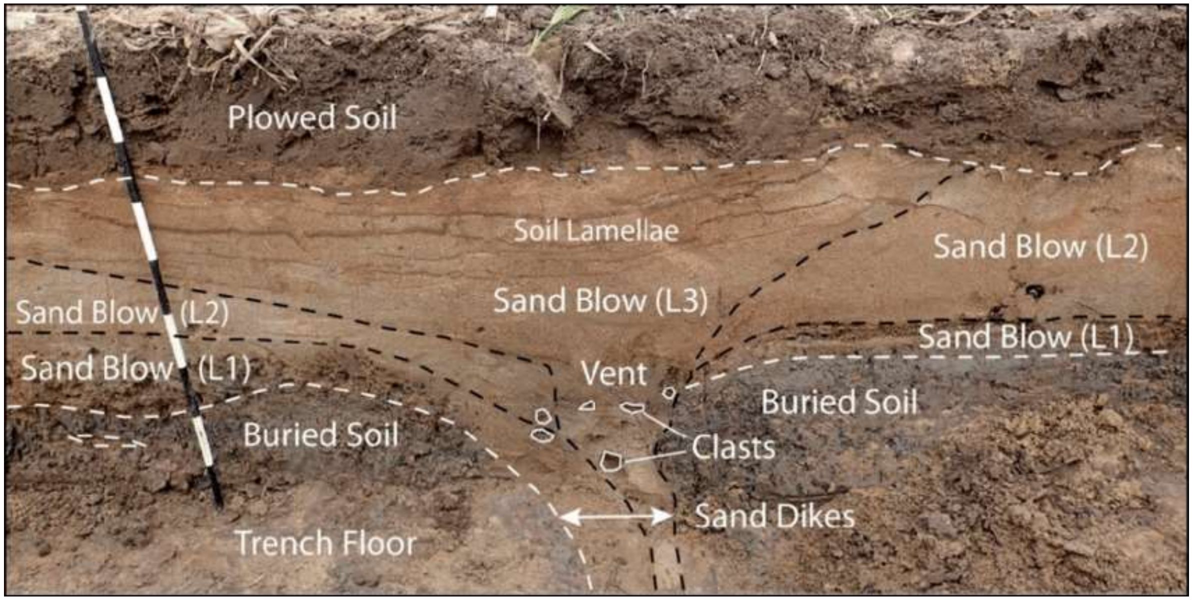


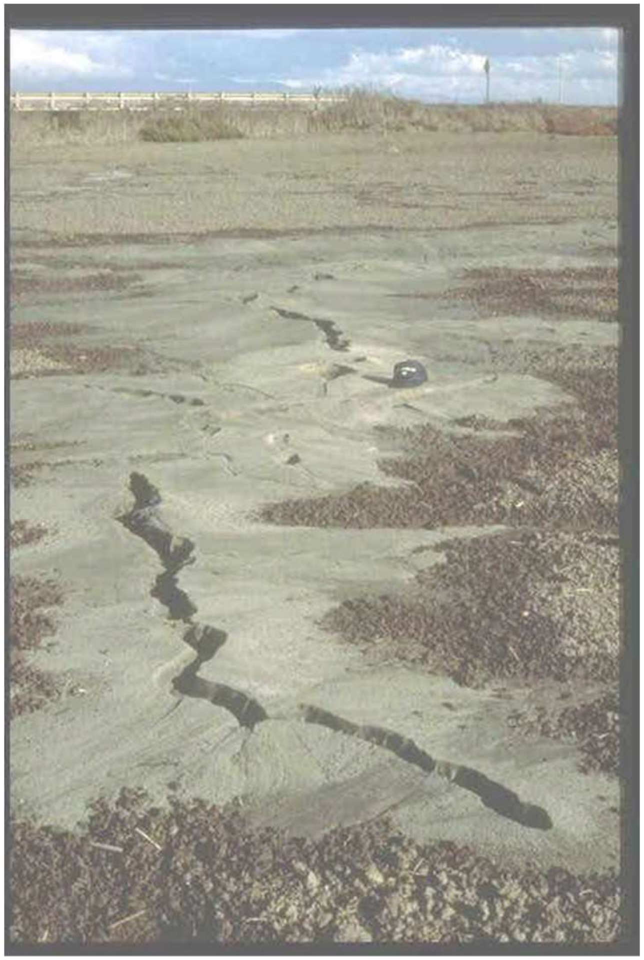
LOCAL SEISMIC SETTING

- The AGS team has been evaluating these Marianna liquefaction features using archeological surveys, geophysical surveys, and paleoliquefaction trenching with the intent of assessing the source, magnitude, and generalized recurrence interval of the seismic events which generated these liquefaction features.
- The liquefaction features were initially identified using aerial photos looking for areas of sand deposits (generally areas where crops will not grow).The team has identified a generally northwest trending linear alignment of liquefaction features covering approximately 4 km.
- Dating from these features suggest the earthquakes that generated the features are prehistoric and date from approximately 5,000 to 41,000 years ago.
- Seismic reflection testing of the soft sediment faulting indicates the presence of a fault seismic source along the identified alignment of the liquefaction features, known as the Daytona Beach Lineament (DBL). It is currently postulated that this fault is inactive.
- Many of the liquefaction features are similar in size to those in the NMSZ (600m x 450m x 2.5m). This indicates very strong ground shaking. The moment magnitude of the seismic events that caused these features has been estimated to be in the range of 6 to 7 (similar to NMSZ events) occurring along the DBL feature.



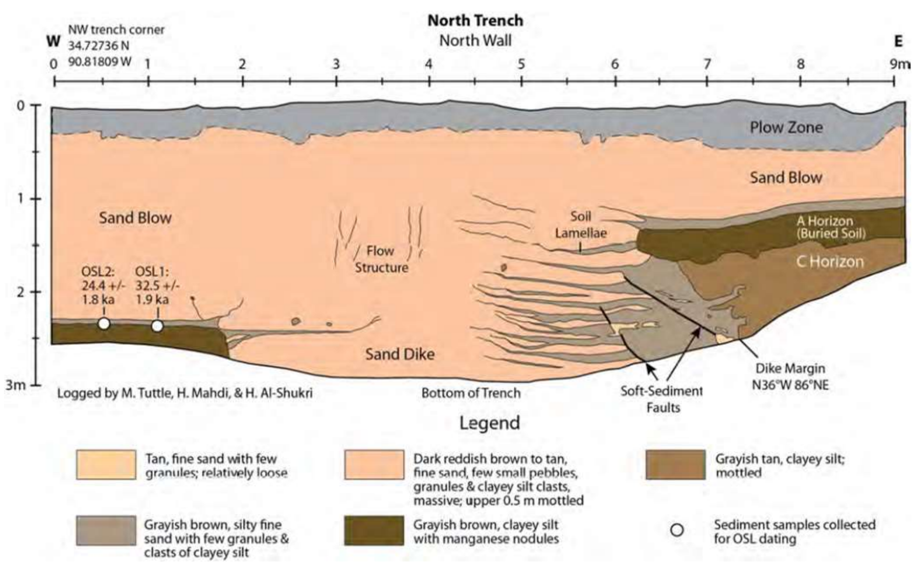
LIQUEFACTION FEATURE - SAND BLOW





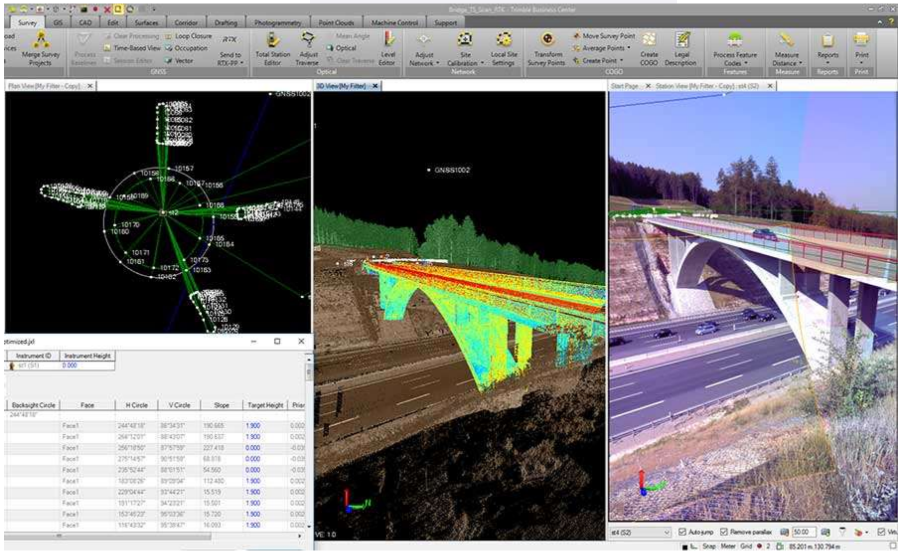
PALEOLIQUEFACTION TRENCHING

- Initial field work consisted of a GPR survey to locate the trench such that the sand dike was exposed in the trench.
- The trenches were then excavated (~4-6 ft) with vertical sides and the walls stabilized as necessary. The excavation walls were troweled smooth and then mapped by hand using graph paper and colored pencils.



SX10 SCANNING TOTAL STATION

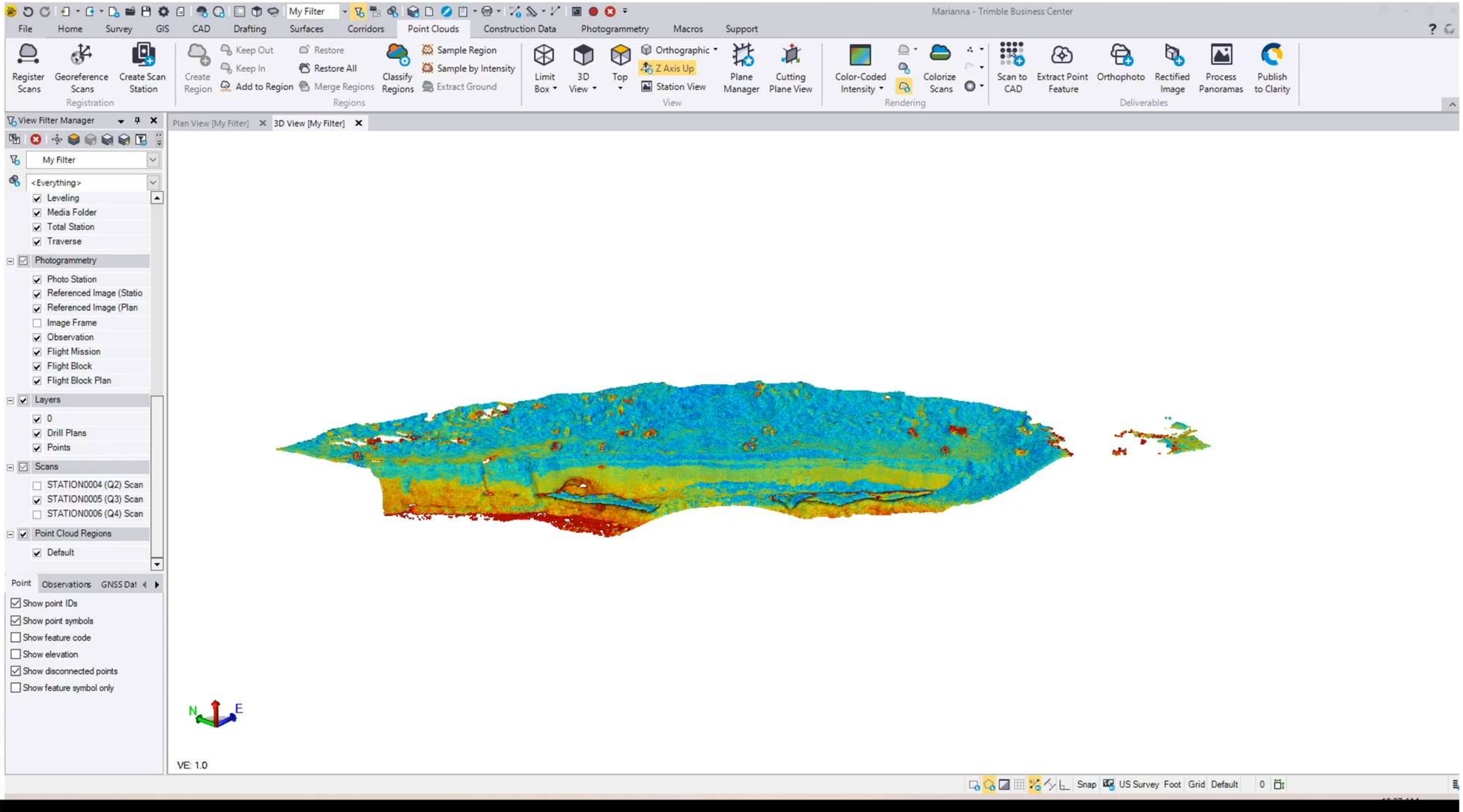
- The scanning total station combines surveying, imaging, and high speed 3D scanning for the defined area of interest.
  - A suite of high resolution still photos is taken which are geo-referenced in order to generate a complete photograph of the survey area.
  - A multi-beam laser survey is conducted for the survey area.
- The survey and imagery are processed together to produce a 3D image of the survey area.
- The intensity of the return multi-beam scan is also recorded for evaluating the survey data.



SX10 FIELD WORK

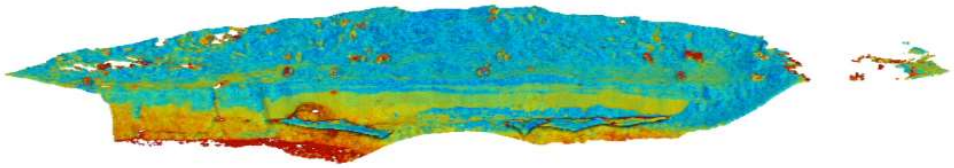
- One scan was performed for each trench.
- The total station was setup near the top of the trench and only one wall of the trench was scanned.
- Nails were inserted into the trench wall at boundaries between different soil layers.
- Each scan took approximately 20 minutes to complete.

SCANNING TOTAL STATION RESULTS

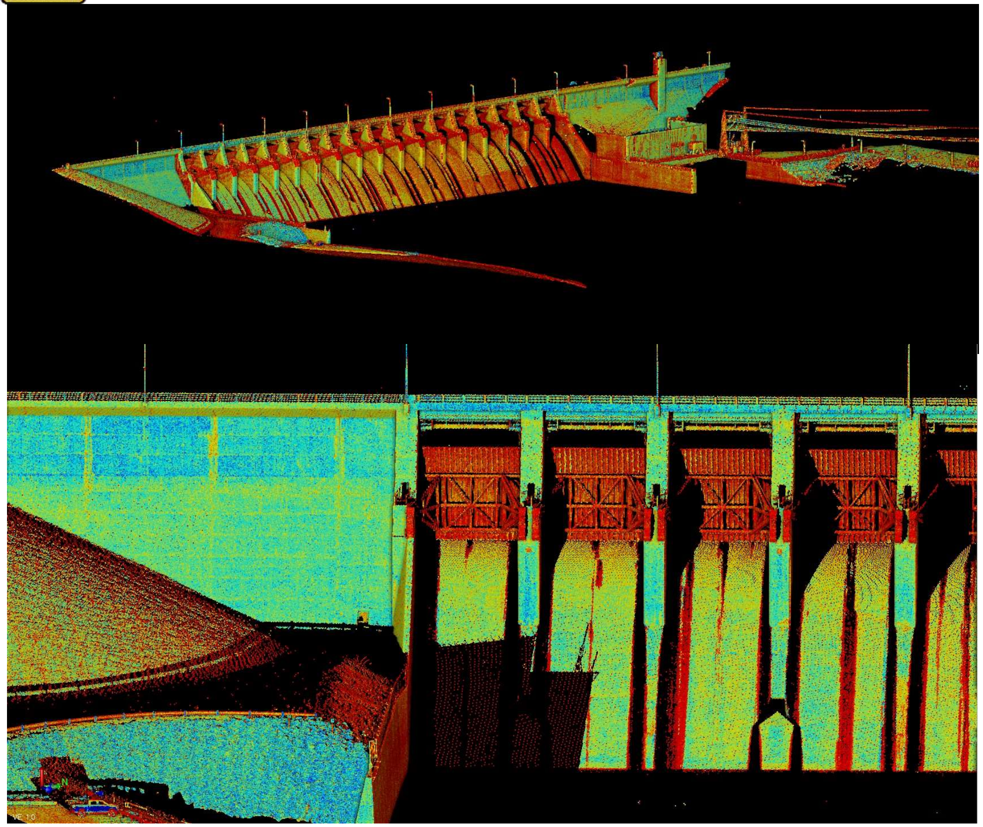


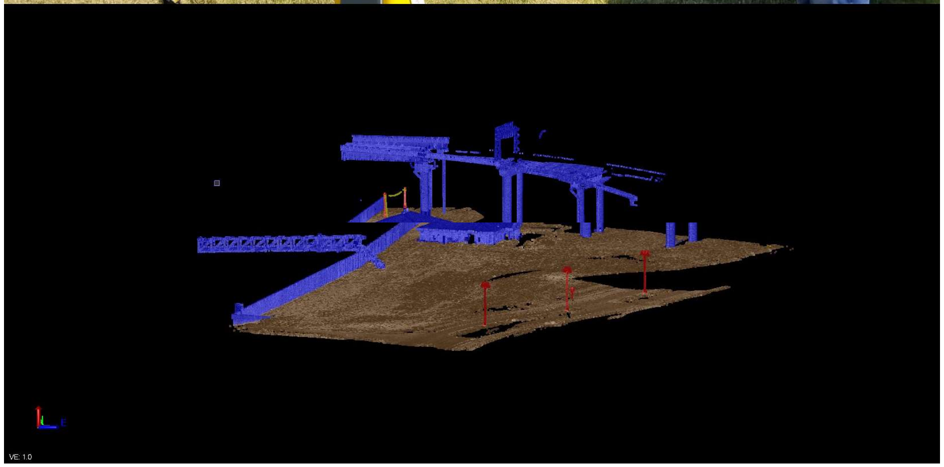
RESULTS/CONCLUSIONS

- This method provides high quality imaging and survey data in a very short timeframe, which is a benefit where conditions make the trench unstable.
- The original intent was to provide a survey quality, high resolution geo-referenced 3D image of the trench; however, the intensity image also provided valuable information to help distinguish soil layers.
- More testing is needed to determine the relationship between return intensity, soil type, and moisture content.
- Multiple scans per trench would eliminate ‘shadows’ in the data.
- These results were well received by the trenching team.
- This methodology has other geotechnical/geophysical applications including post failure investigation, possible surficial seepage mapping of embankment, test pit logging, inspection of completed works, etc.



OTHER SX10 PROJECT EXAMPLES





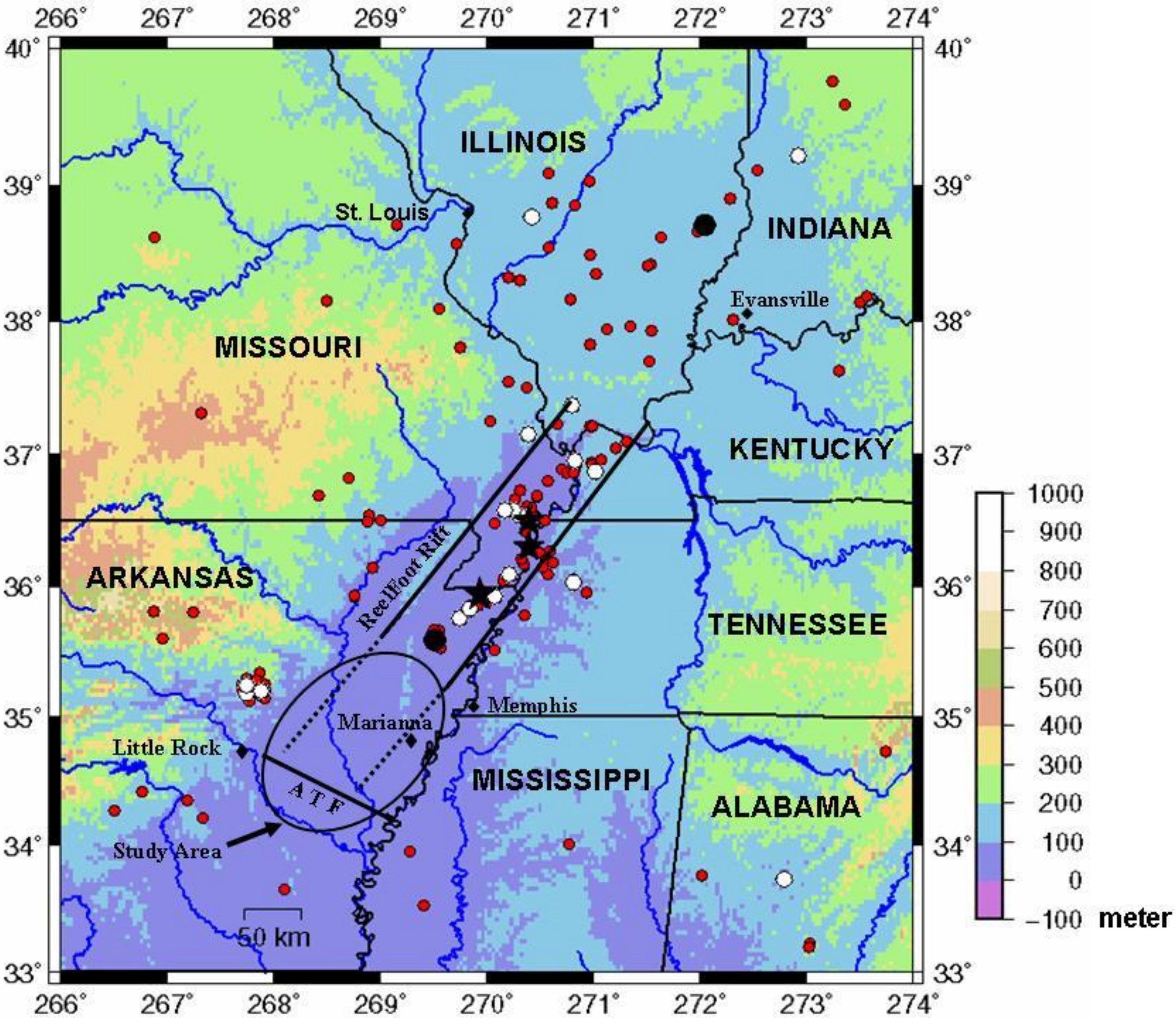
Earthquake Feature Recognition Ground Penetrating Radar

Haydar Al-Shukri, Rauf Hussein, Hanan Mahdi, and Martitia Tuttle

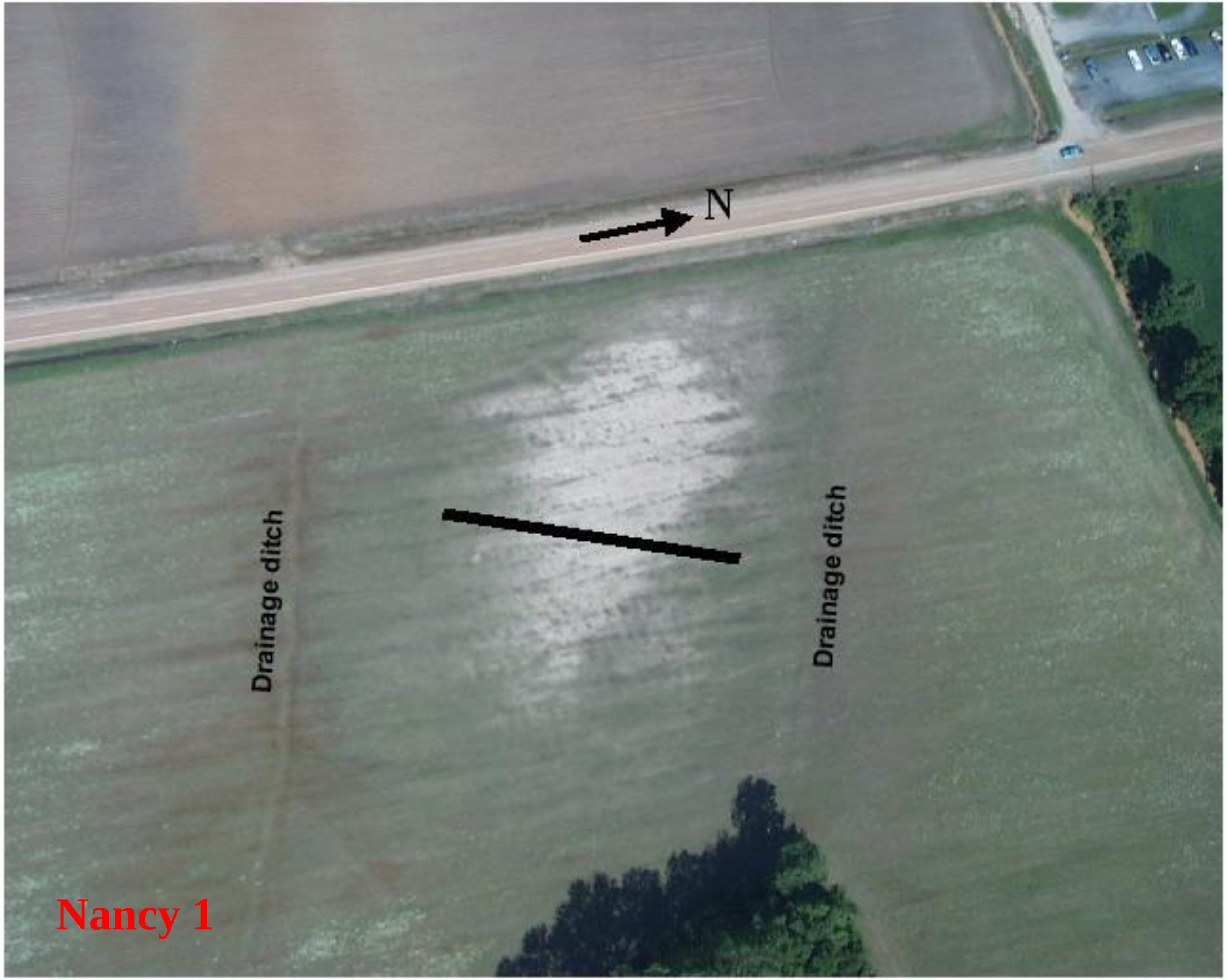
AGS Training Workshop

Forrest City, AR

November 6, 2019



266° 267° 268° 269° 270° 271° 272° 273° 274°
40° 39° 38° 37° 36° 35° 34° 33°
ILLINOIS
INDIANA
MISSOURI
KENTUCKY
ARKANSAS
TENNESSEE
MISSISSIPPI
ALABAMA
St. Louis
Evansville
Memphis
Marianna
Little Rock
Reelfoot Rift
A T F
Study Area
50 km
1000 900 800 700 600 500 400 300 200 100 0 −100 meter


N
Drainage ditch
Drainage ditch
Nancy 1

Typical Sand Blow in the Study Area

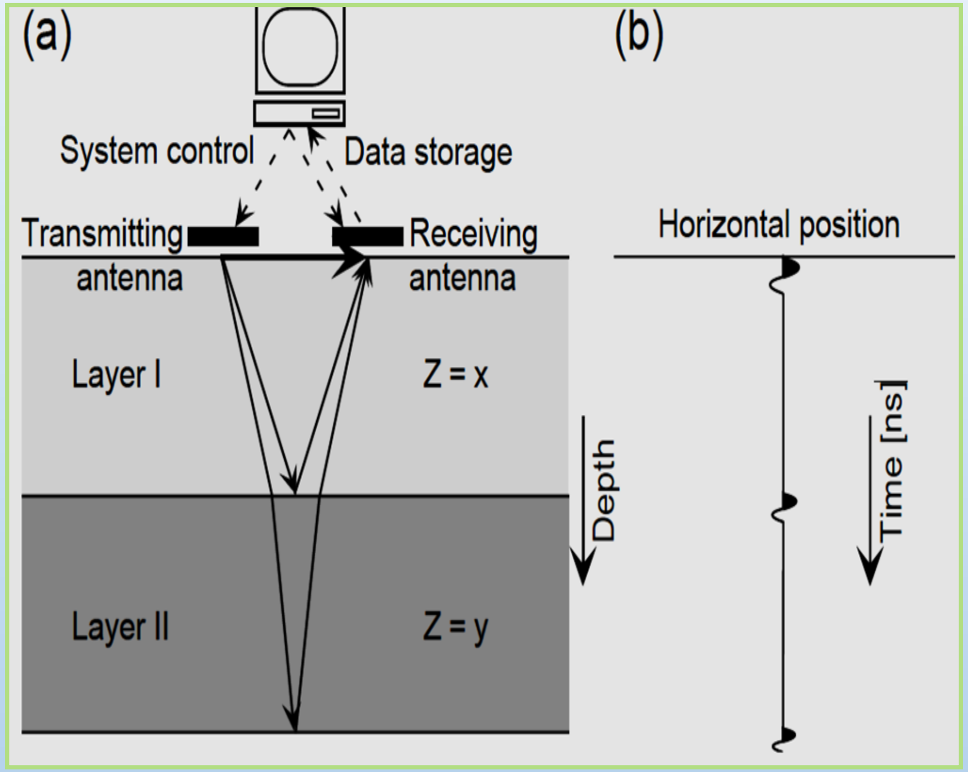
Ground Penetrating Radar

- **Ground Penetrating Radar (GPR) is a geophysical tool used to investigate the subsurface through 2-D and 3-D high-resolution images**

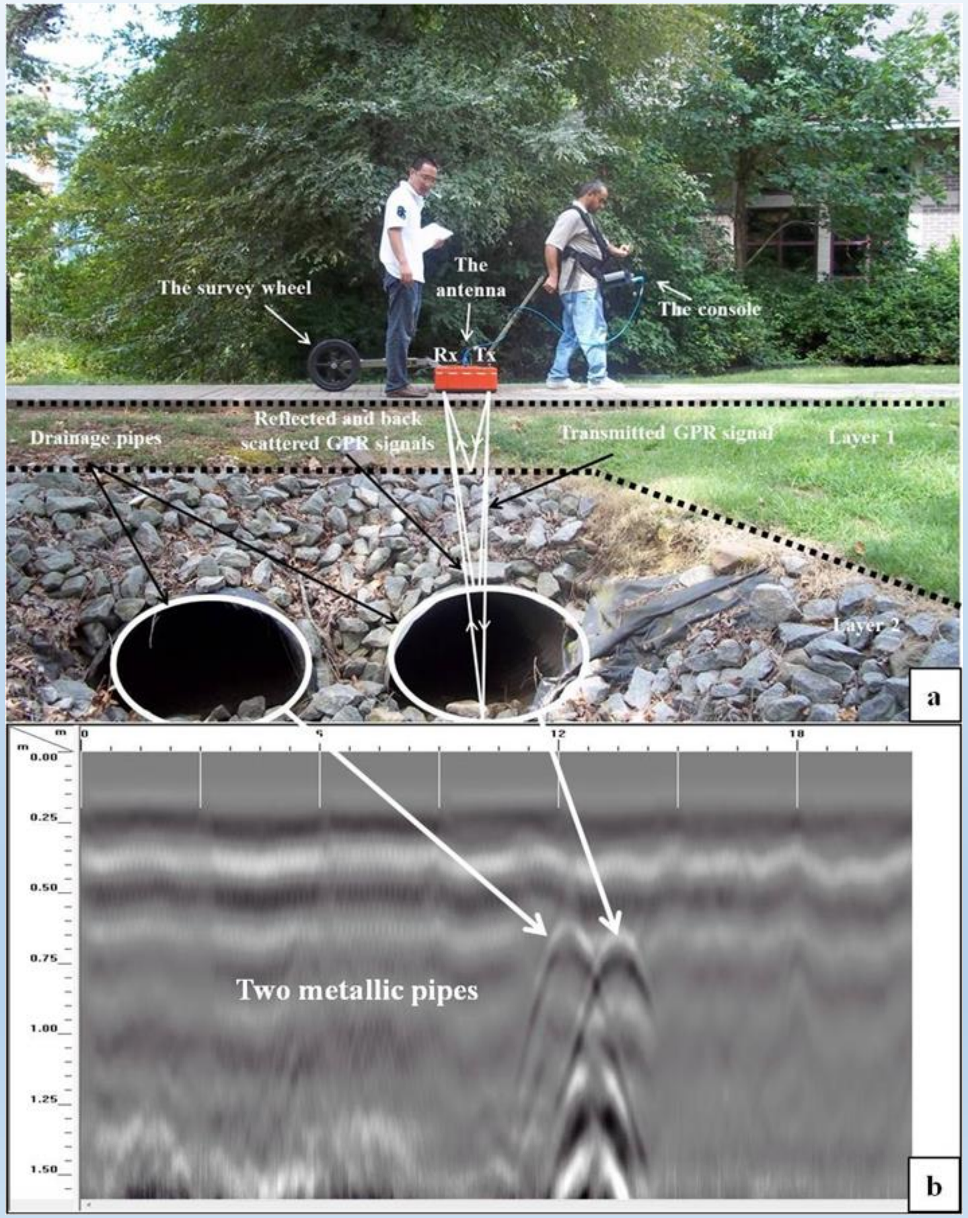
Applications of GPR:

- **Hydrology**
- **Archaeological applications**
- **Highways and road investigations**
- **Geological applications**
- **Environmental applications**
- **Engineering and geotechnical applications**
- **Soil investigation**

GROUND PENETRATING RADAR "GPR"



Van Dam and Schlager, 2000



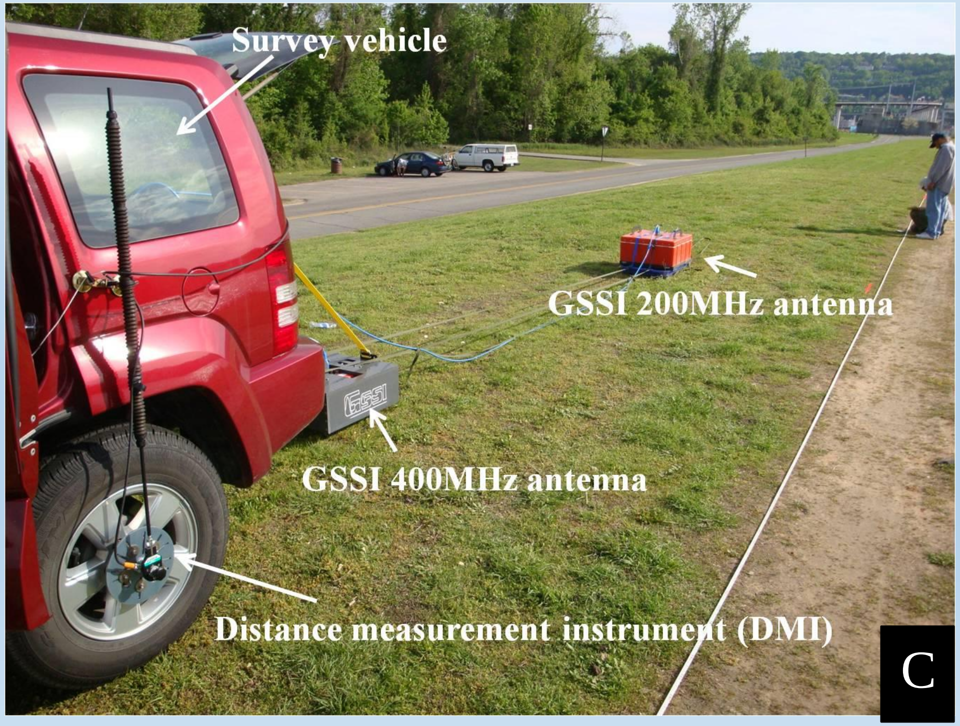
Ground Penetrating Radar

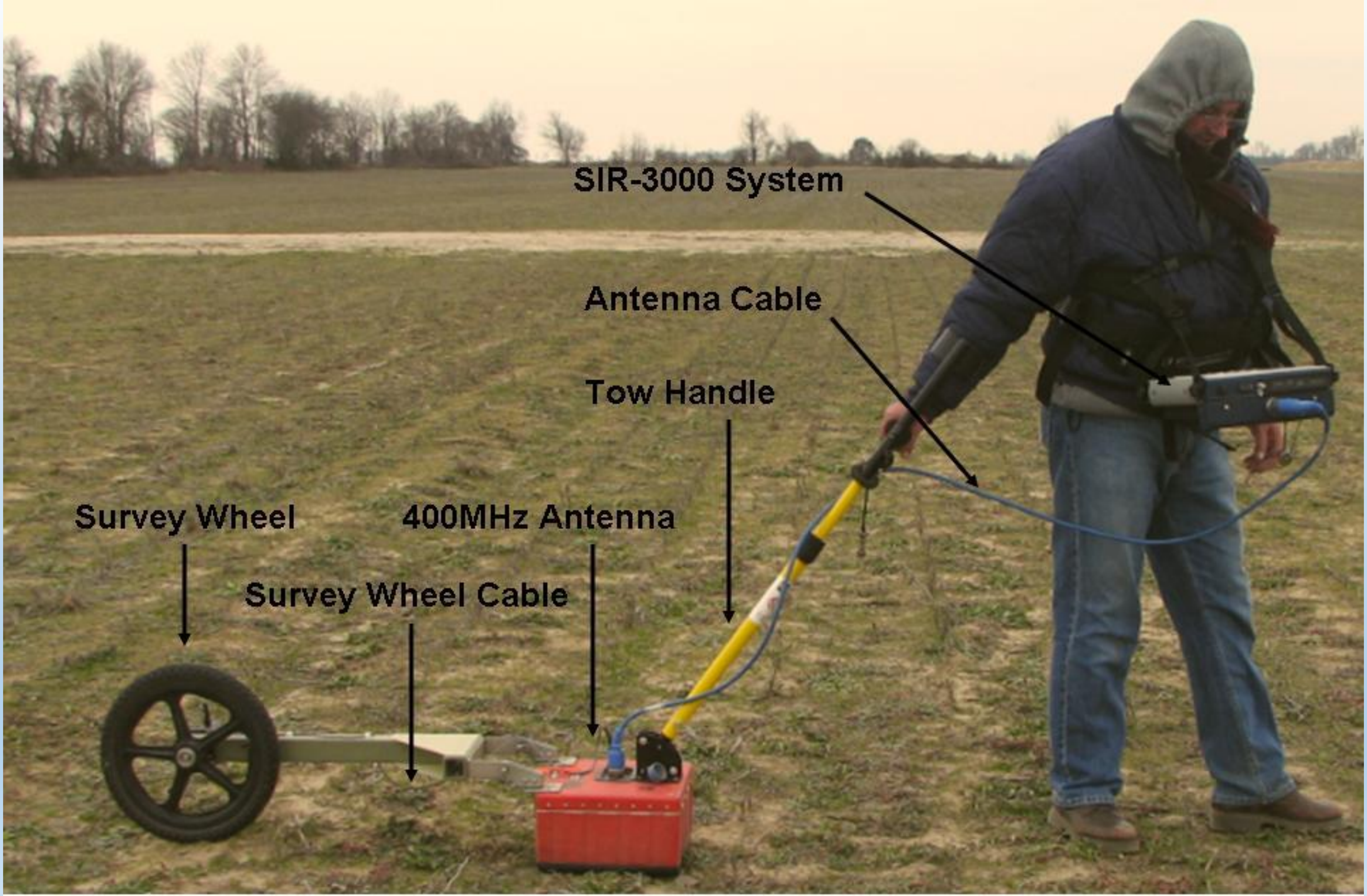
GPR Advantages:

1. It is a non-invasive method.
2. Vehicle operated system that can be run at a normal traffic speeds.
3. Continuous profile measurements are efficient for large surveys
4. Provides 2-D and 3-D high-resolution images.
5. Provides real-time analysis.
6. Powerful in detecting small changes in physical and electric properties of the material
7. Very sensitive to changes in the hydrological conditions of soil.

GSSI SIR-3000 System

GSSI SIR-30 System

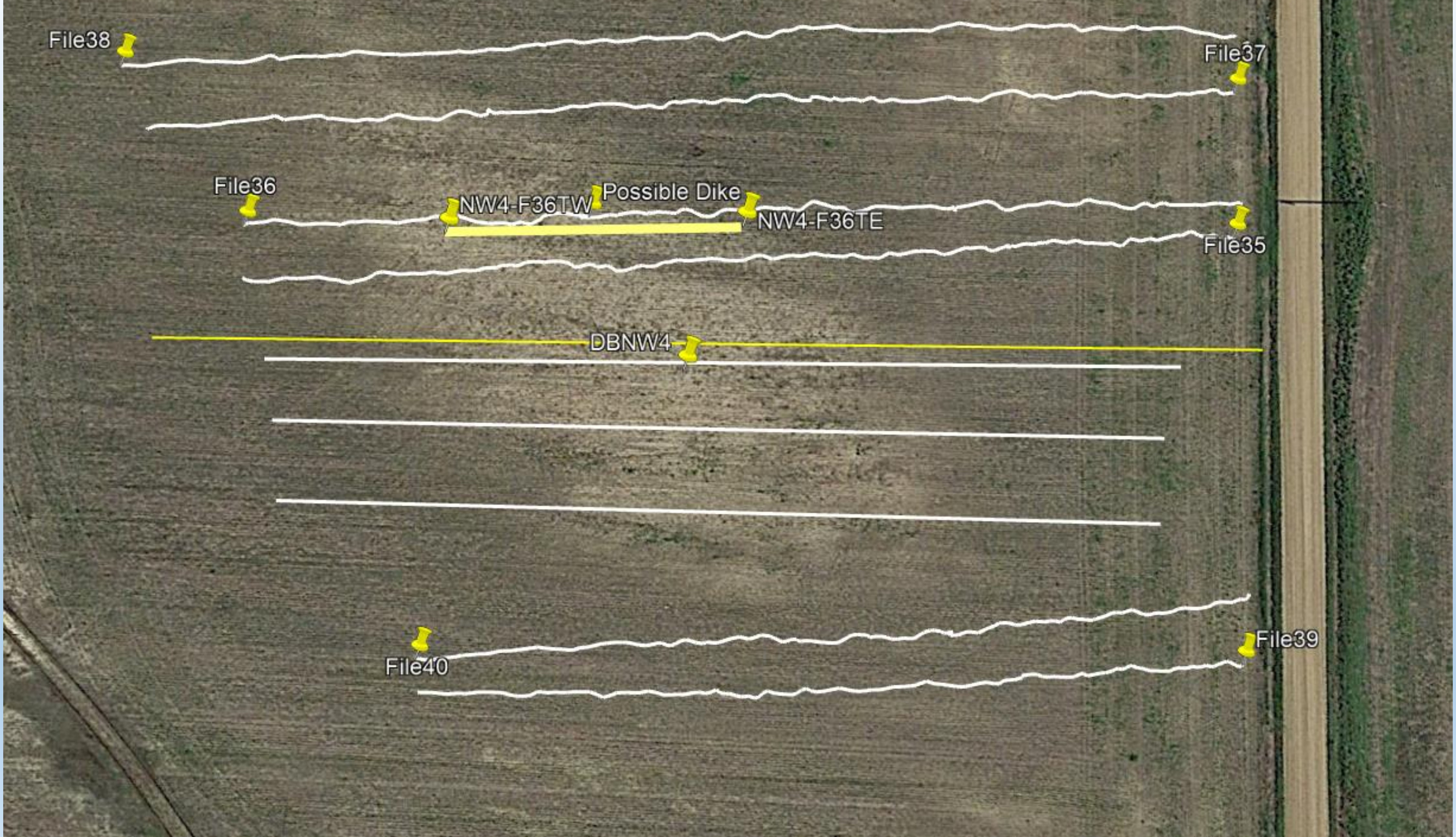



SIR-3000 System
Antenna Cable
Tow Handle
Survey Wheel
400MHz Antenna
Survey Wheel Cable

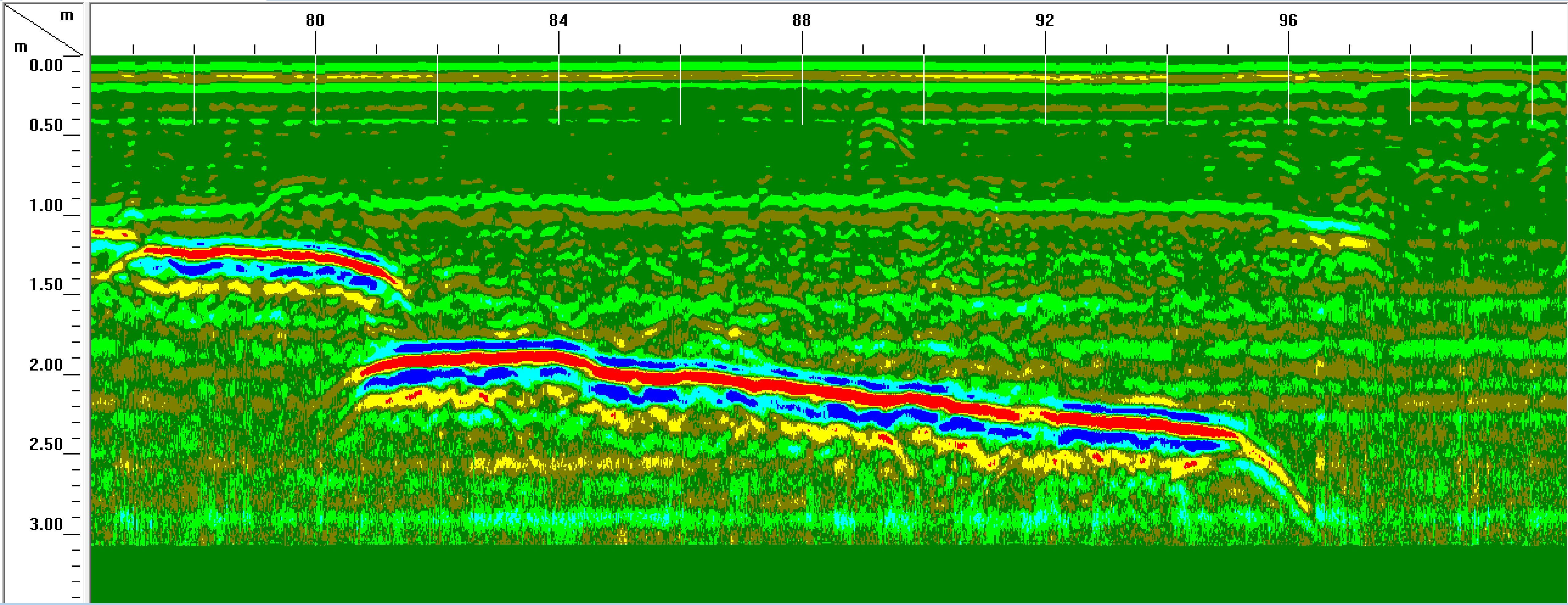
Application to Paleoseismology

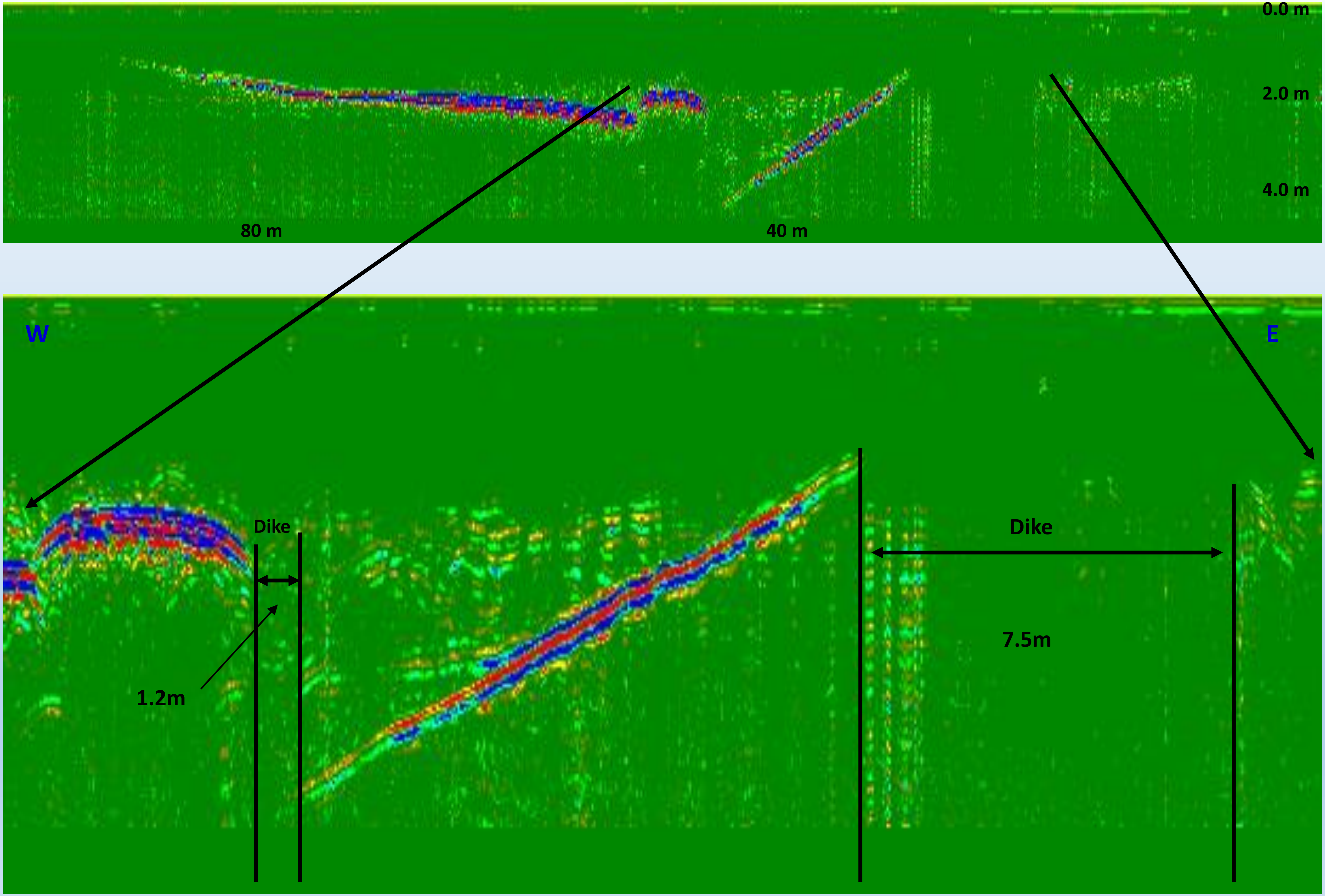

Where to trench?

Develop a Survey Plan



Ground Penetrating Radar System

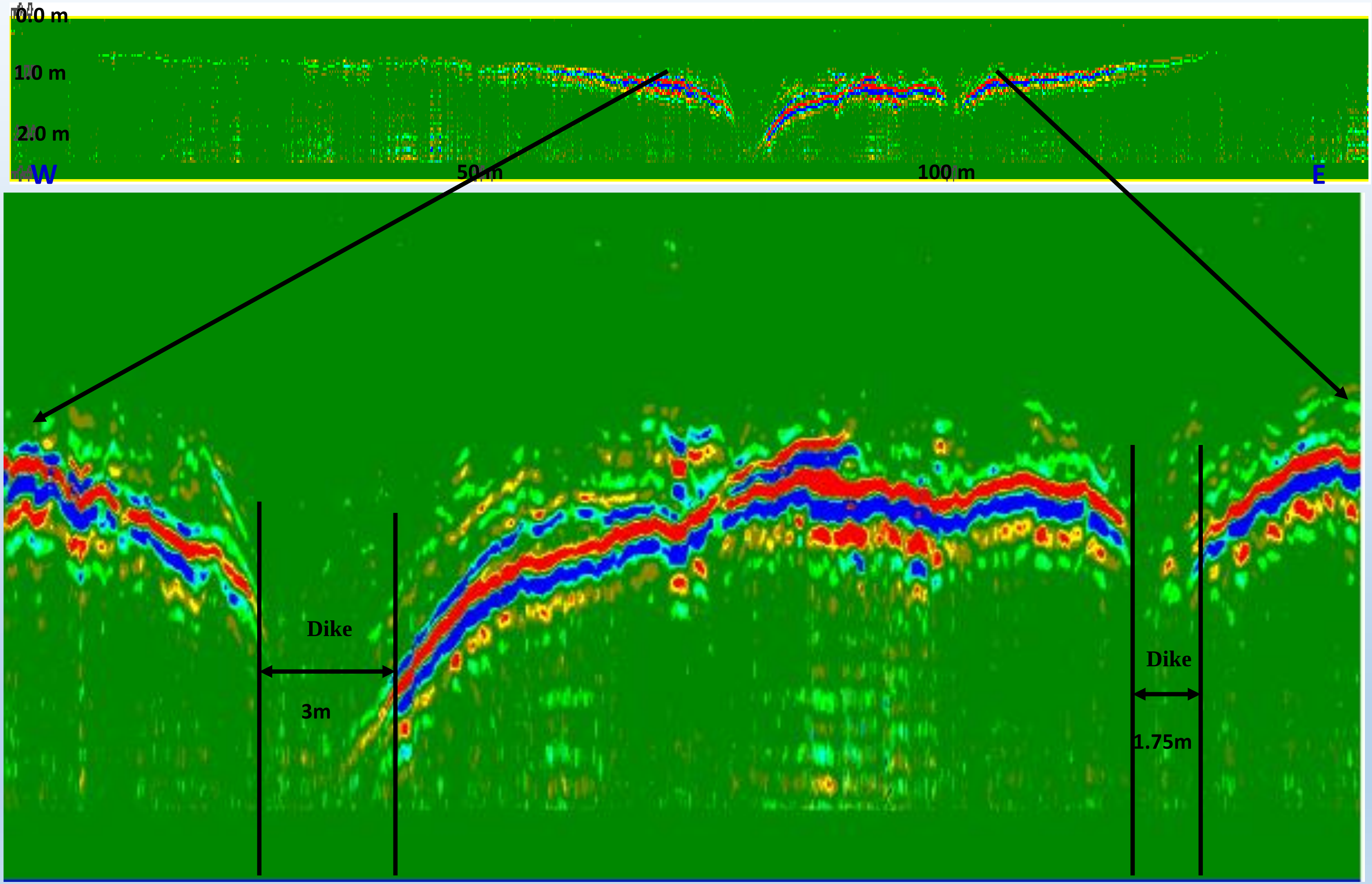

m
m
80
84
88
92
96
0.00
0.50
1.00
1.50
2.00
2.50
3.00


0.0 m
2.0 m
4.0 m
80 m
40 m
W
E
Dike
1.2m
Dike
7.5m

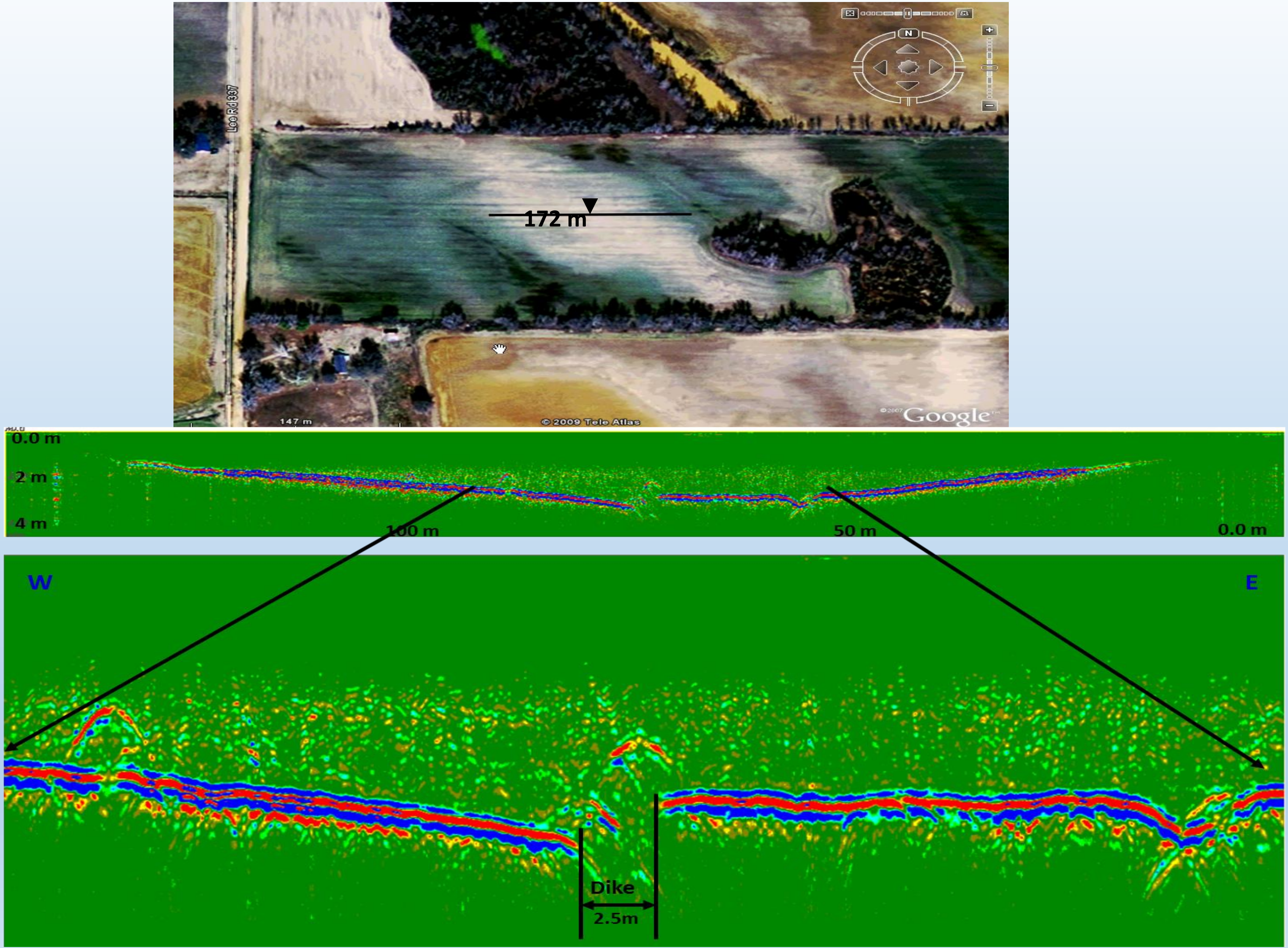


LR


479 m
243
Key Corner Rd
N
75 m
159 m
148m
100 m
5 m
237 m
© 2009 Tele Atlas
Image State of Arkansas
©2007 Google™
187 m
Pointer lat 34.713269° lon -90.808386°
Streaming 100%
Eye alt 648 m

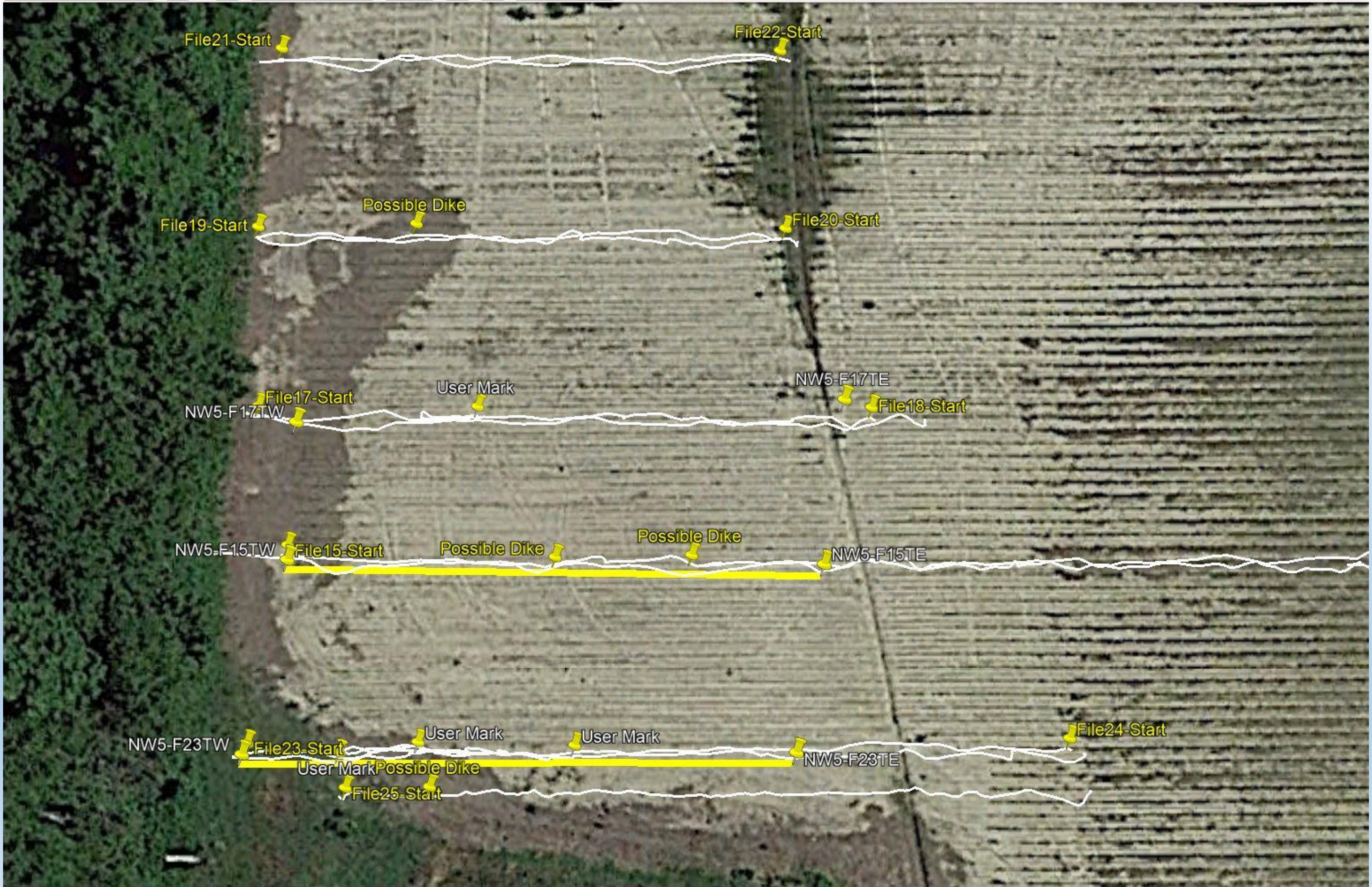


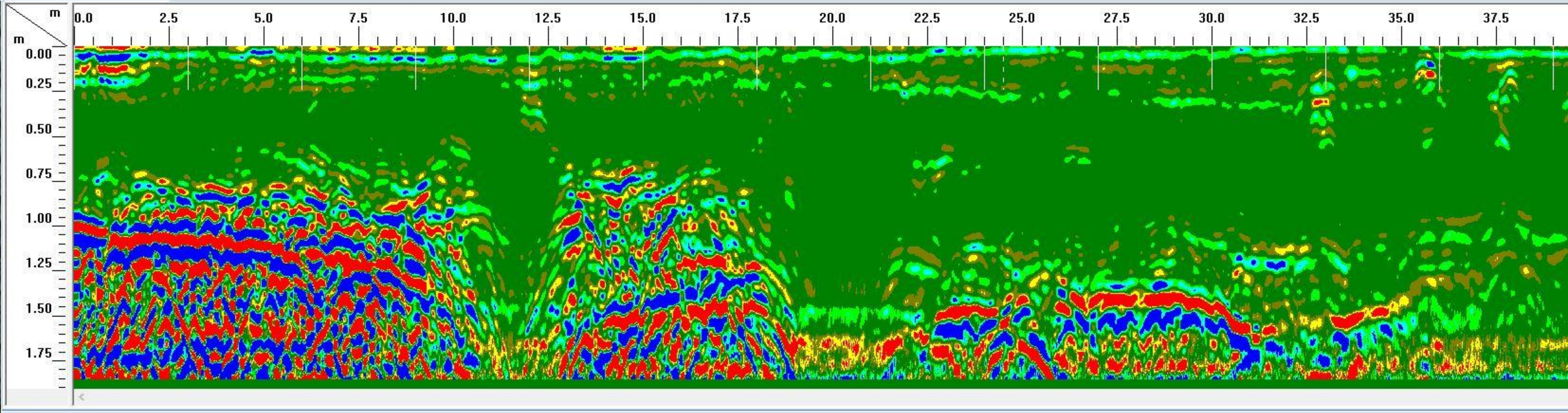
0.0 m
1.0 m
2.0 m
W
50 m
100 m
E
Dike
3m
Dike
1.75m



Lee Rd 337
172 m
147 m
© 2009 Tele Atlas
Google
0.0 m
2 m
4 m
100 m
50 m
0.0 m
W
E
Dike
2.5m

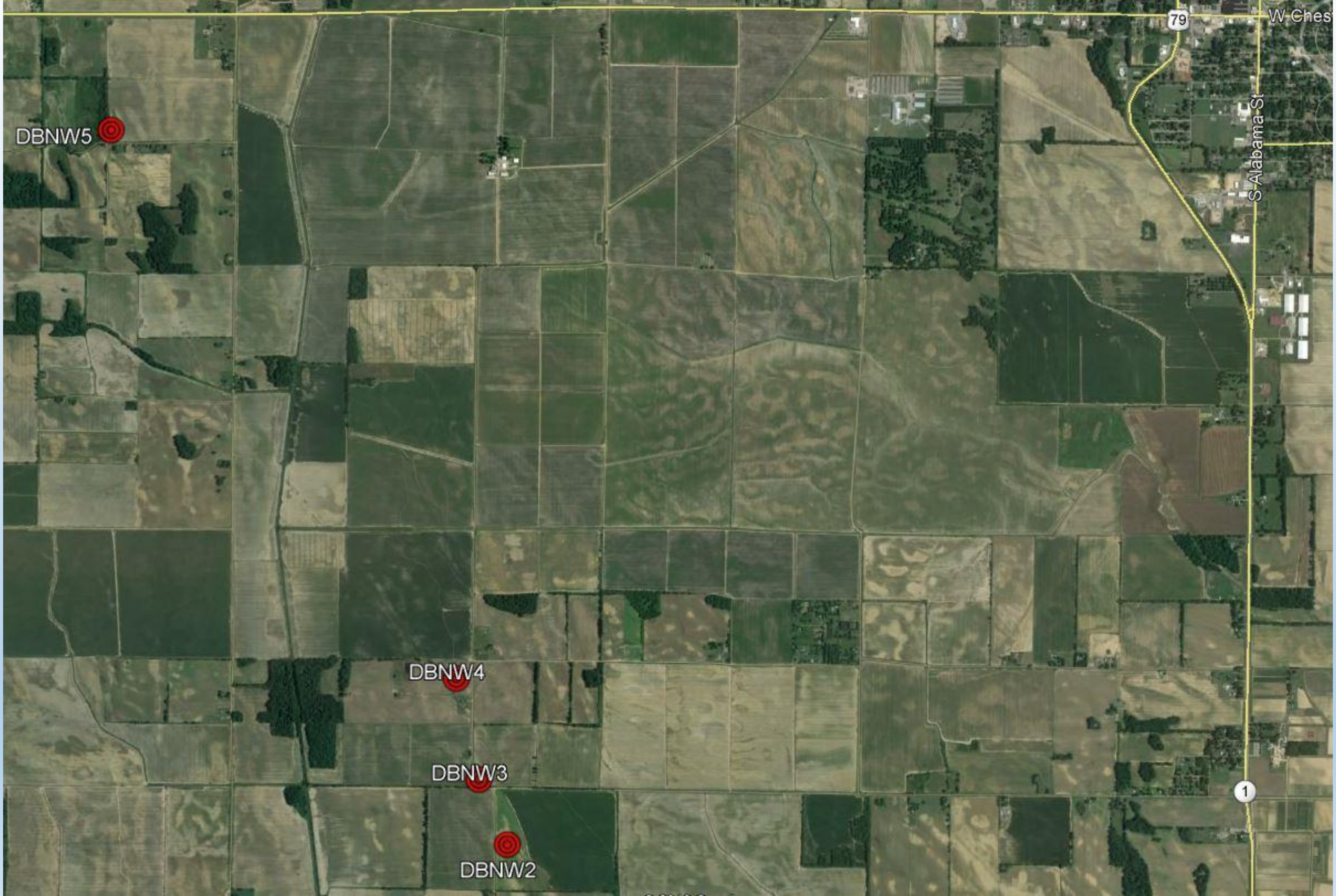
Sites investigated recently


File21-Start
File22-Start
Possible Dike
File19-Start
File20-Start
User Mark
NW5-F17TE
File17-Start
File18-Start
NW5-F17TW
Possible Dike
NW5-F15TW
File15-Start
Possible Dike
NW5-F15TE
User Mark
User Mark
File24-Start
NW5-F23TW
File23-Start
NW5-F23TE
User Mark
Possible Dike
File25-Start

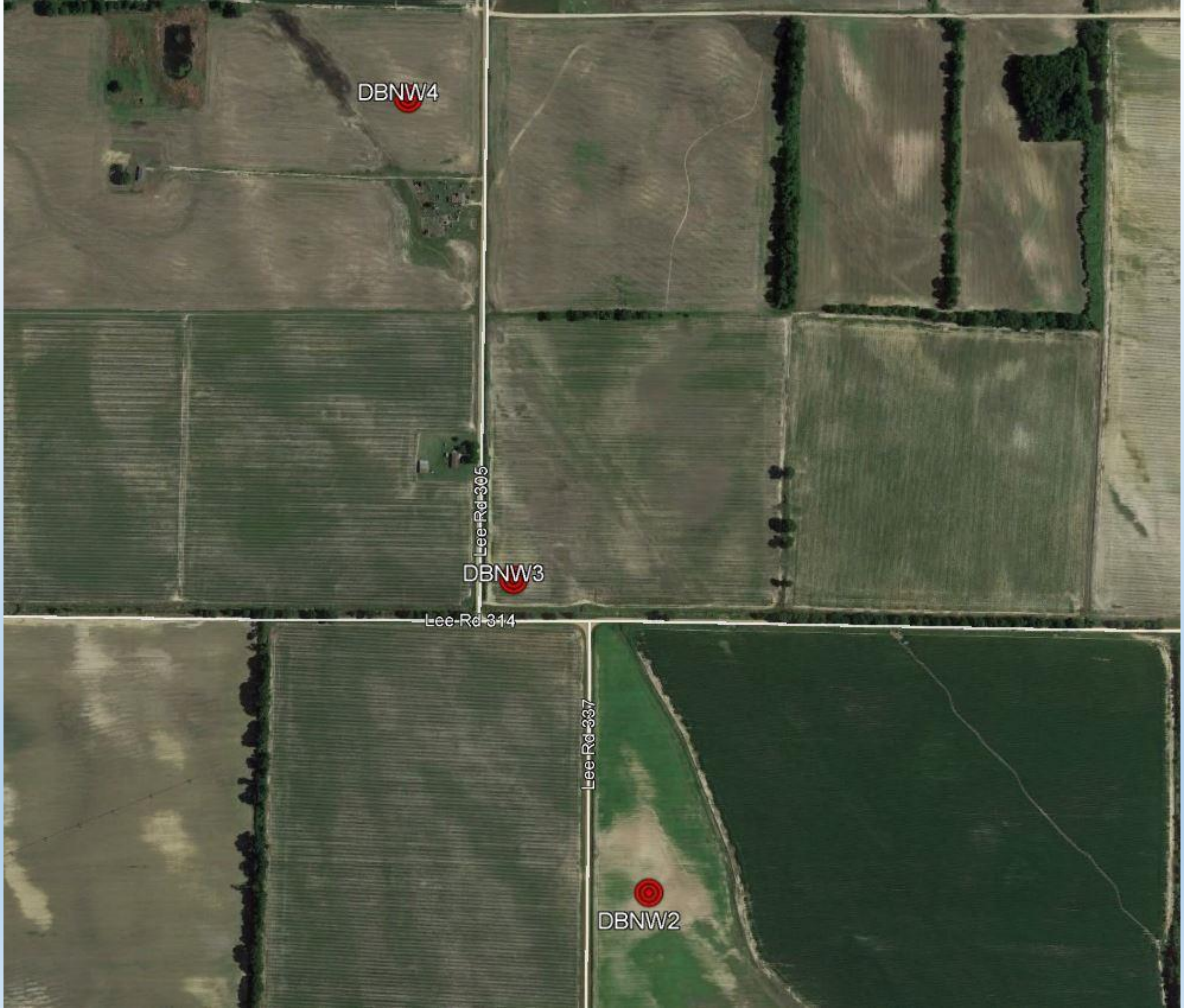


m
m
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
22.5
25.0
27.5
30.0
32.5
35.0
37.5
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75

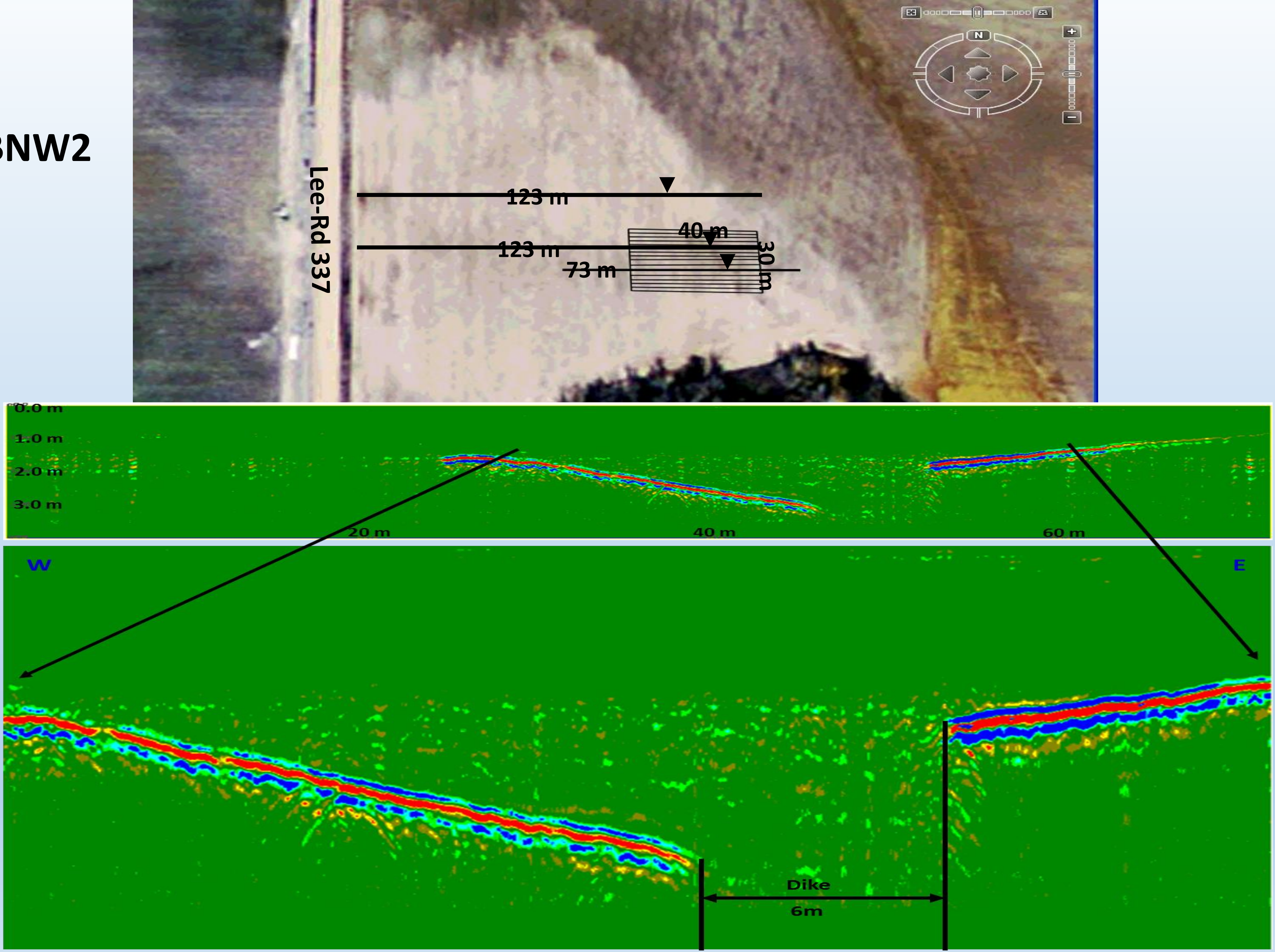
Sandblow Sites to be visited today



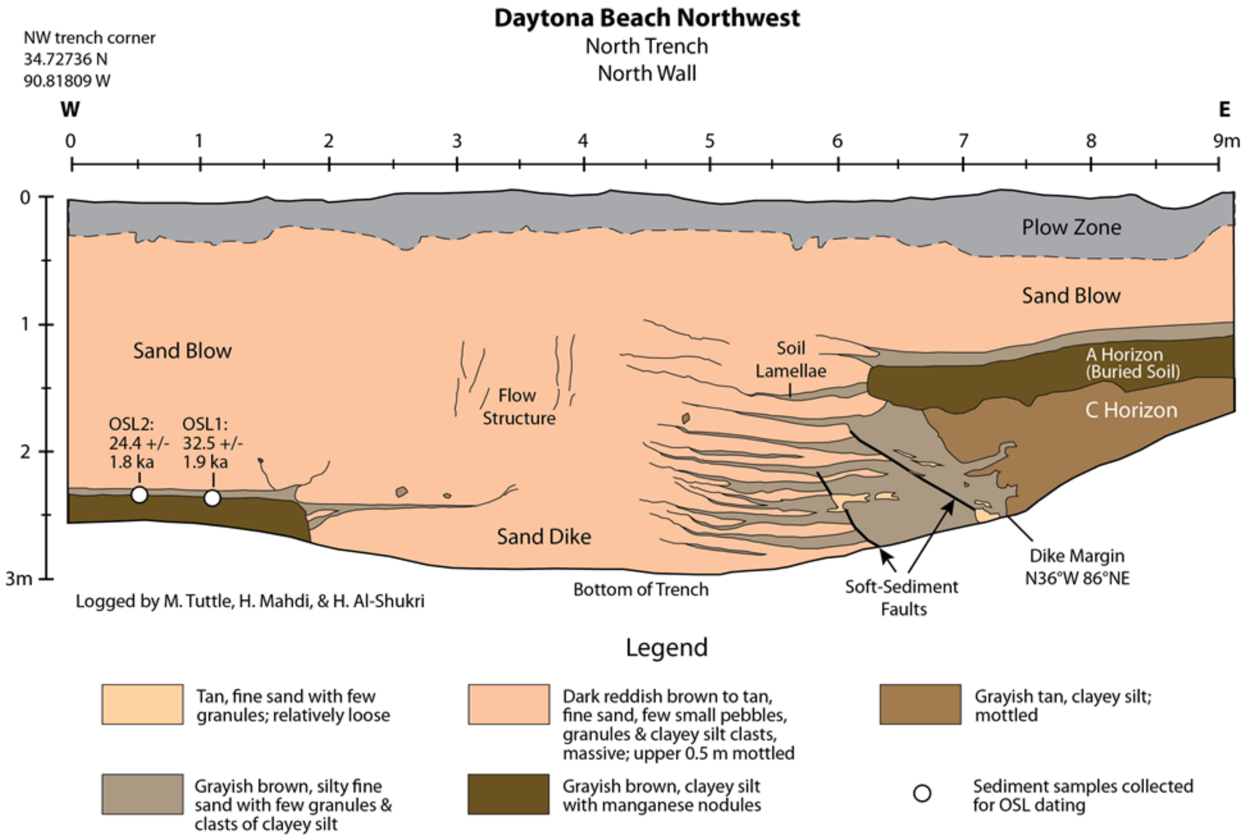
W Ches
79
S Alabama St
DBNW5
DBNW4
DBNW3
DBNW2
1

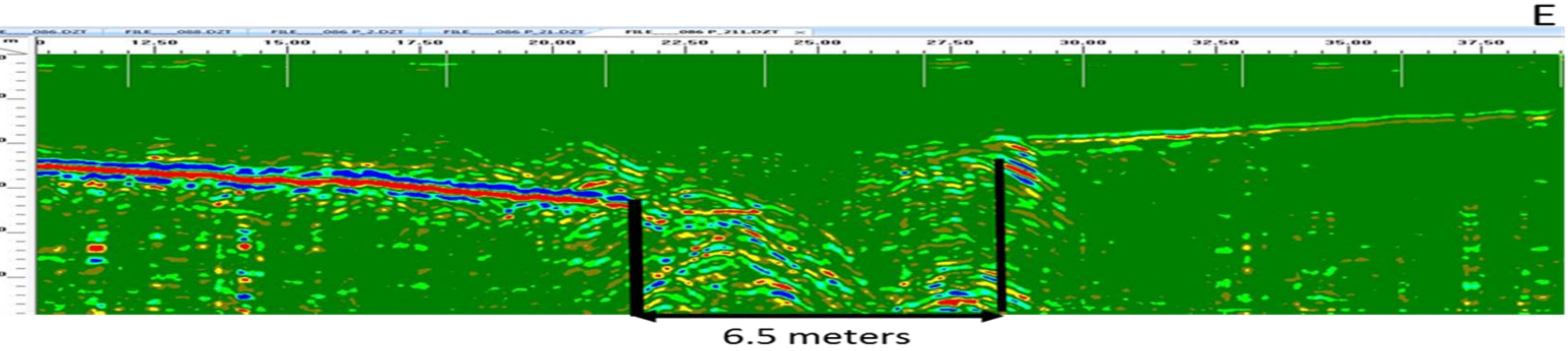

DBNW4
Lee Rd 305
DBNW3
Lee Rd 314
Lee Rd 337
DBNW2

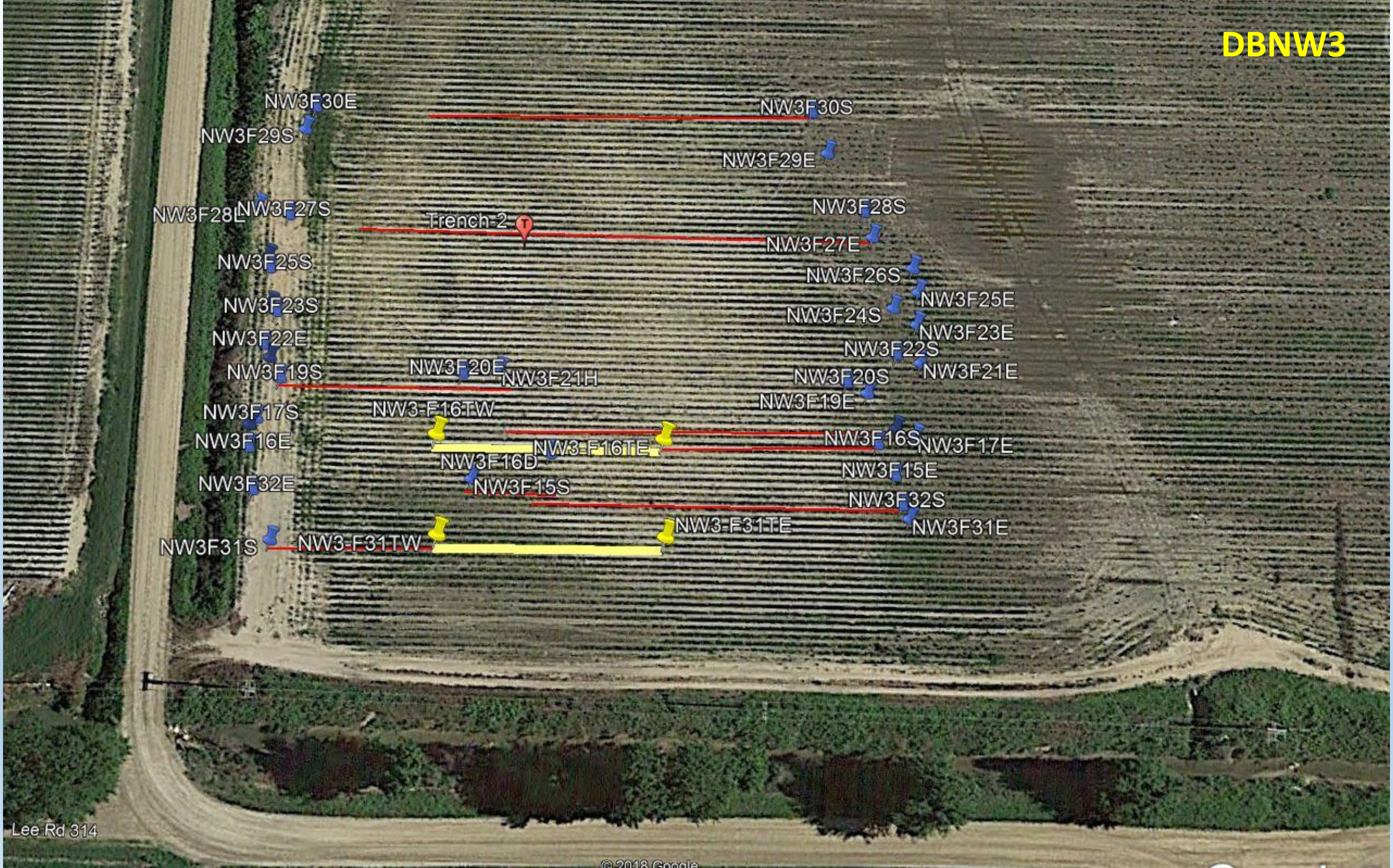
DBNW2

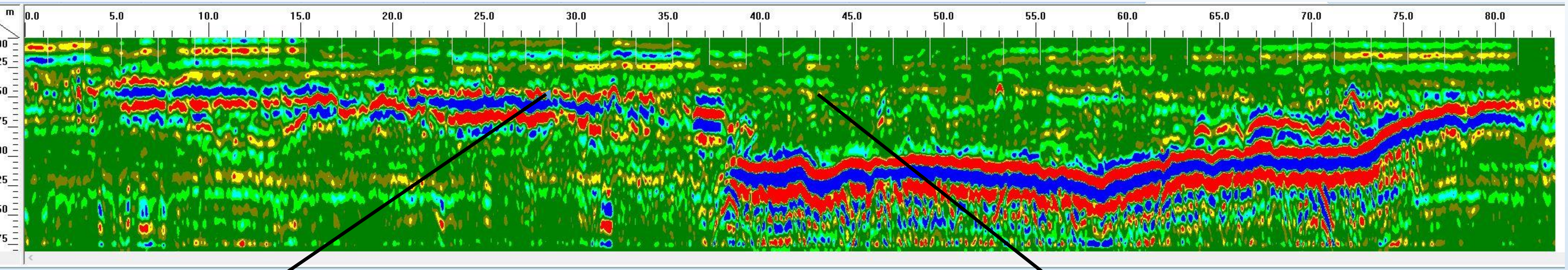

Lee-Rd 337
123 m
40 m
123 m
30 m
73 m
0.0 m
1.0 m
2.0 m
3.0 m
20 m
40 m
60 m
W
E
Dike
6m

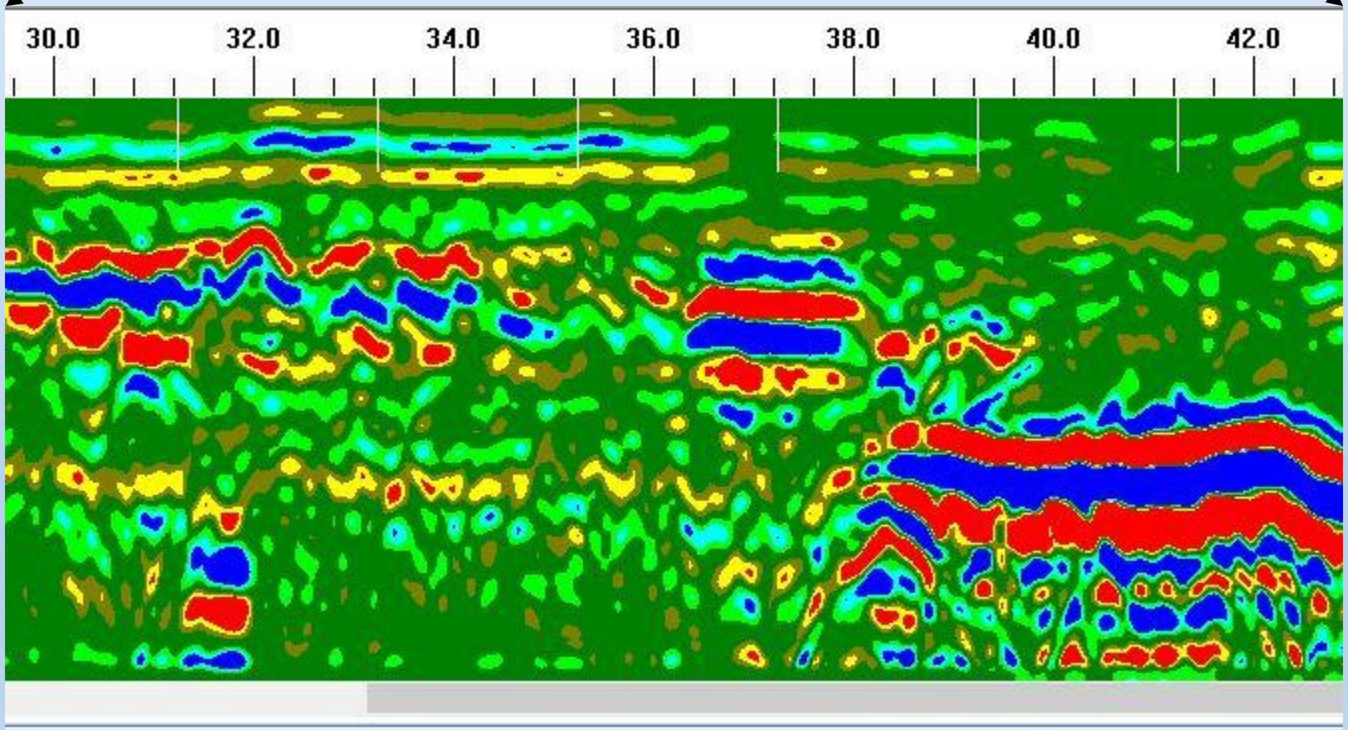
DBNW2


Daytona Beach Northwest
North Trench
North Wall
NW trench corner
34.72736 N
90.81809 W
W
E
0
1
2
3
4
5
6
7
8
9m
0
1
2
3m
Plow Zone
Sand Blow
Sand Blow
Soil
Lamellae
A Horizon
(Buried Soil)
C Horizon
Flow
Structure
OSL2:
24.4 +/-
1.8 ka
OSL1:
32.5 +/-
1.9 ka
Sand Dike
Dike Margin
N36°W 86°NE
Soft-Sediment
Faults
Bottom of Trench
Logged by M. Tuttle, H. Mahdi, & H. Al-Shukri
Legend
Tan, fine sand with few granules; relatively loose
Dark reddish brown to tan, fine sand, few small pebbles, granules & clayey silt clasts, massive; upper 0.5 m mottled
Grayish tan, clayey silt; mottled
Grayish brown, silty fine sand with few granules & clasts of clayey silt
Grayish brown, clayey silt with manganese nodules
Sediment samples collected for OSL dating


E
12.50
15.00
17.50
20.00
22.50
25.00
27.50
30.00
32.50
35.00
37.50
6.5 meters

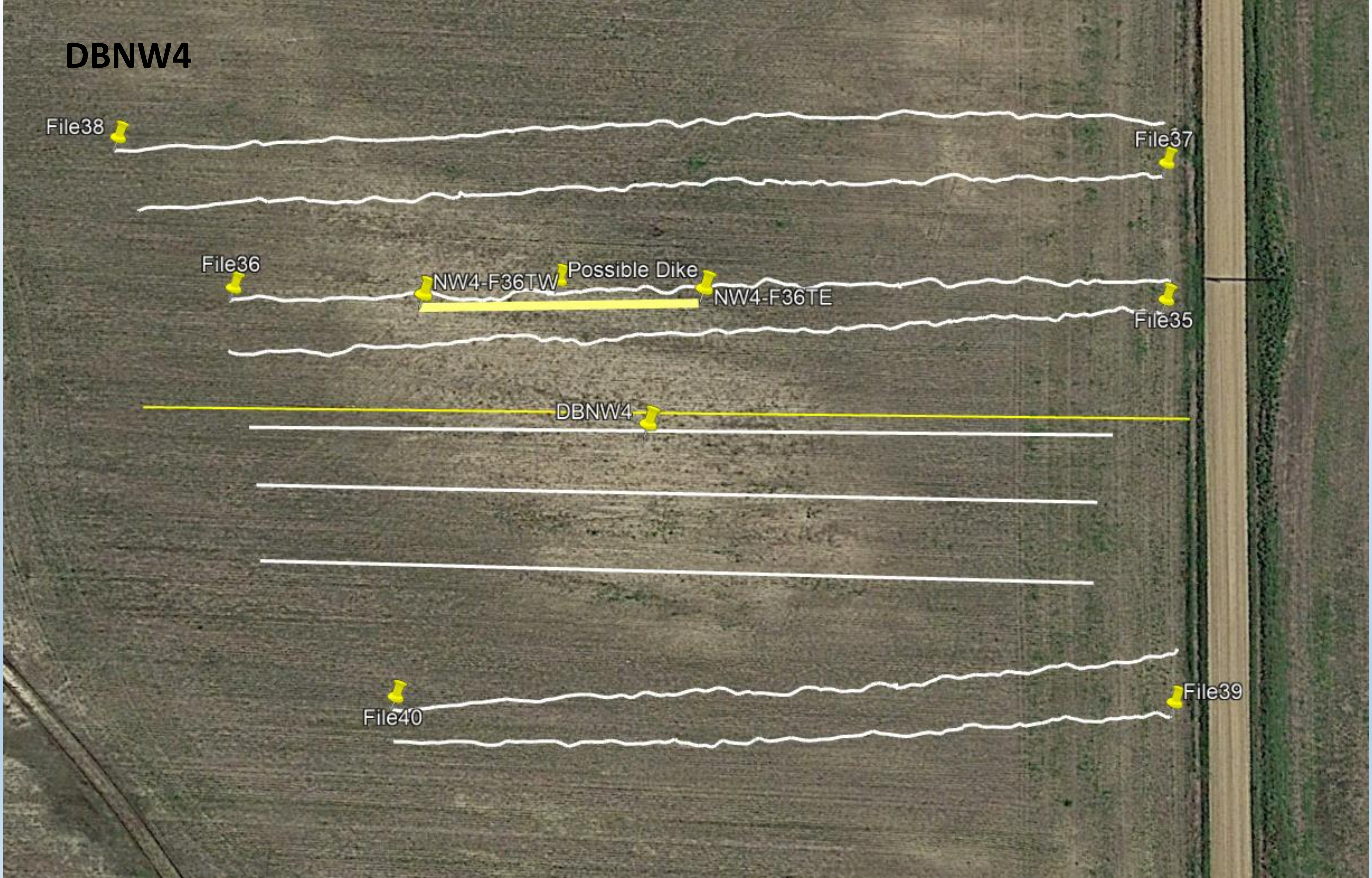

DBNW3
NW3F30E
NW3F30S
NW3F29S
NW3F29E
NW3F28S
NW3F28L
NW3F27S
Trench-2
NW3F27E
NW3F25S
NW3F26S
NW3F25E
NW3F23S
NW3F24S
NW3F23E
NW3F22E
NW3F22S
NW3F19S
NW3F20E
NW3F21H
NW3F20S
NW3F21E
NW3F19E
NW3F17S
NW3-F16TW
NW3F16E
NW3-F16TE
NW3F16S
NW3F17E
NW3F16D
NW3F15E
NW3F32E
NW3F15S
NW3F32S
NW3-F31TE
NW3F31E
NW3F31S
NW3-F31TW
Lee Rd 314
© 2018 Google


m
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0
45.0
50.0
55.0
60.0
65.0
70.0
75.0
80.0


30.0
32.0
34.0
36.0
38.0
40.0
42.0

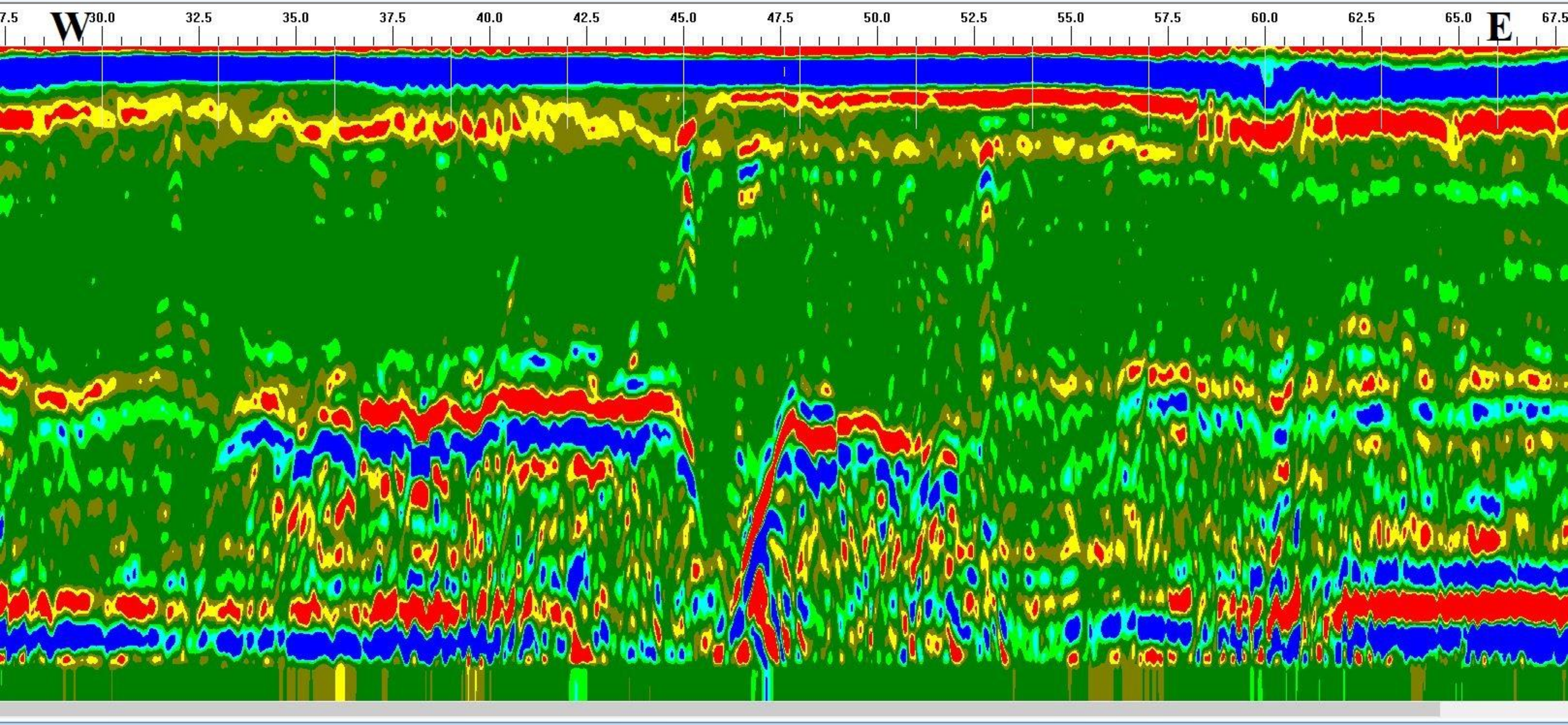
DBNW3

DBNW4



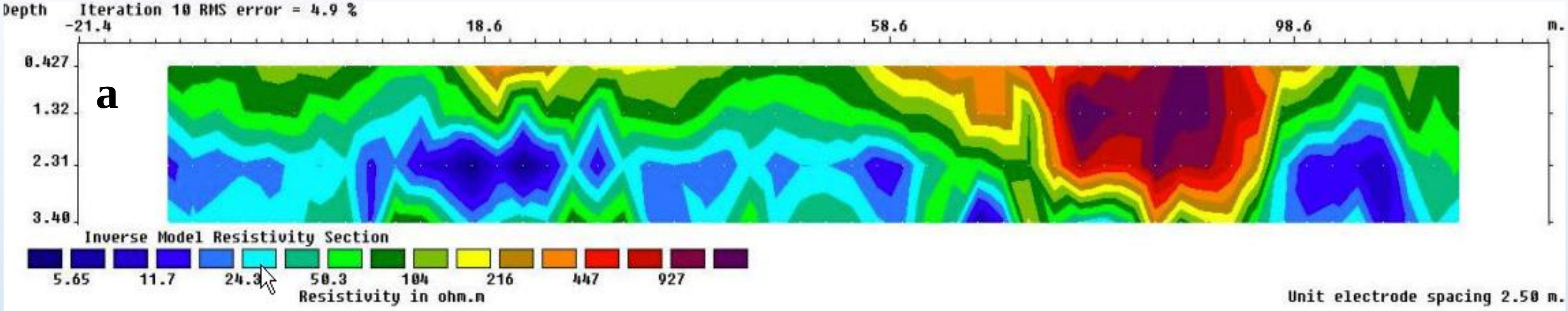
File38
File37
File36
NW4-F36TW
Possible Dike
NW4-F36TE
File35
DBNW4
File40
File39

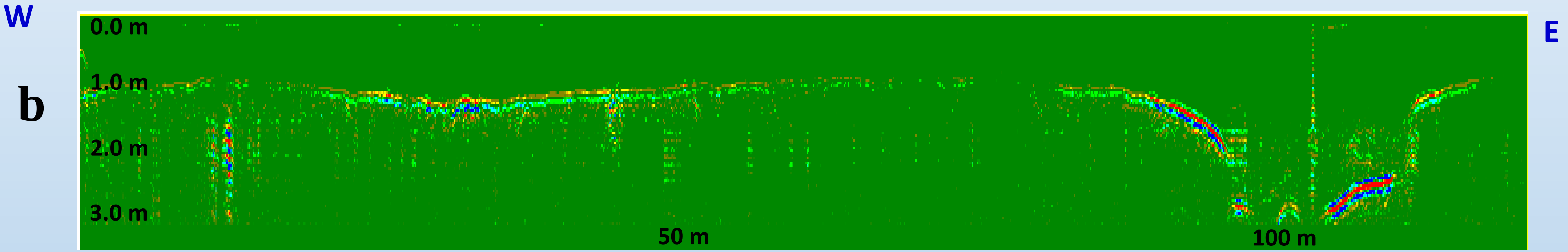
DBNW4

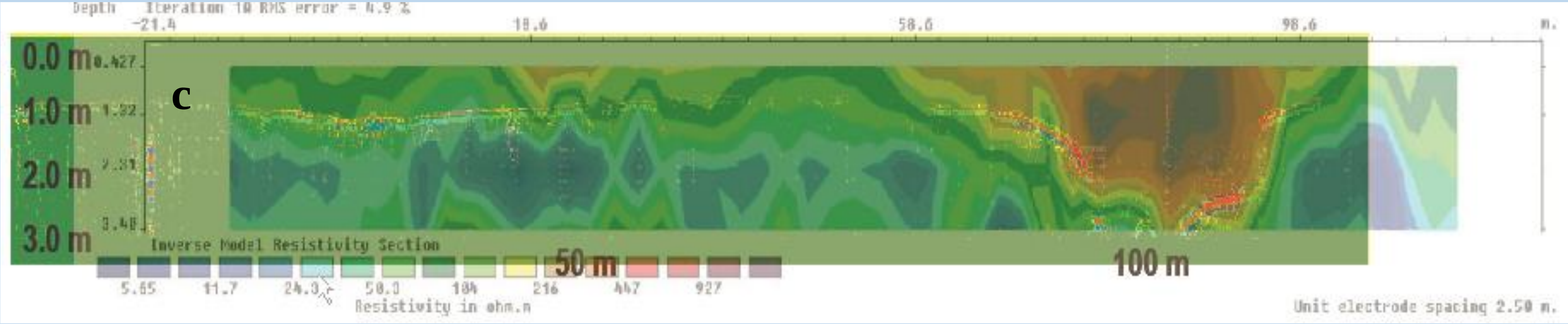


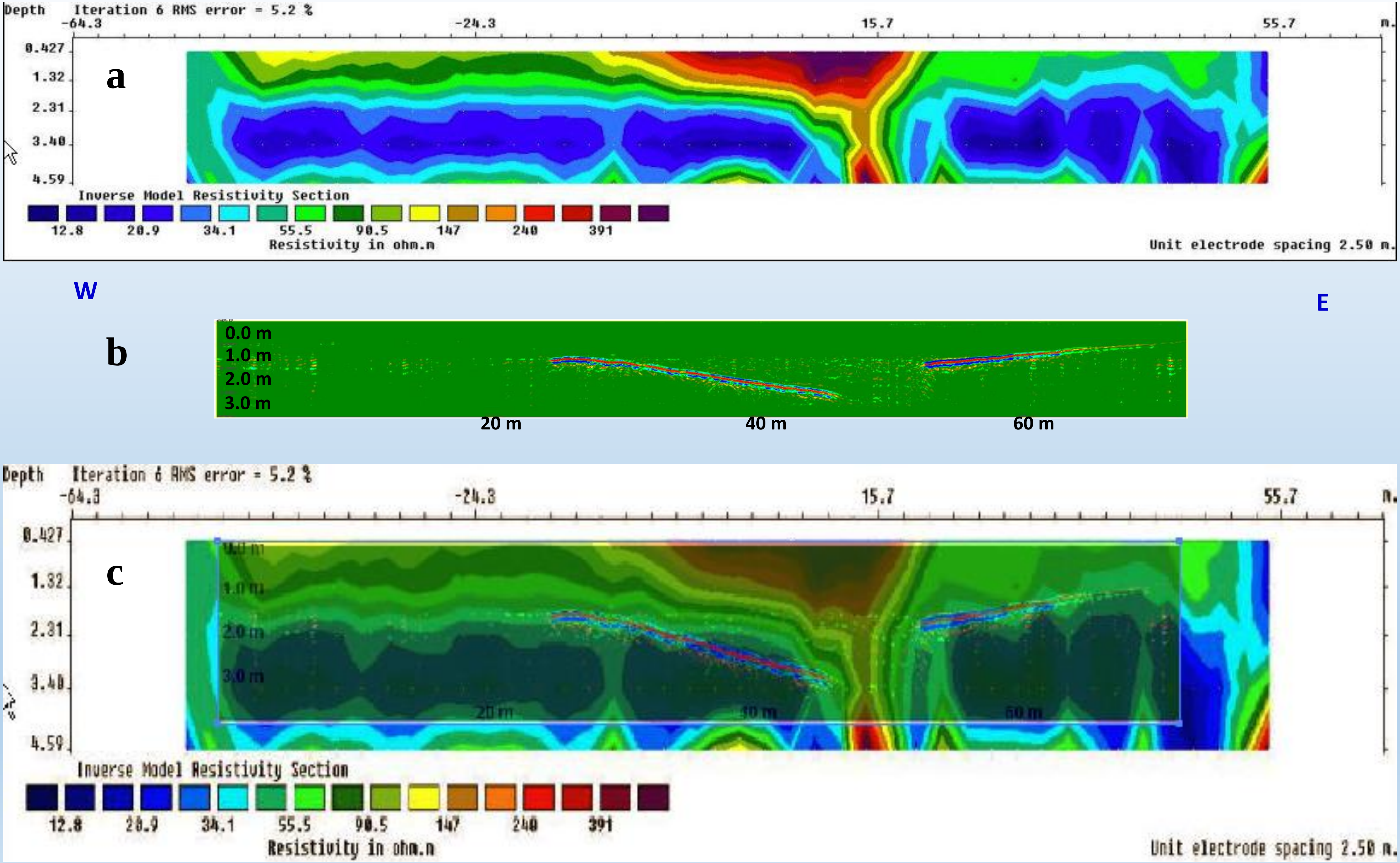
7.5
W
30.0
32.5
35.0
37.5
40.0
42.5
45.0
47.5
50.0
52.5
55.0
57.5
60.0
62.5
65.0
E
67.5

Comprehensive Analysis

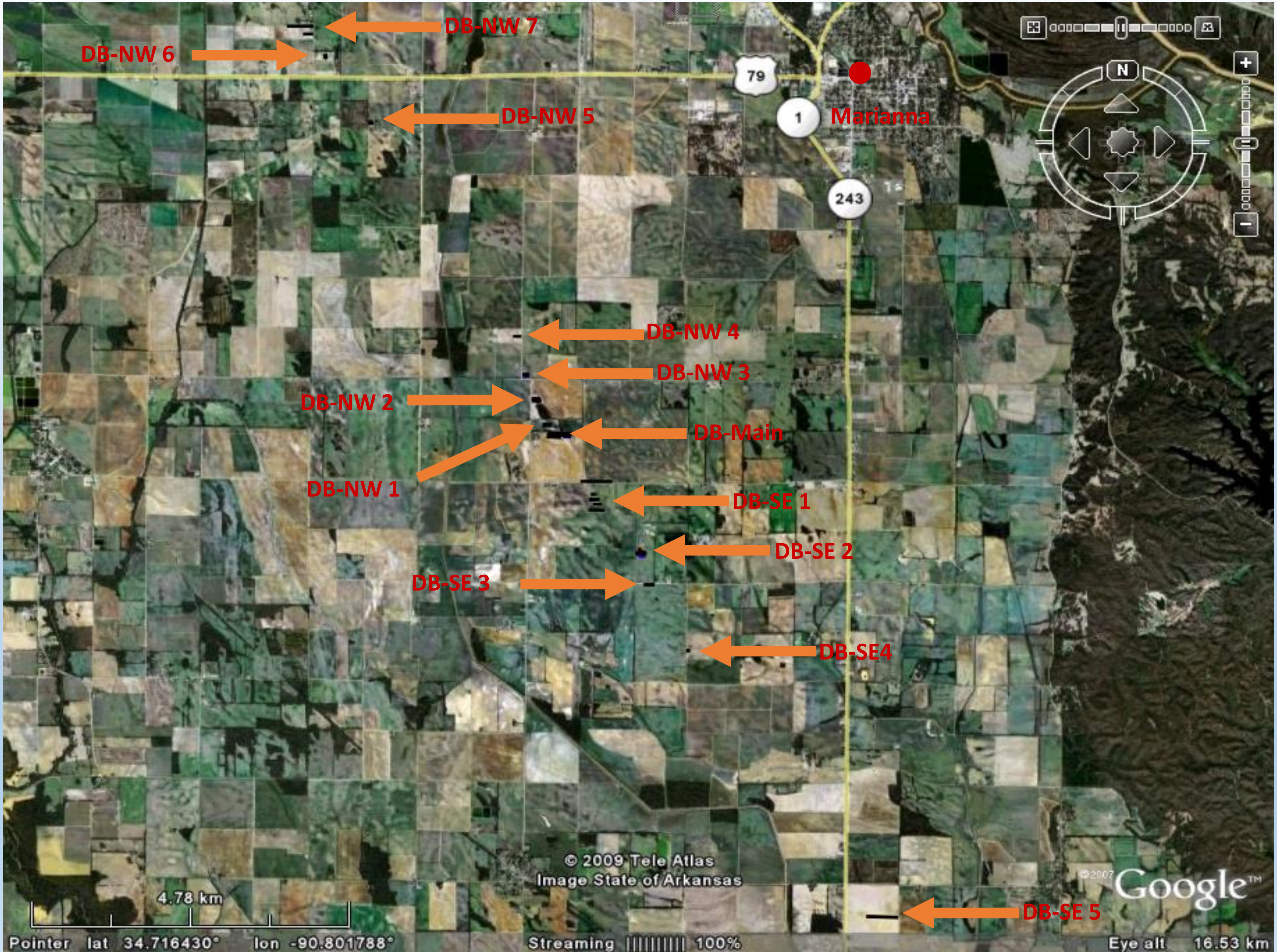

Depth Iteration 10 RMS error = 4.9 %
-21.4
18.6
58.6
98.6
m.
0.427
1.32
2.31
3.40
a
Inverse Model Resistivity Section
5.65
11.7
24.3
50.3
104
216
447
927
Resistivity in ohm.m
Unit electrode spacing 2.50 m.

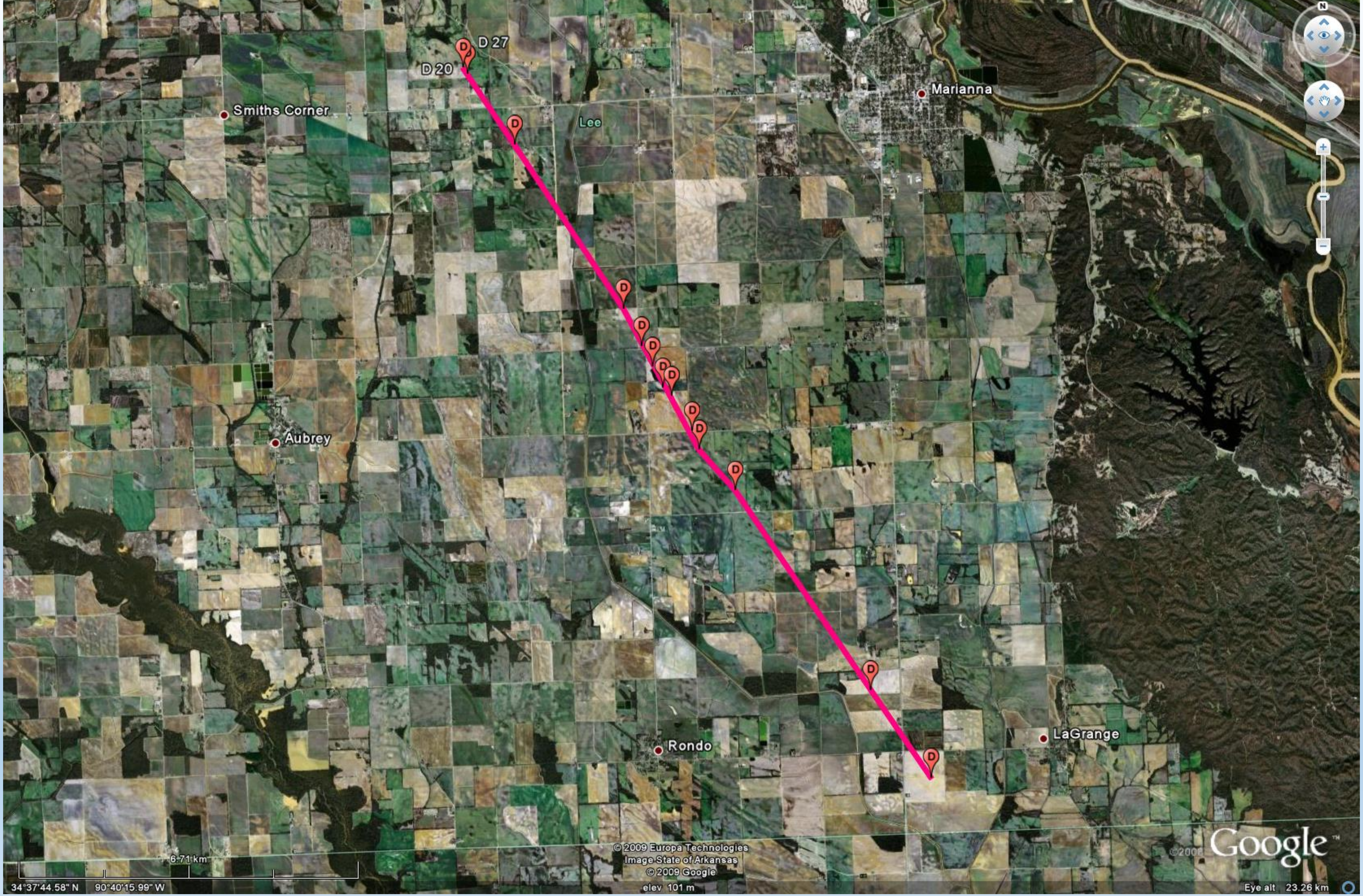

W
E
0.0 m
1.0 m
2.0 m
3.0 m
b
50 m
100 m


c
0.0 m
1.0 m
2.0 m
3.0 m
50 m
100 m



Depth Iteration 6 RMS error = 5.2 %
-64.3
-24.3
15.7
55.7
m.
0.427
1.32
2.31
3.40
4.59
a
Inverse Model Resistivity Section
12.8
20.9
34.1
55.5
90.5
147
240
391
Resistivity in ohm.m
Unit electrode spacing 2.50 m.
W
E
b
0.0 m
1.0 m
2.0 m
3.0 m
20 m
40 m
60 m
Depth Iteration 6 RMS error = 5.2 %
-64.3
-24.3
15.7
55.7
m.
0.427
1.32
2.31
3.40
4.59
c
Inverse Model Resistivity Section
12.8
20.9
34.1
55.5
90.5
147
240
391
Resistivity in ohm.m
Unit electrode spacing 2.50 m.


DB-NW 7
DB-NW 6
79
1
Marianna
DB-NW 5
243
DB-NW 4
DB-NW 3
DB-NW 2
DB-Main
DB-NW 1
DB-SE 1
DB-SE 2
DB-SE 3
DB-SE4
© 2009 Tele Atlas
Image State of Arkansas
©2007
Google™
4.78 km
DB-SE 5
Pointer lat 34.716430° lon -90.801788°
Streaming 100%
Eye alt 16.53 km


D 27
D 20
Marianna
Smiths Corner
Lee
Aubrey
LaGrange
Rondo
6.71 km
© 2009 Europa Technologies
Image State of Arkansas
© 2009 Google
Google
34°37'44.58" N 90°40'15.99" W
elev 101 m
Eye alt 23.26 km

Results

- The sand blows concentrated near Marianna area
- The intensity (number and size) of sand blows reduced in all directions
- A new source zone
- Independent of the New Madrid SZ
- Has been extensively active in the past 5K years
- Our geotechnical analysis suggests that earthquakes in the M 6-6.5 range could induce liquefaction and therefore be responsible for the formation of the large sand blows.
- Several large earthquakes took place in the area
- The risk has not been evaluated yet
- The return period has not been determined and more research is need

Assessment of Cyclic Behavior of Mississippi Embayment Sand Based on Cyclic Triaxial Tests

Hamed Tohidi [1], David Arellano[2], Ashraf Elsayed[3], Chris Cramer[2], Shahram Pezeshk[2], Roy Van Arsdale[2], Stephen Horton[2]

[1]Graduate Research Assistant, The University of Memphis, Memphis ,TN, 38152, htohidi@Memphis.edu

[2] The University of Memphis, Memphis, TN, 38152

[3] Arkansas State University, Jonesboro, AR, 72401

Abstract:

The simplified procedure for evaluating the soil liquefaction potential of cohesionless soils is based on estimating the cyclic stress ratio (CSR) from an empirical relationship that is based on the cyclic triaxial test results of Sacramento River sand. Grain size analysis results indicate that the grain size distribution of Mississippi Embayment sand from Vicksburg, Mississippi is different than Sacramento River sand.

Soil properties that influence liquefaction potential and cyclic behavior include grain size distribution, grain shape, mineral composition, and age. Therefore, this study will evaluate the following hypothesis: the cyclic behavior of Mississippi Embayment sand is different than Sacramento River sand and, consequently, the CSR based on cyclic triaxial tests of Mississippi Embayment sand will be different than the current simplified method of determining CSR that is based on cyclic triaxial tests on Sacramento River sand. For this study, sand samples will be obtained from various locations in the MS Embayment and from trenches displaying remnants of liquefied sand to perform cyclic triaxial tests and to evaluate CSR.

Introduction and Background:

Seed and Idriss (1967) presented a general procedure for evaluating liquefaction potential that consisted of the following steps:

1. Determination of shear stress time history produced by the earthquake.
2. Convert the stress time history of the earthquake into an equivalent number of uniform stress cycles as a function of depth as shown by the cyclic stress developed for N cycles by earthquake motions curve in Figure 1.
3. Estimation of the required number of cycles that induces liquefaction at various depths based on the cyclic triaxial lab tests using the equivalent number of uniform cycles from step 2 as shown by the cyclic stress causing liquefaction in N cycles curve in Figure 1.
4. Determination of the liquefiable zones by comparing the shear stresses caused by the earthquake from step 2 with the estimation of cycles that induces liquefaction from step 3 as shown by the zone of liquefaction designation in Figure 1 the zone of liquefaction is the zone where the equivalent number of uniform stress cycles exceeds the cyclic stress causing liquefaction.

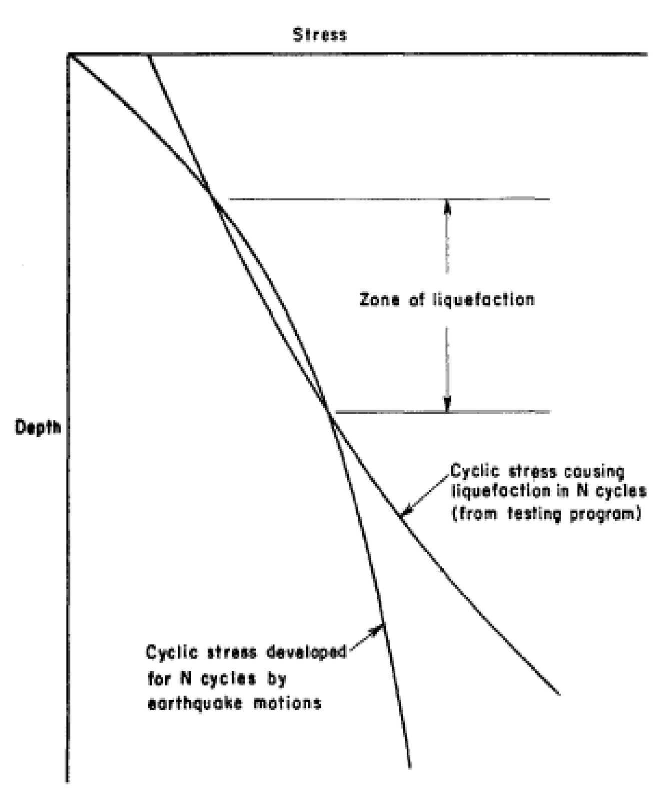


Figure 1. Method of evaluating liquefiable zone

Introduction and Background Continued:

In 1971 Seed and Idriss simplified the general procedure for evaluating liquefaction potential that consisted of three evaluations:

1. Simplified procedure for evaluating stresses induced by the earthquake,
2. Simplified procedure for evaluating stresses causing liquefaction,
3. Evaluation of liquefaction potential.

To evaluate the stresses induced by an earthquake, the simplified method consists of a relationship to compute maximum shear stress (τ_{max}). In the initial equation of computing τ_{max}, the behavior of a soil column above the soil element at a depth of h was considered to be rigid but, it is known that the soil column behaves as a deformable body, hence a stress reduction coefficient (r_d) was applied to the initial τ_{max} equation.

As shown in Figure 2, the magnitude of shear stress that occurs during an earthquake in the field varies from cycle to cycle. Based on the shear stress time history of the Niigata earthquake, Seed and Idriss determined that the average shear stress induced by the earthquake was about 65% of the maximum shear stress. Thus, they suggested a reduction of 0.65 to equation of τ_{max} to estimate the average shear stress (τ_{ave}).

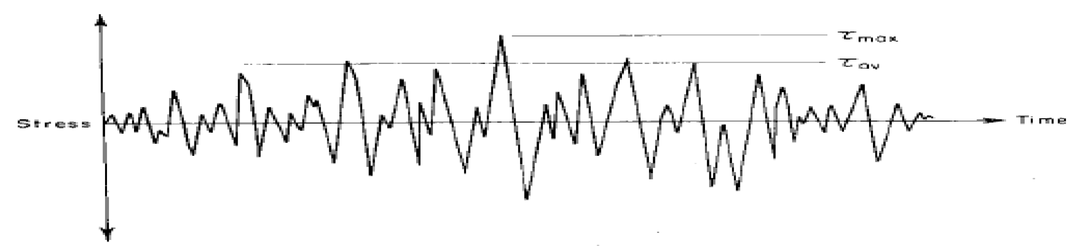


Figure 2. Shear stress time history of Niigata earthquake

Following the simplified procedure and by comparing the cyclic triaxial test results with τ_{ave} induced at any depth by an earthquake, Seed and Idriss determined the liquefiable zones and expressed cyclic stress ratio (CSR) causing liquefaction in the field in terms of $\frac{\tau_{ave}}{\sigma'_v}$ given by:

$$CSR = \frac{\tau_{ave}}{\sigma'_v} = 0.65\left(\frac{a_{max}}{g}\right)\left(\frac{\sigma_v}{\sigma'_v}\right)r_d \quad (1)$$

CSR is one of the main parameters of calculating Factor of Safety (FS) against liquefaction as follows:

$$FS = \frac{CRR}{CSR} \quad (2)$$

Methodology:

Soil properties that influence liquefaction potential and cyclic behavior include grain size distribution, grain shape, mineral composition, and age (Obermeier, 1989). Since the grain size distribution of Niigata sand was similar to Sacramento River sand, the cyclic triaxial test results of Seed and Lee's study (1966) on Sacramento River sand was used in the simplified procedure. Figure 3 shows a comparison of grain size distribution between Sacramento River sand and Mississippi Embayment sand and the Figure indicates that the grain size distribution curves of Mississippi Embayment sand is different from Sacramento River sand. Therefore, this study will evaluate the following hypothesis: the cyclic behavior of Mississippi Embayment sand is different than Sacramento River sand and, consequently, the CSR based on cyclic triaxial tests of Mississippi Embayment sand will be different than the current simplified method of determining sand using Equation 1 that is based on cyclic triaxial tests on Sacramento River sand.

Methodology Continued:

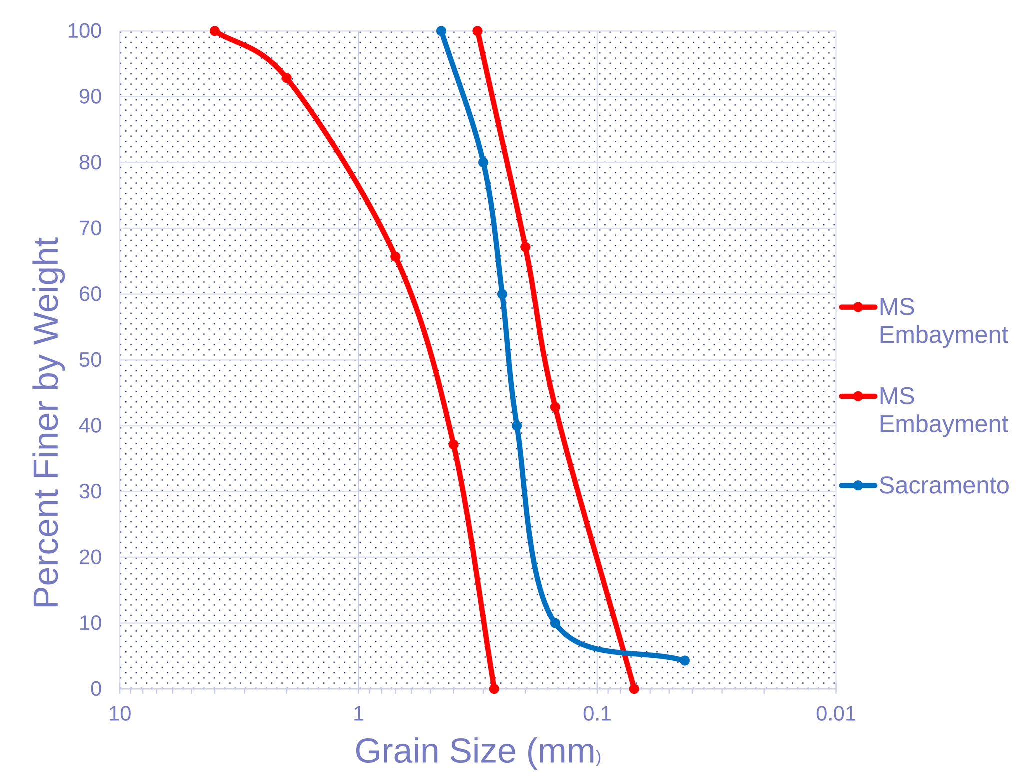


Figure 3. Comparison of the grain size distribution of Sacramento River sand and MS Embayment sand

For this study it has proposed to obtain samples from various locations in the MS Embayment and from trenches of liquefied sand of the area. Cyclic triaxial tests will be performed on sand specimens at Arkansas State University at various densities and confining stresses.

The MS embayment sand will be compared with the results of Sacramento River Sand and the influence of the test results on CSR will be determined.

The MS Embayment sand test results will be used with available field test data of Western Tennessee to develop Liquefaction Probability Curves (LPCs) and these LPCs will be compared with the LPCs developed based on Sacramento River Sand test results inherent in the current simplified method of liquefaction analysis.

Acknowledgements:

This material is based upon work supported by the Department of Housing and Urban Development National Disaster Resilience Award.

References:

Koester, J. P. (2018). “Triggering and post-liquefaction strength issues in fine-grained soils.” *Physics and Mechanics of Soil Liquefaction*, 79–89.

Obermeier, S. F. (1989). “The New Madrid earthquakes; an engineering-geologic interpretation of relict liquefaction features.” *Professional Paper*.

Seed, H. B., and Idriss, I. M. (1967). “Analysis of Soil Liquefaction: Niigata Earthquake.” *Journal of the Soil Mechanics and Foundations Division Proceedings of the American Society of Civil Engineers*.

Seed, H. B., and Idriss, 1. M. (1971). "Simplified Procedure for Evaluating Soil Liquefaction Potential," *Journal of the Soil Mechanics and Foundations Division,* ASCE, Vol. 97, SM9, pp. 1249-1273.

Seed, H. B., and Lee, K. L. (1966). “ Liquefaction of Saturated Sands During Cyclic Loading.” *Journal of the Soil Mechanics and Foundations Division*, 92(6), 105–134.

Paleoseismic Studies Using Geophysical Techniques: Sand Blow Features in Eastern Arkansas

A Dissertation Presentation Prepared by

Rauf Hussein

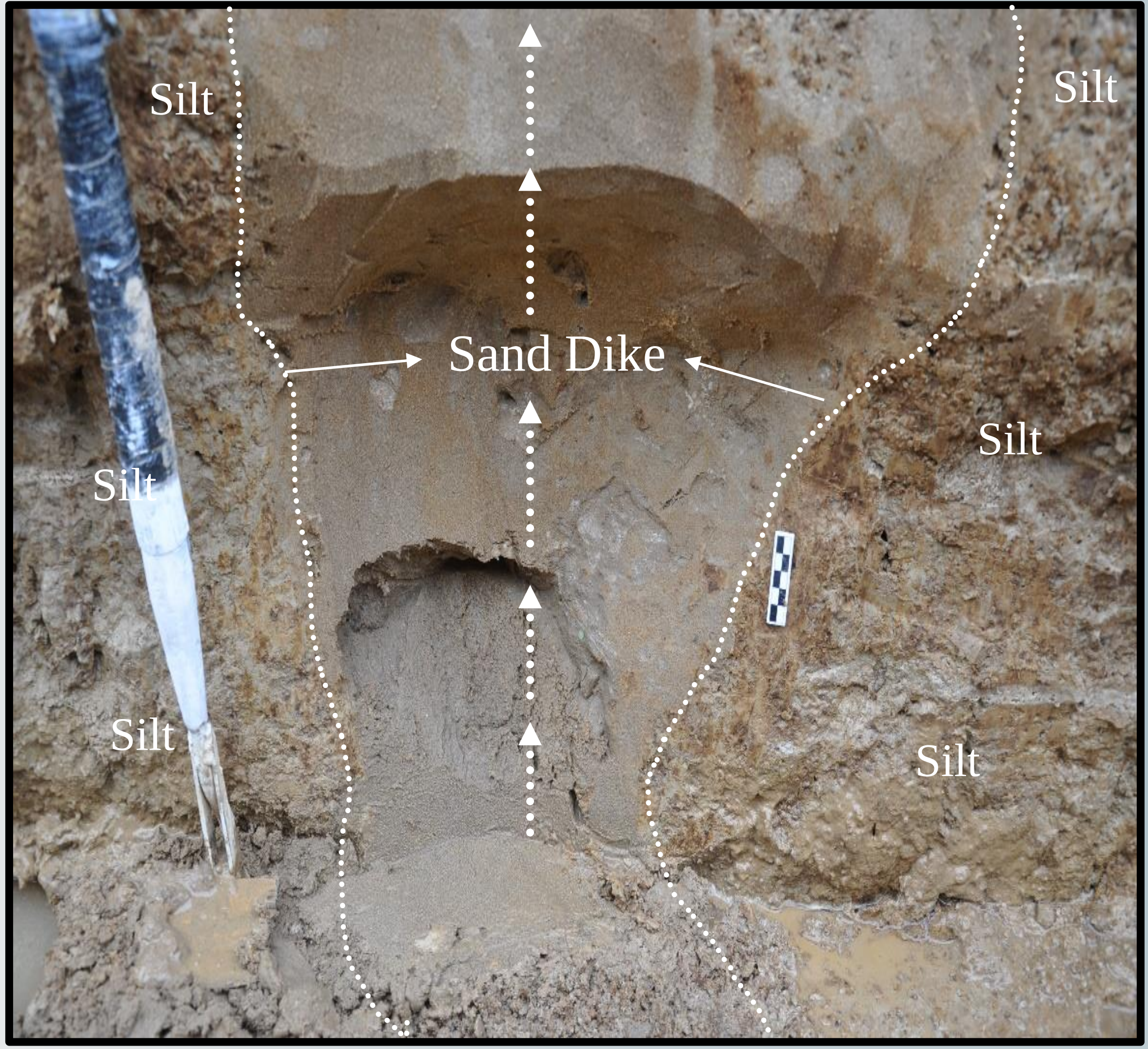
University of Arkansas at Little Rock

September 2020

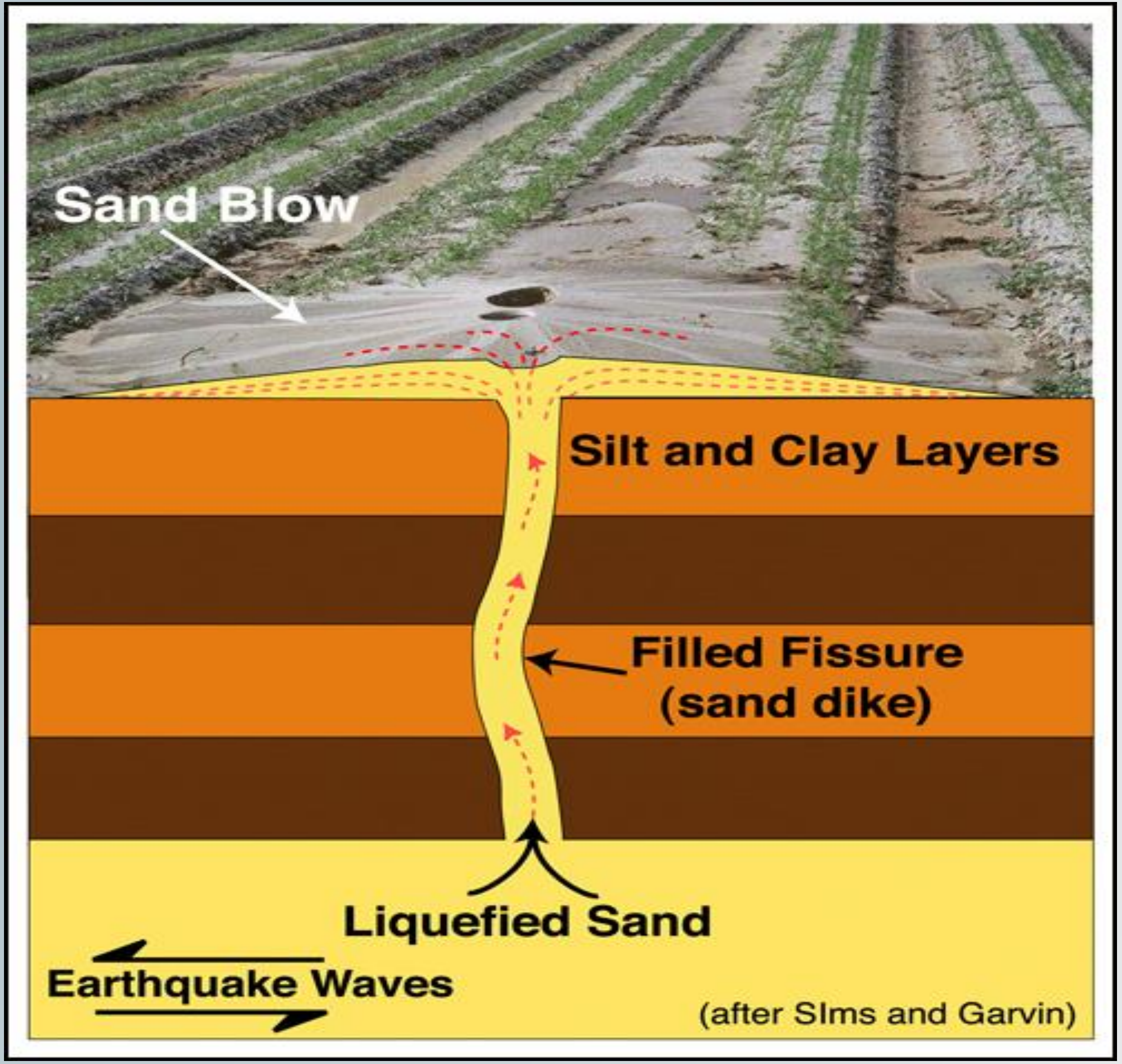
Outline:

- **What are Sand Blows?**
- **Why Do We Need to Study Them?**
- **What is Geophysics?**
- **Site Location**
- **Problem Statement and Main Objectives**
- **Significance of the Study**
- **Methodology and Data Collection:**
  - **GIS Analysis**
  - **GPR Analysis**
  - **Paleoseismic Investigations (Trenching, Logging, Sampling, Dating and Magnitude Estimation)**
- **Results and Discussions**
- **Conclusions, Recommendations and Future Work**

What are Sand Blows?



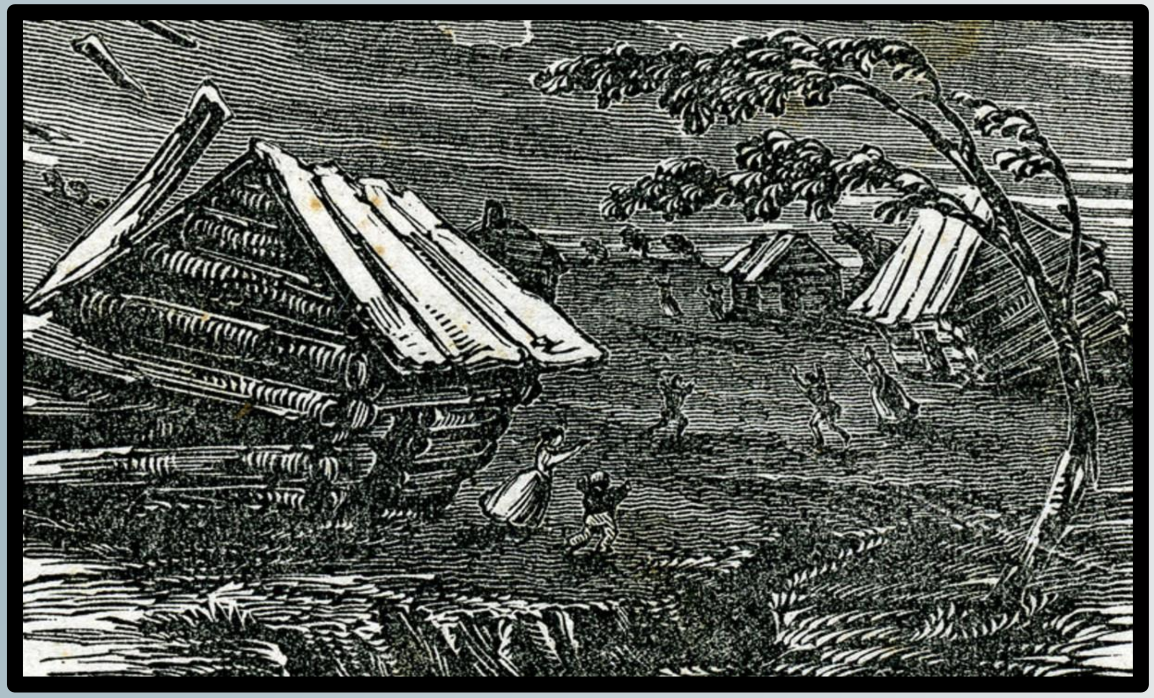
Photograph showing a sand dike in the Marianna area.



Schematic showing a sand dike and sand blow (from USGS).

Why Do We Need to Study Them?

Damage in Boston from 1755 Cape Ann earthquake (SSA, 2018).



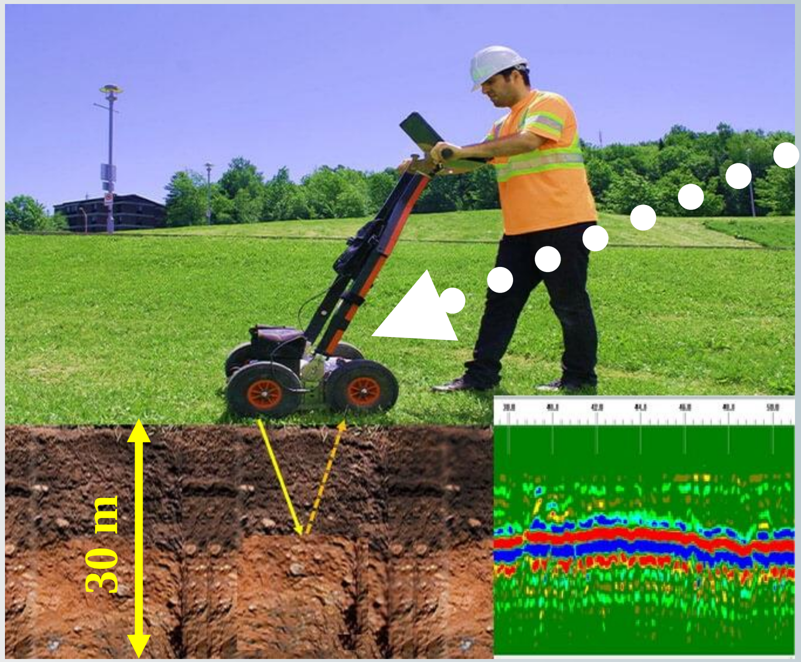
The great earthquake at New Madrid (1811-1812) (Howe, 2019).

"The Past Informs the Future" (USGS).

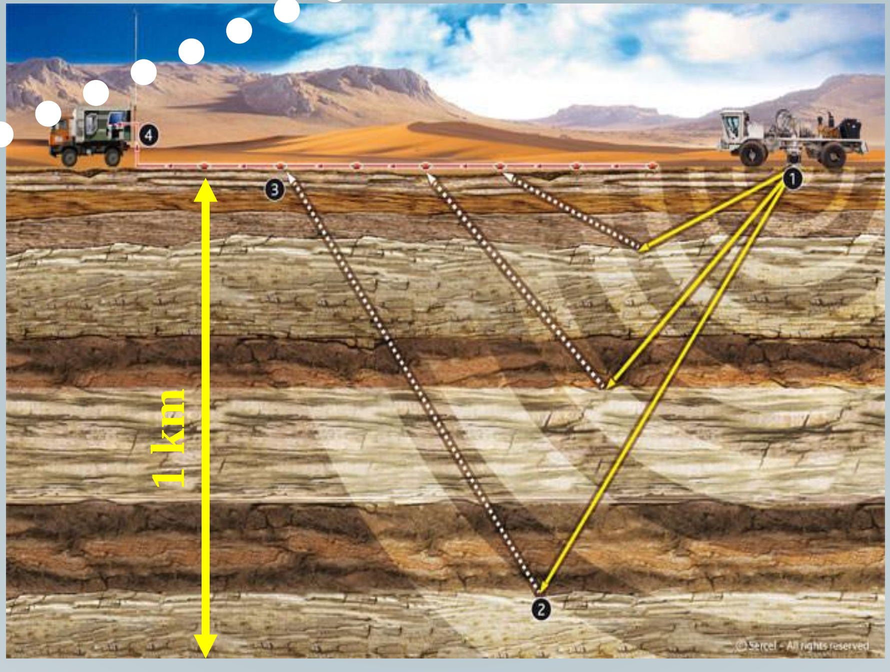
What is Geophysics?

Geophysics is a subject of natural science concerned with the physical properties of the Earth.

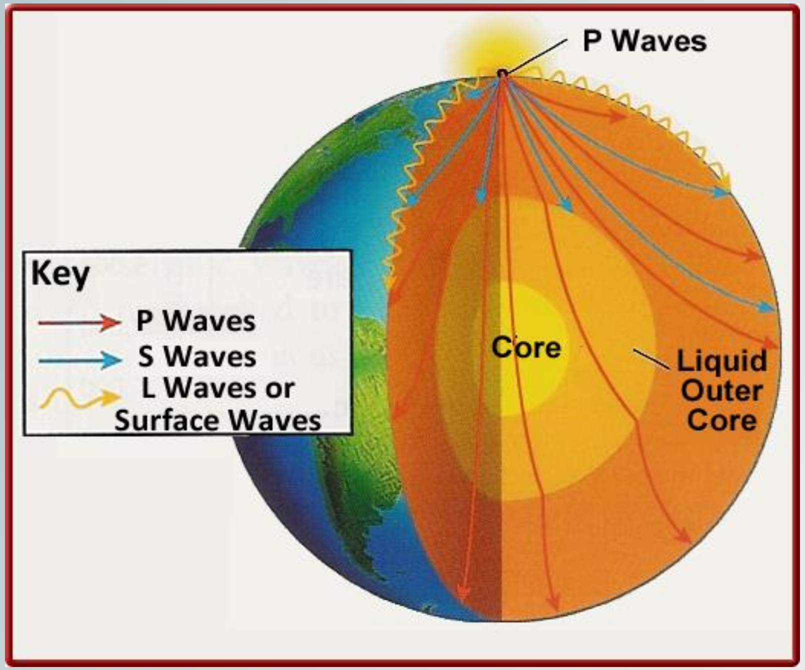
- Gravity
- Magnetics
- Resistivity
- Seismic
- Ground penetrating radar (GPR)



GPR method (FPrimeC, 2016).

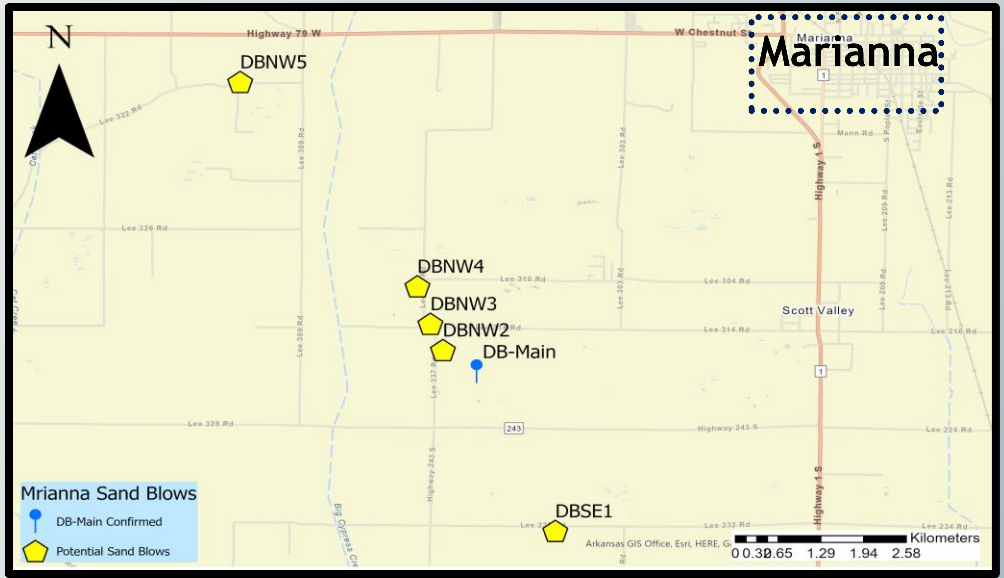


Seismic Reflection (Sercel, 2020).

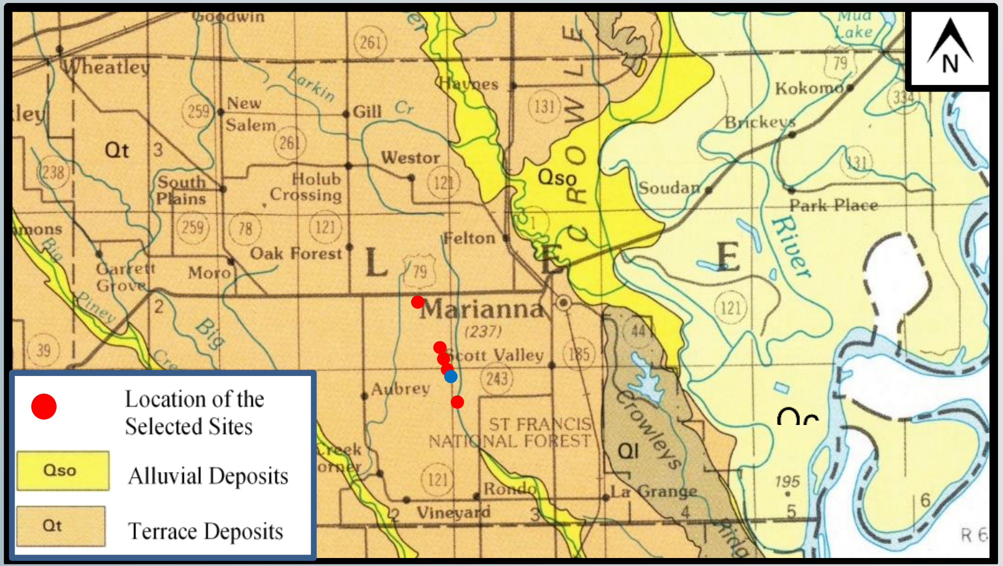


Seismic waves travel through the earth (Arif, 2017).

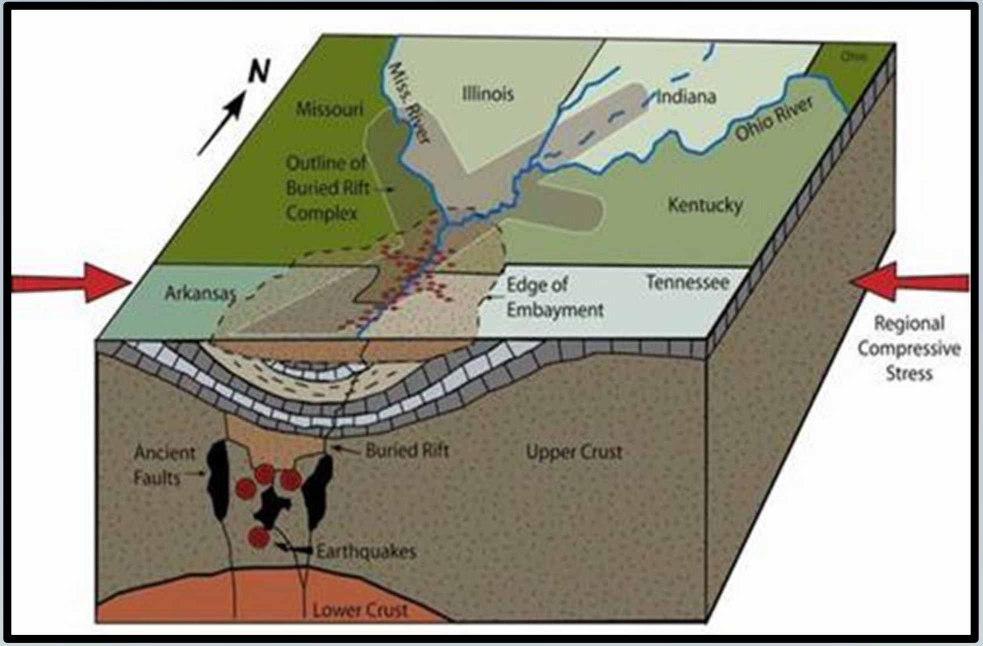
Location of the Study Area?



GIS Map Showing the Geographic Location of the Study Area.



Geologic Map of Lee County, Arkansas. Modified from (Haley, 1993).



Tectonic Setting of the Study Area by (Ebersole, n. d.).

Problem Statement and Main Objectives?

- **Studies have shown that information about earthquakes is incomplete.**
- **Other information is not totally understood.**
- **The objective of this study is to use GPR for sand blow investigations.**
- **The integration of GIS, satellite images as well as orthoimageries can be a powerful tool for sand blow studies.**

Significance of the Study?

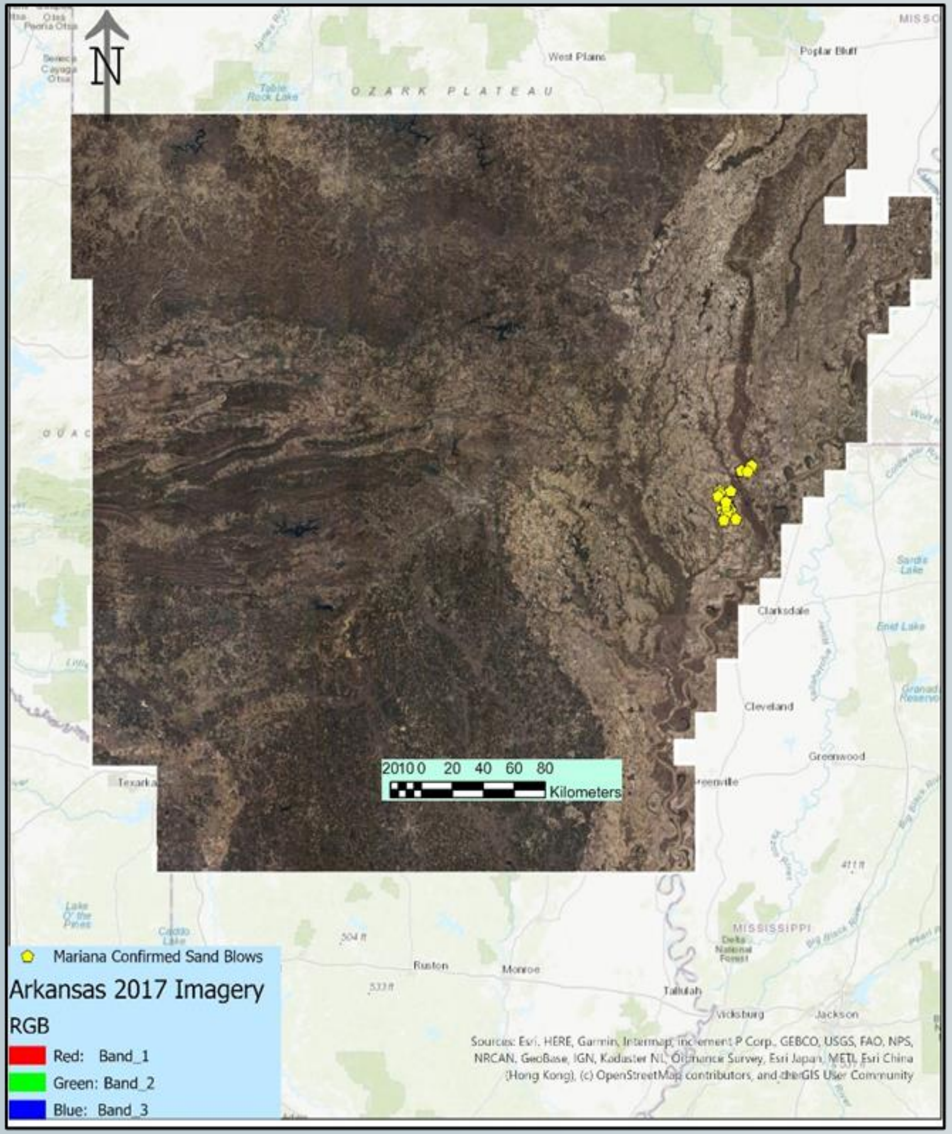
- **The findings of this study will improve the seismic risk assessment process for engineering applications.**

Earthquake-resistant construction (EKU, 2020).

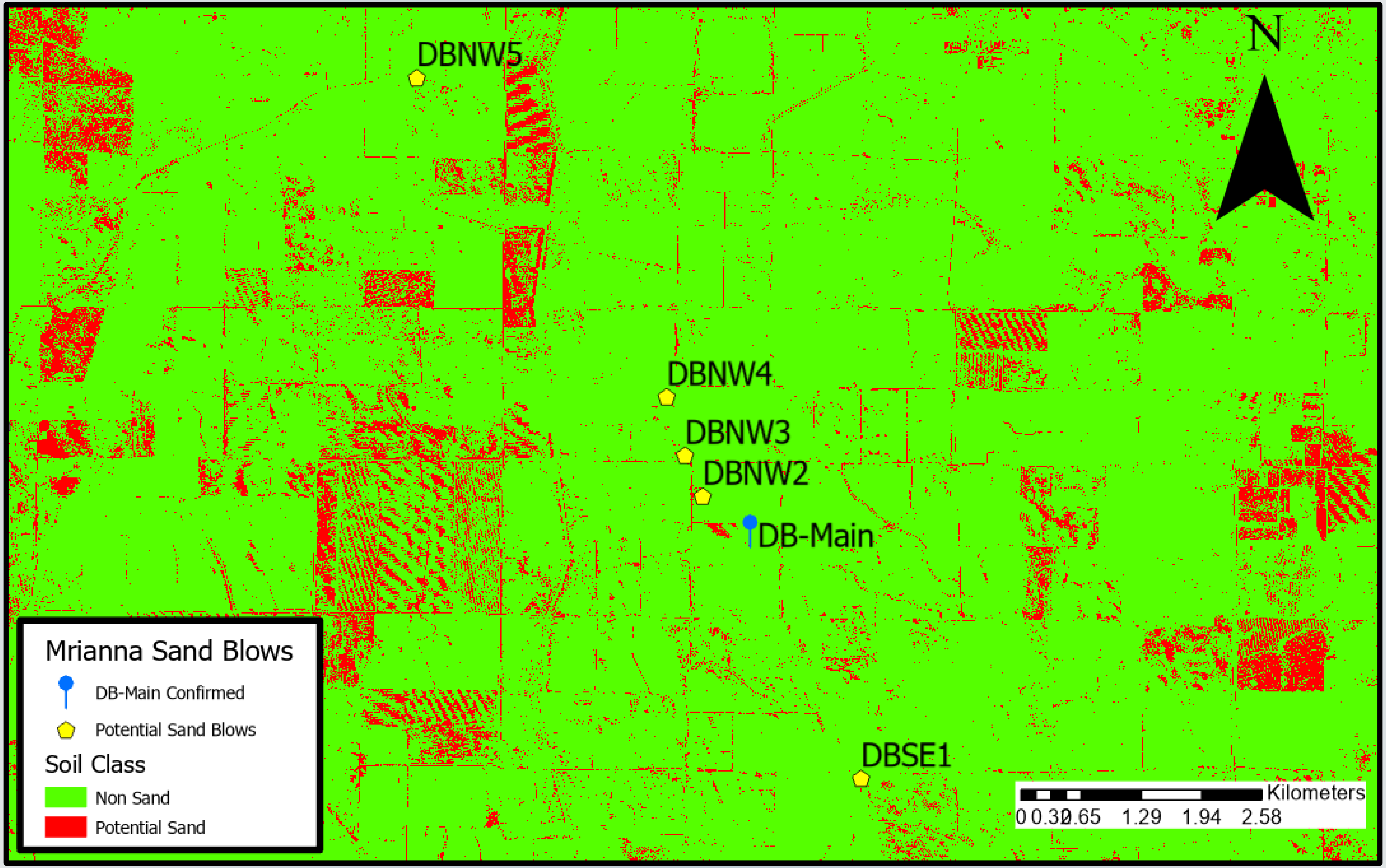
Technical Approach and Data Collection:

1- GIS Analysis:

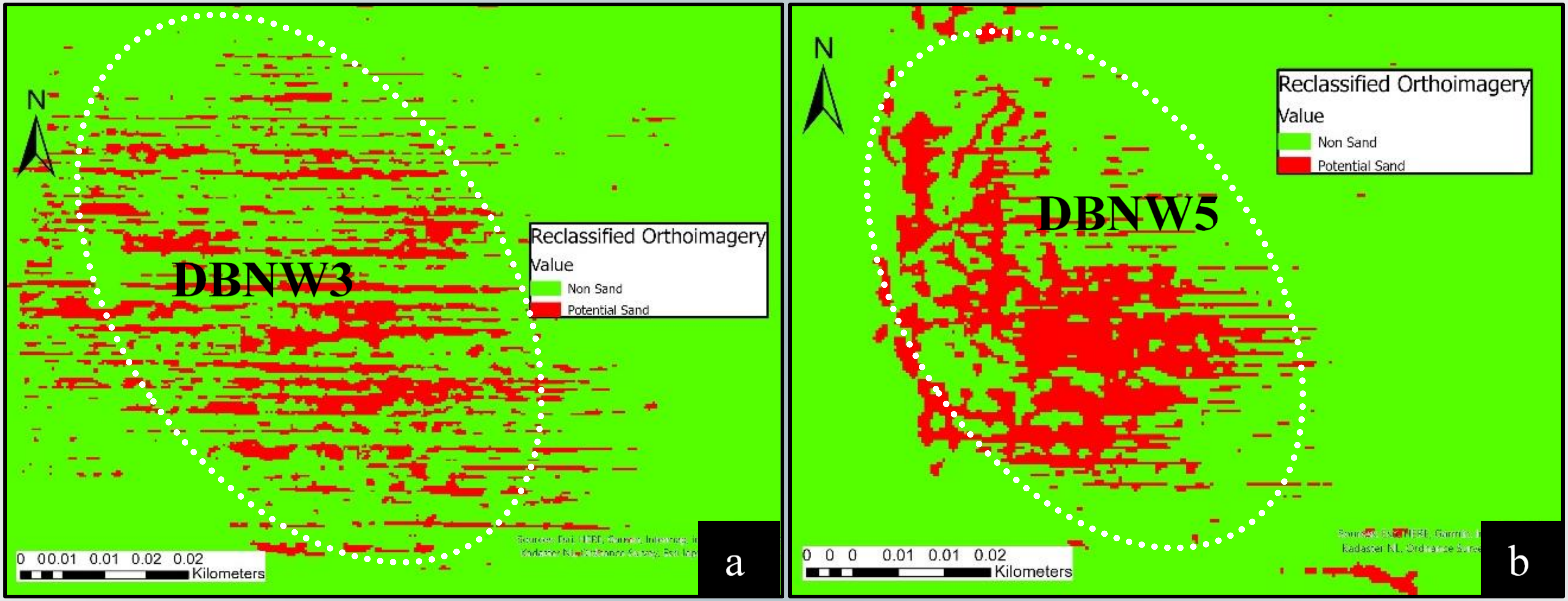
- The confirmed sand blows: RGB values (>180).
- The surrounding area: RGB values (<180).



Unprocessed GIS map showing a 30-cm resolution orthoimagery for the state of Arkansas. The yellow circles indicate the confirmed sand blows at Marianna area.

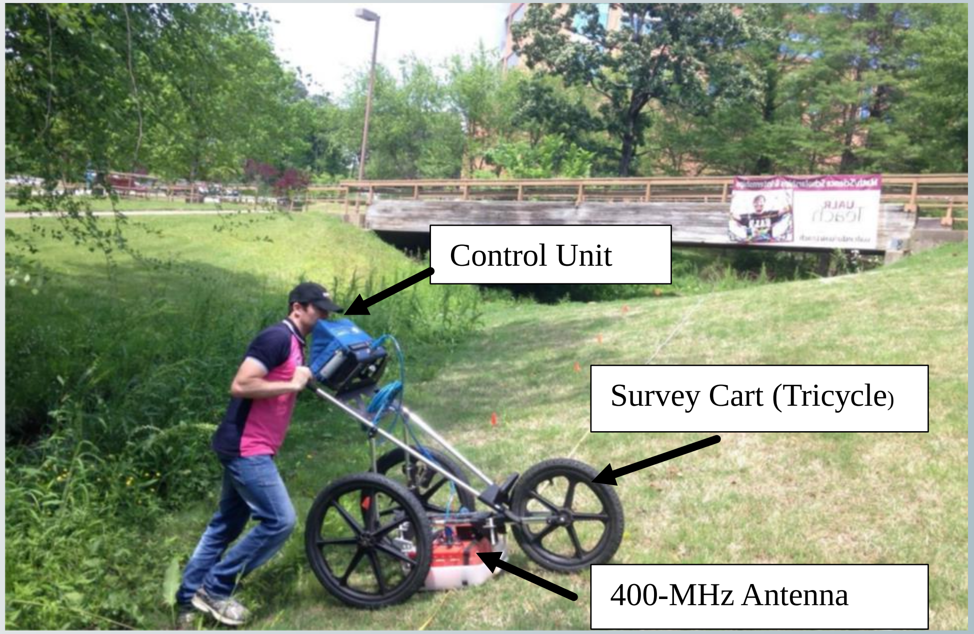


Processed-reclassified GIS map showing the location of potential sandy surfaces at Marianna area.

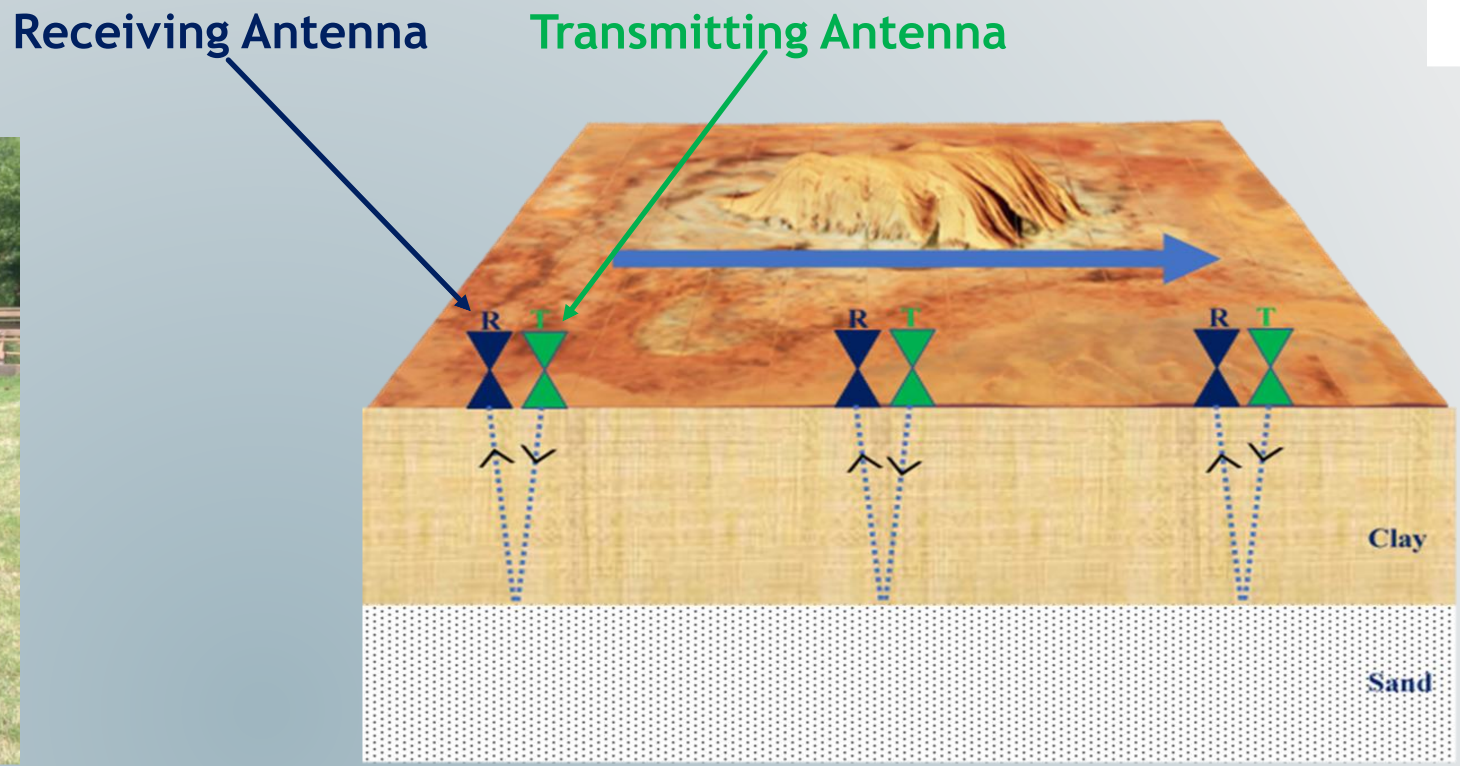


Zoomed-in reclassified GIS maps showing sandy surfaces (red color) and non-sandy surfaces (green color): a) Potential sand blow at DBNW3, and b) Potential sand blow at DBNW5.

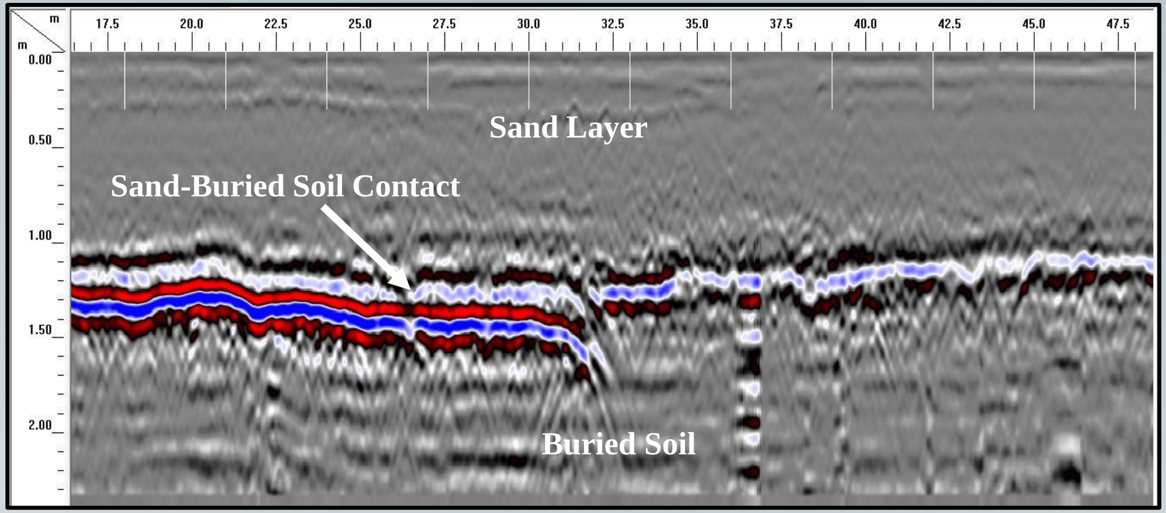
2- *GPR Application:*



Complete GPR system.



Schematic image showing reflection GPR mode.

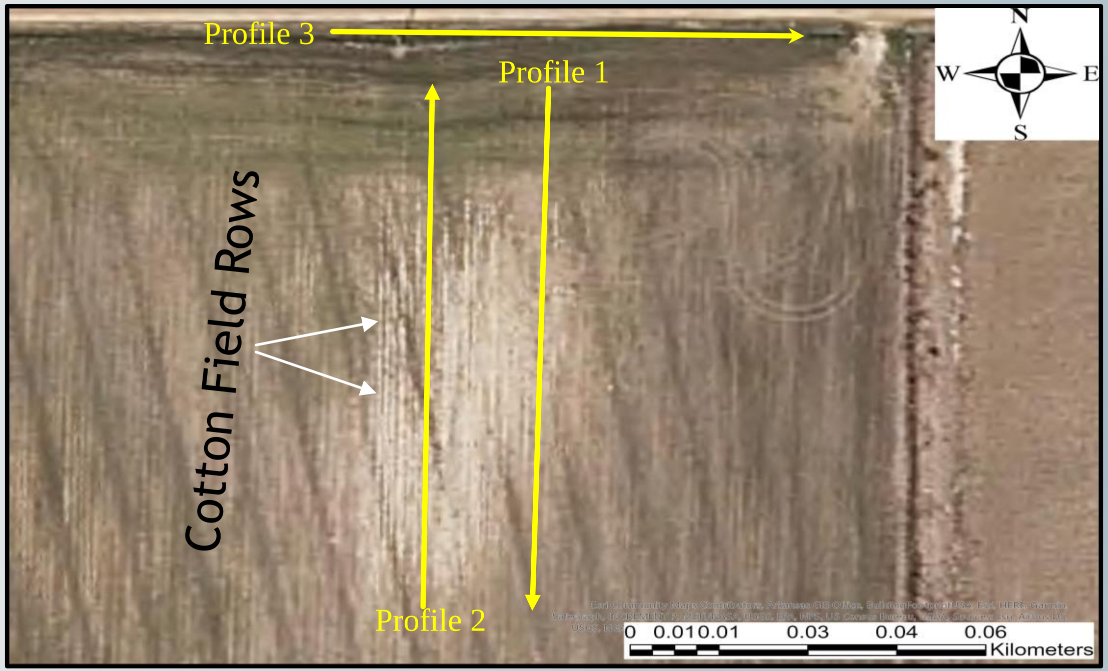


Processed GPR data collected at the Marinna area.

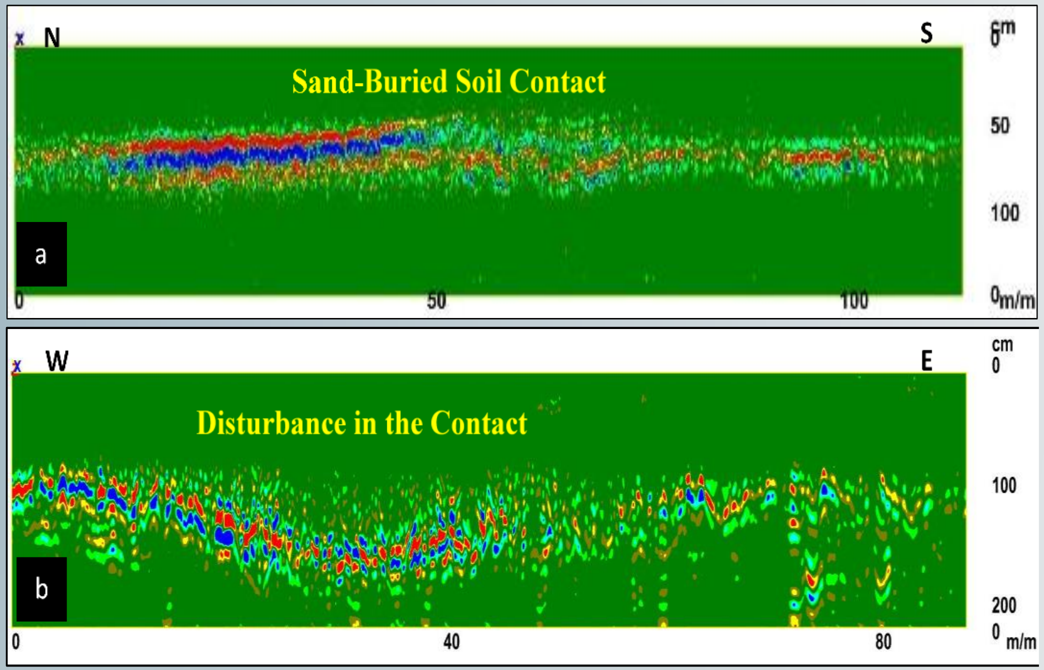
2.1– GPR Data Collection:

▶ Site 1 (DBSE1):

This site is located about 2.6 km to the southeast of DB-Main.



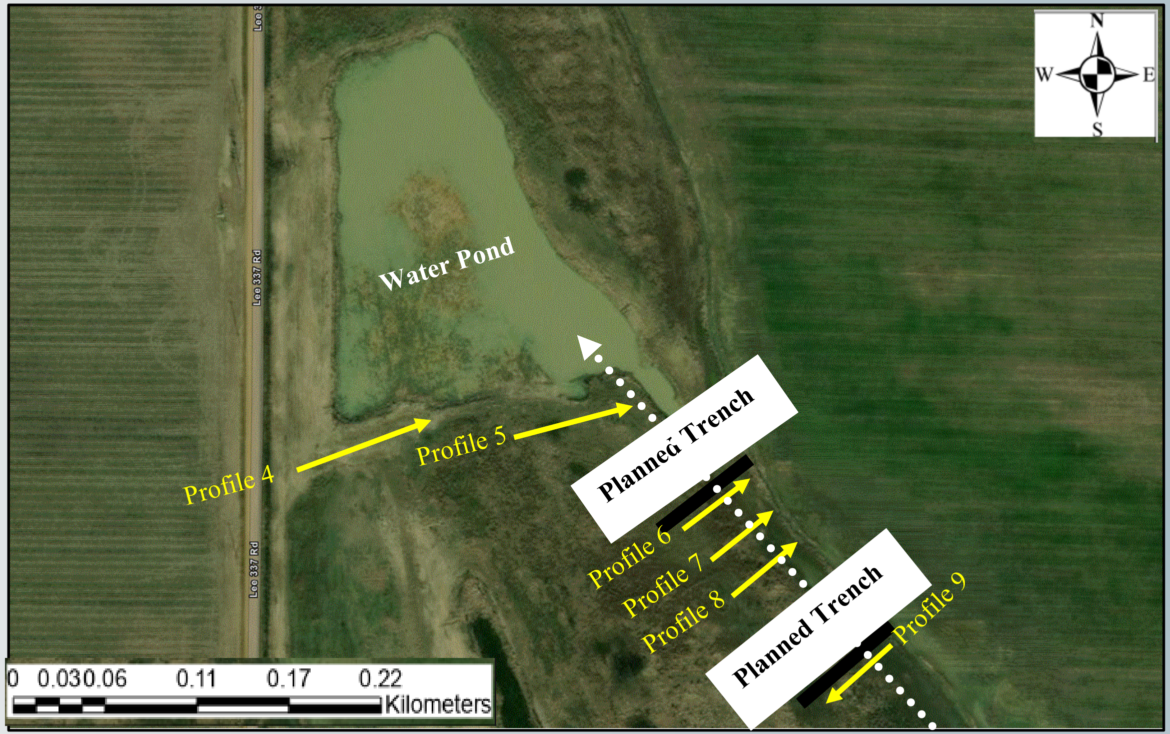
GIS Imagery showing the location of GPR profiles (yellow solid lines) collected on Site-1 (DBSE1). The light-colored soils indicate the location of the potential sand blow.



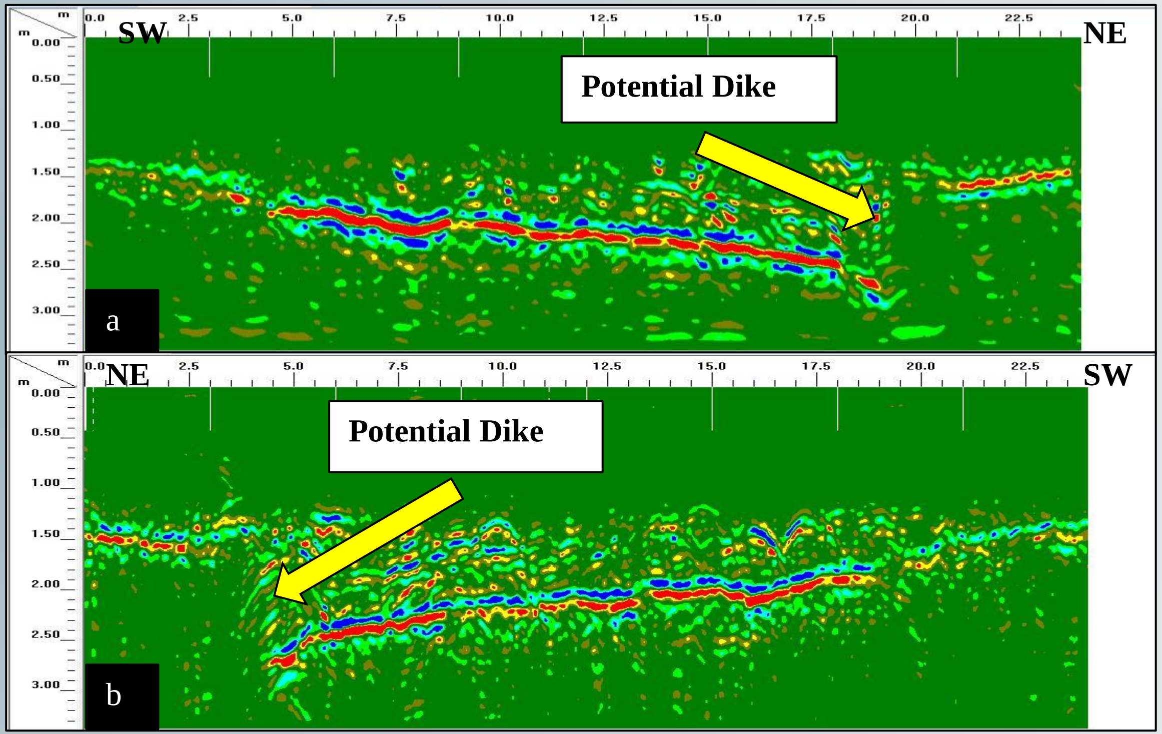
GPR data collected on Site-1 (DBSE1): a) GPR data of profile 1, and b) GPR data of profile 3.

▶ Site 2 (DBNW2):

This site is located about 0.5 km to the northwest of DB-Main.



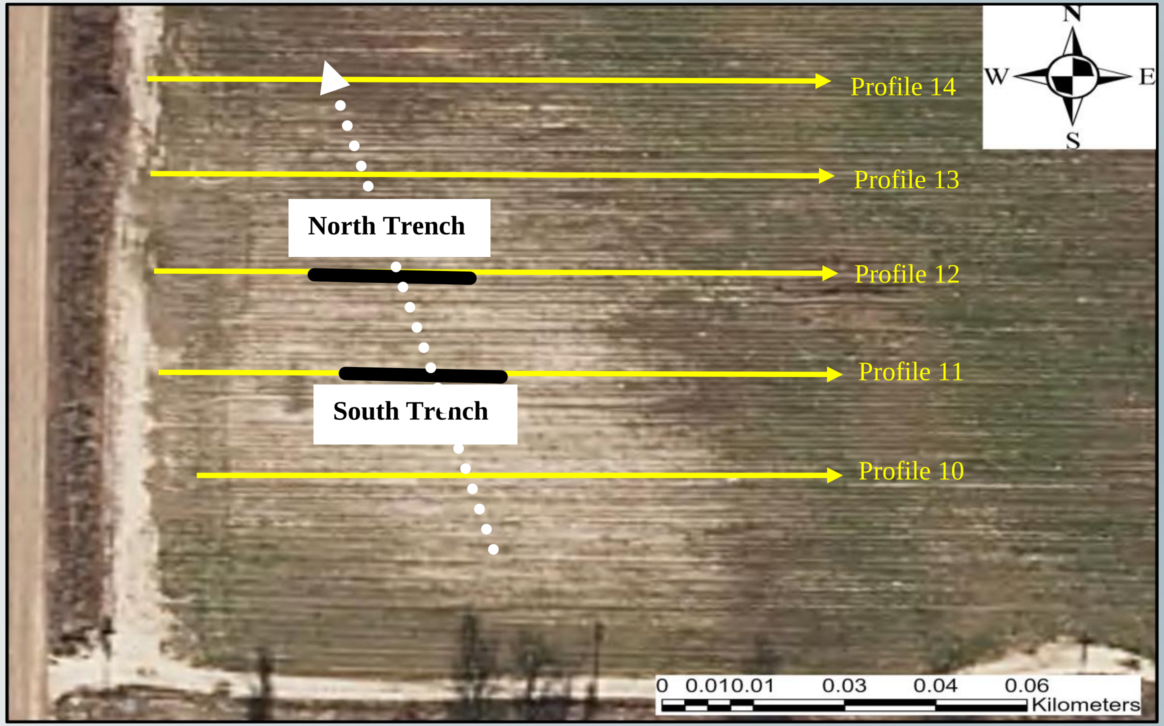
GIS Imagery showing the location of GPR profiles (yellow solid lines) collected on Site-2 (DBNW2). Black solid lines indicate the location of the planned trench sites.



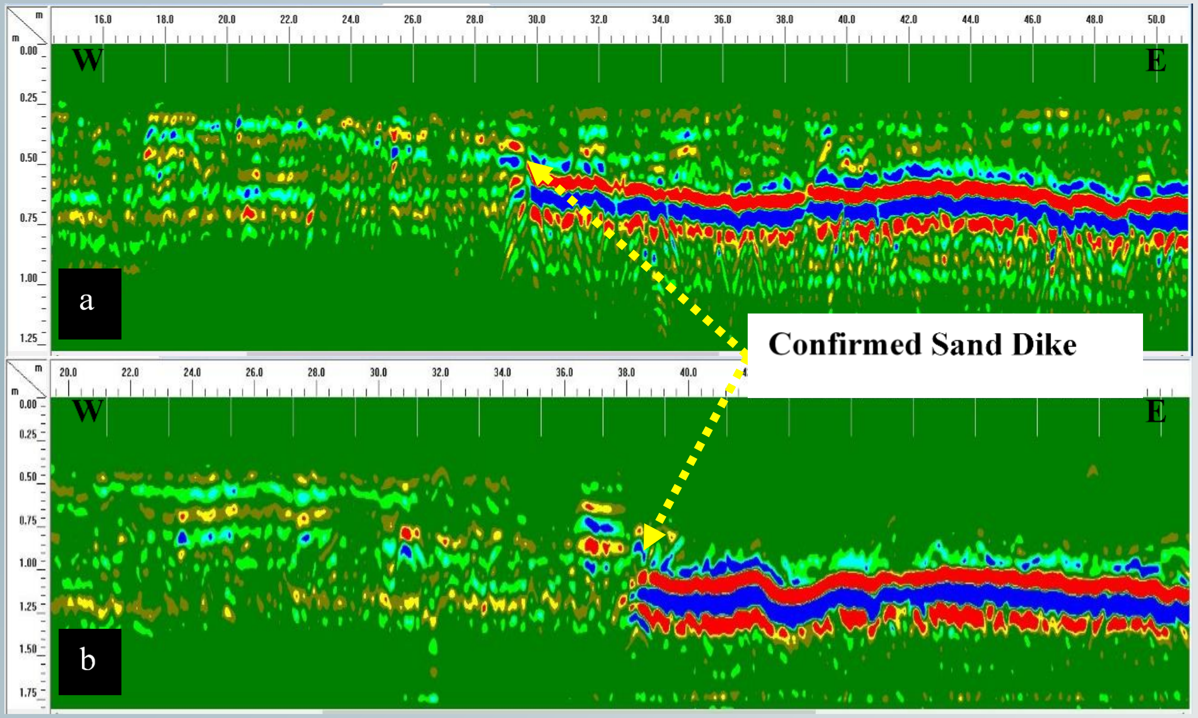
GPR data collected on Site-2 (DBNW2): a) GPR data of profile 6, and b) GPR data of profile 9.

Site 3 (DBNW3):

This site is located about 1.2 km to the northwest of DB-Main.



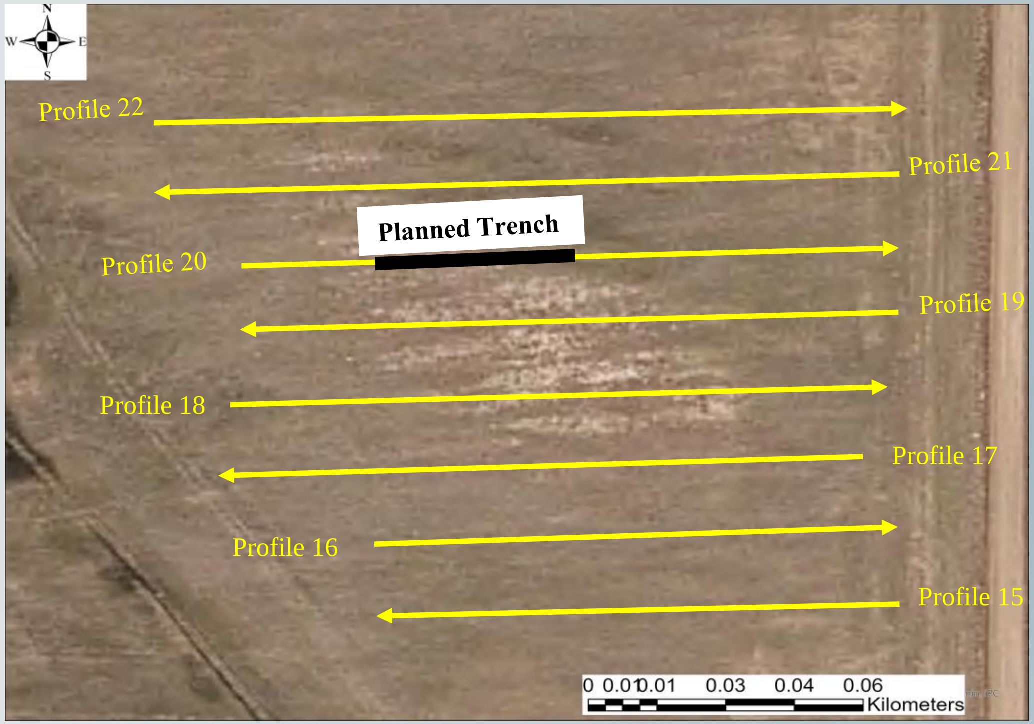
GIS Imagery showing the location of GPR profiles (yellow solid lines) collected on Site-3 (DBNW3). Black solid lines indicate the location of the trench sites. White dotted line indicates the strike direction of the sand dike.



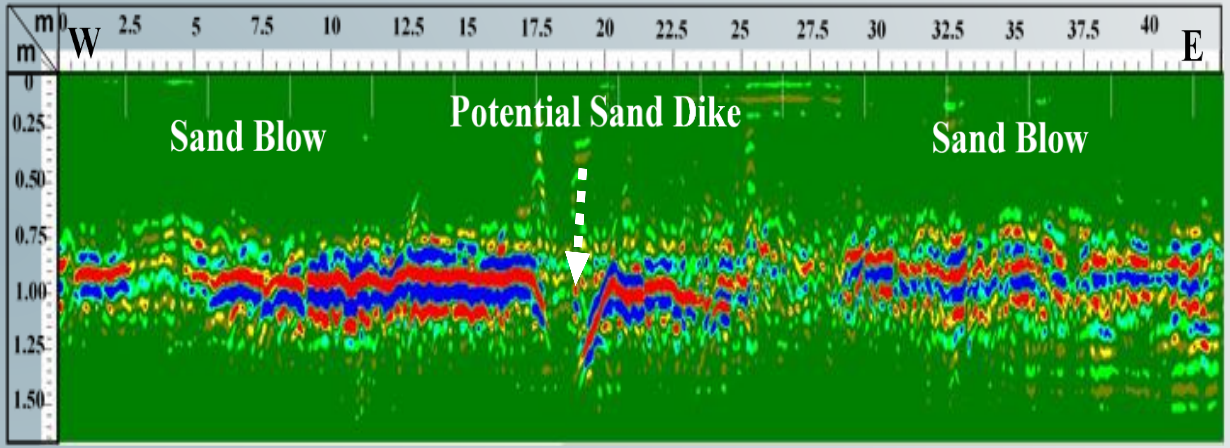
GPR data collected on Site-3 (DBNW3): a) GPR data of profile 12, and b) GPR data of profile 11.

▶ Site 4 (DBNW4):

This site is located about 1.8 km to the northwest of DB-Main.



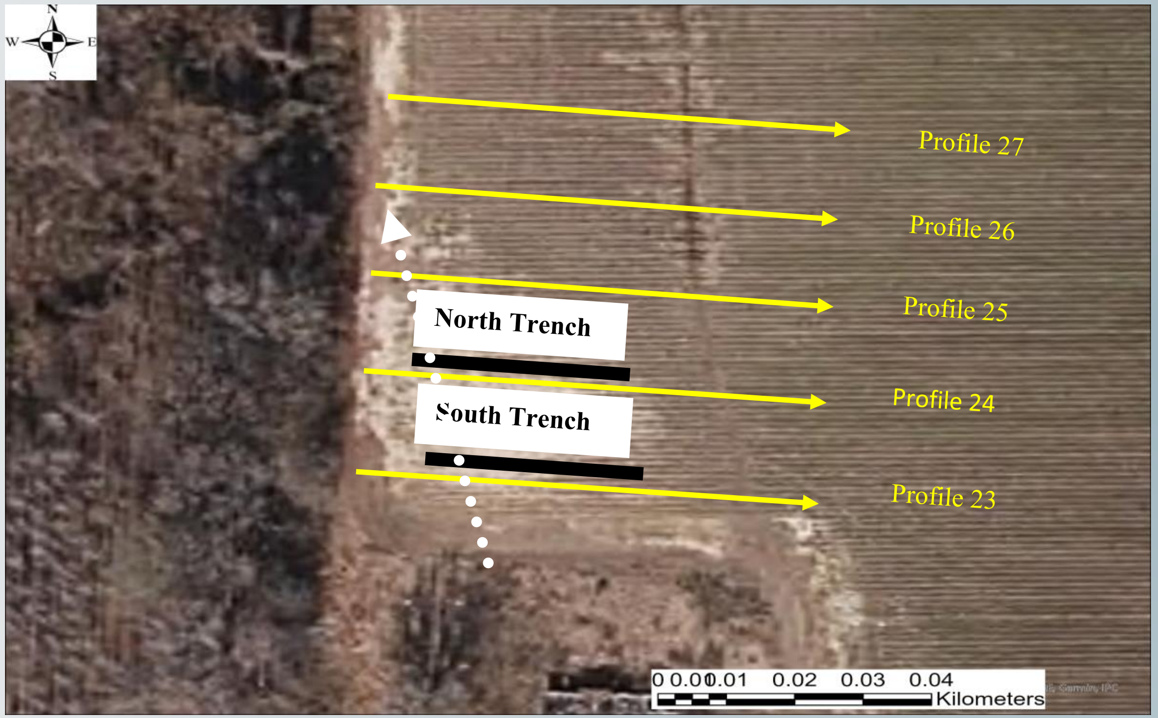
GIS Imagery showing the location of GPR profiles (yellow solid lines) collected on Site-4 (DBNW4). Black solid line indicates the location of the planned trench sites.



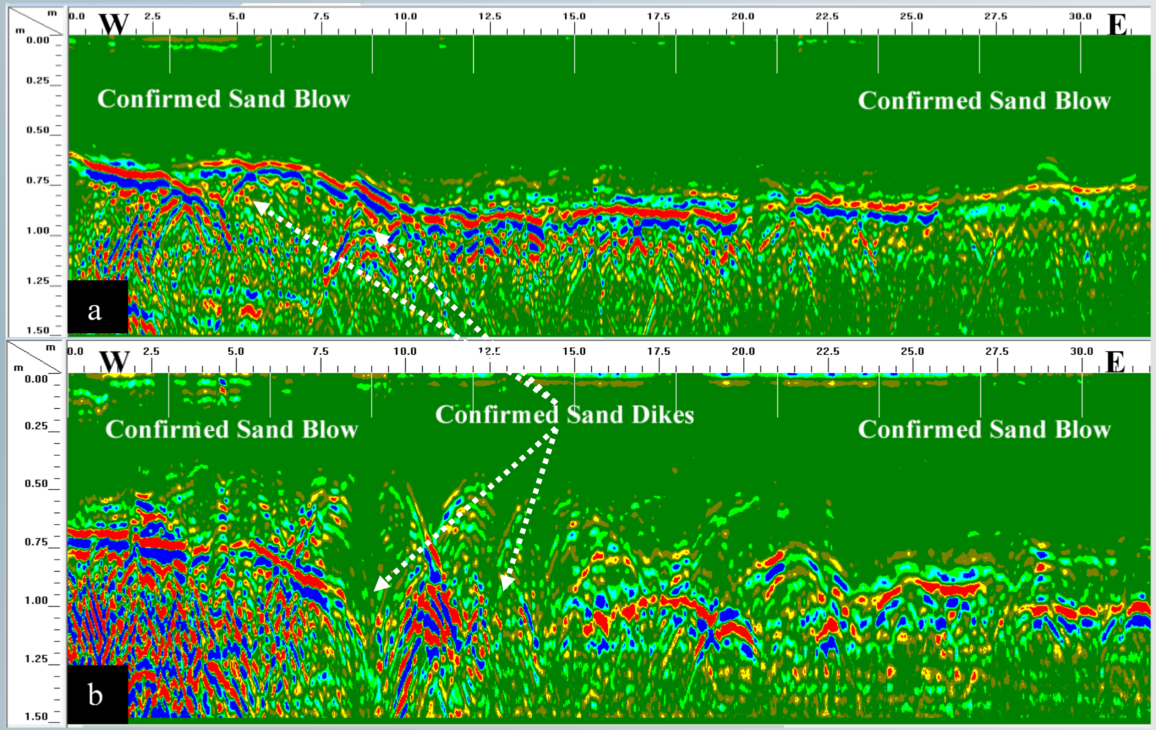
GPR data of profile 20 collected on Site-4 (DBNW4).

▶ Site 5 (DBNW5):

This site is located about 6 km to the northwest of DB-Main, which is the farthest site so far discovered in that direction.



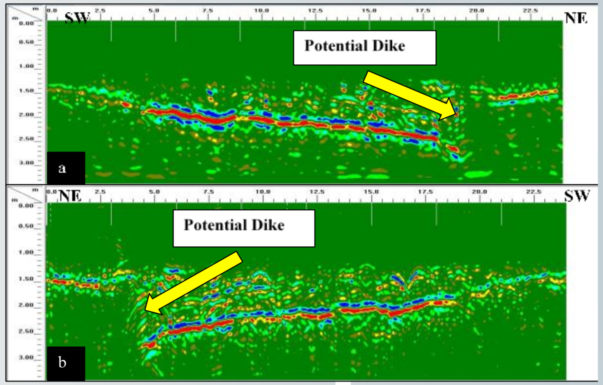
GIS Imagery showing the location of GPR profiles (yellow solid lines) collected on Site-5 (DBNW5). Black solid lines indicate the location of the trench sites. White dotted line indicates the strike direction of the sand dike.



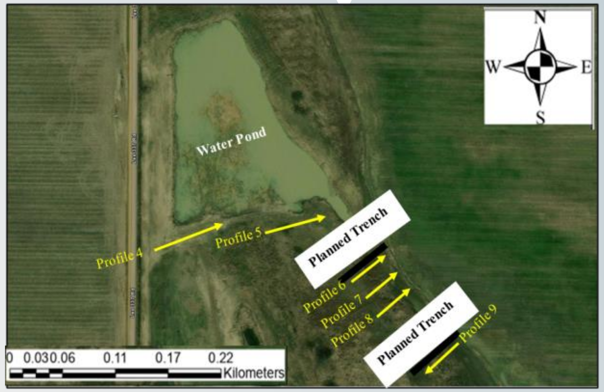
GPR data collected on Site-5 (DBNW5): a) GPR data of profile 24, and b) GPR data of profile 23.

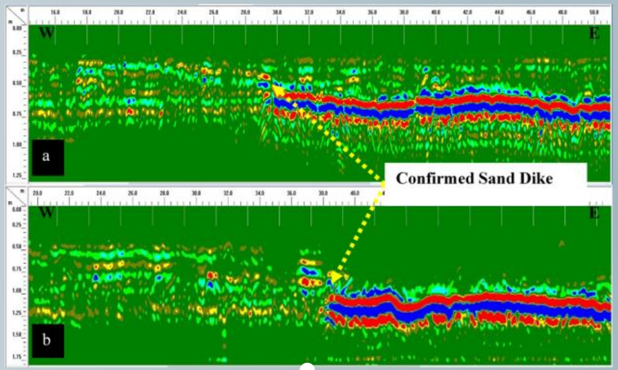
Summary of the GPR Results

GPR data was used to identify trench locations at four sites: DBNW2, DBNW3, DBNW4, and DBNW5, respectively.

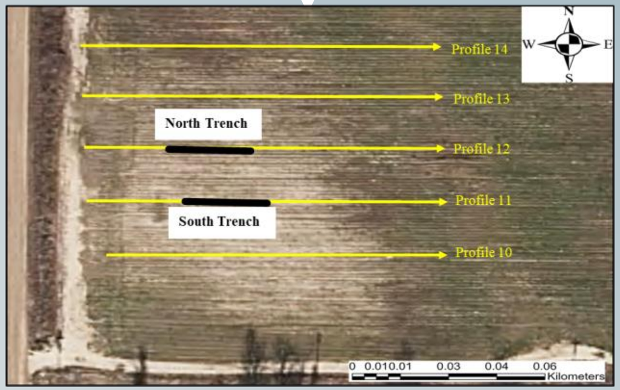


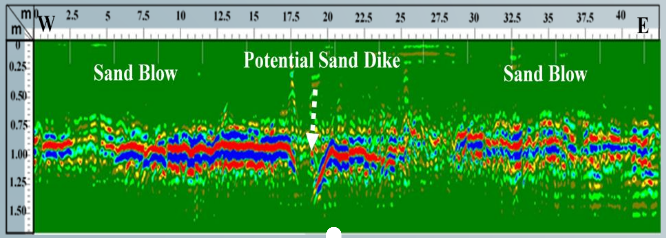
Daytona Beach Northwest 2



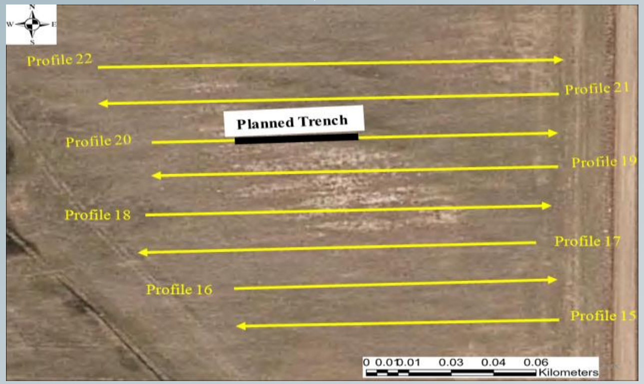


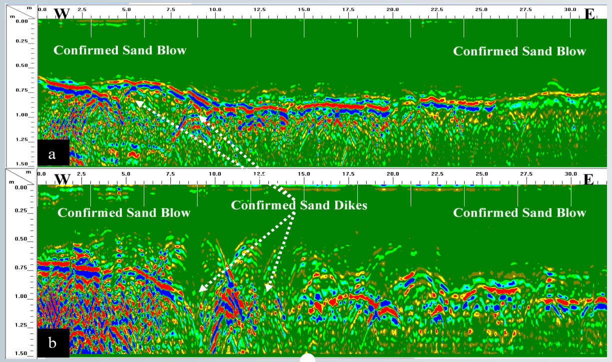
Daytona Beach Northwest 3



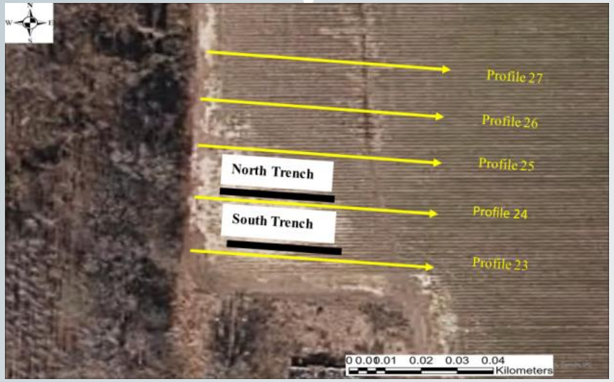


Daytona Beach Northwest 4





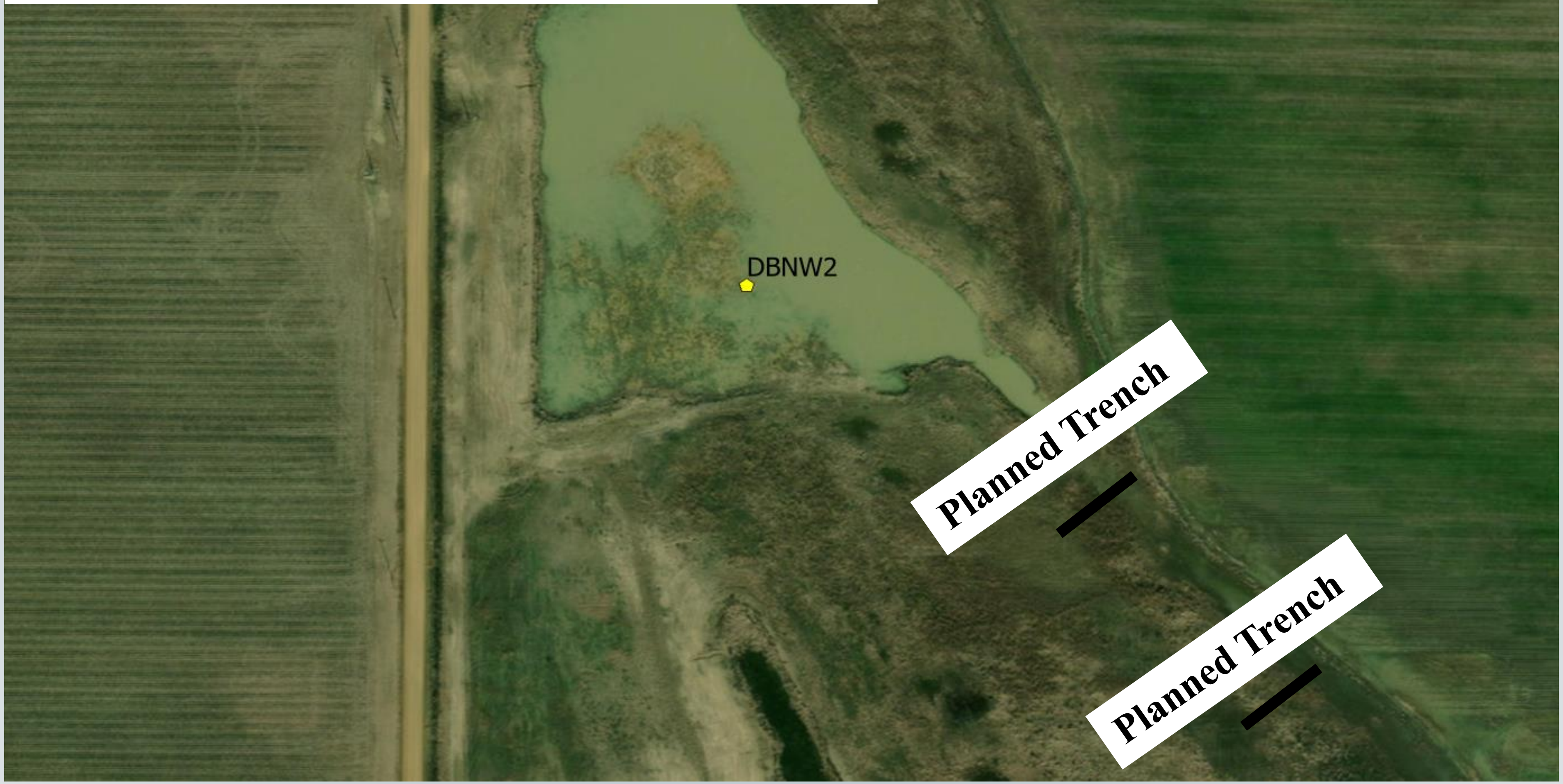
Daytona Beach Northwest 5



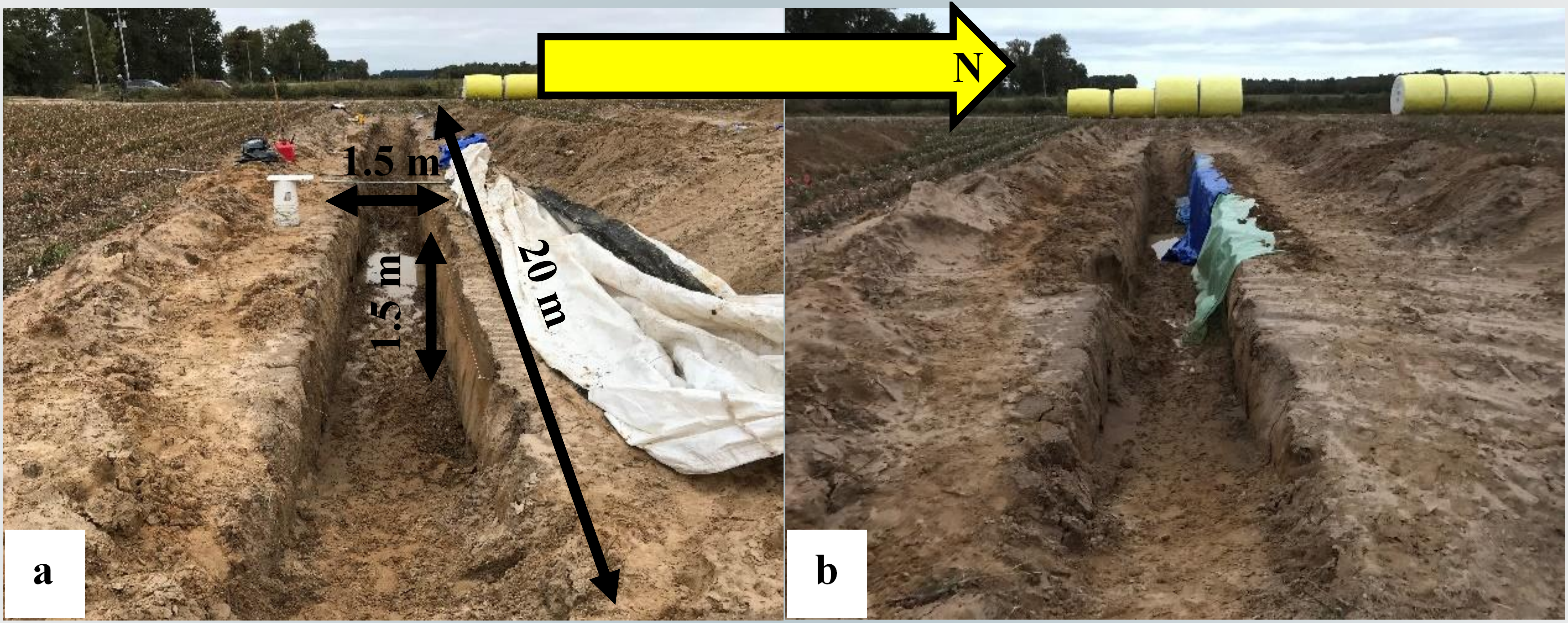
3- Paleoseismology Investigations:

3.1- Trenching:

- Trenching at Site 2 (DBNW2):



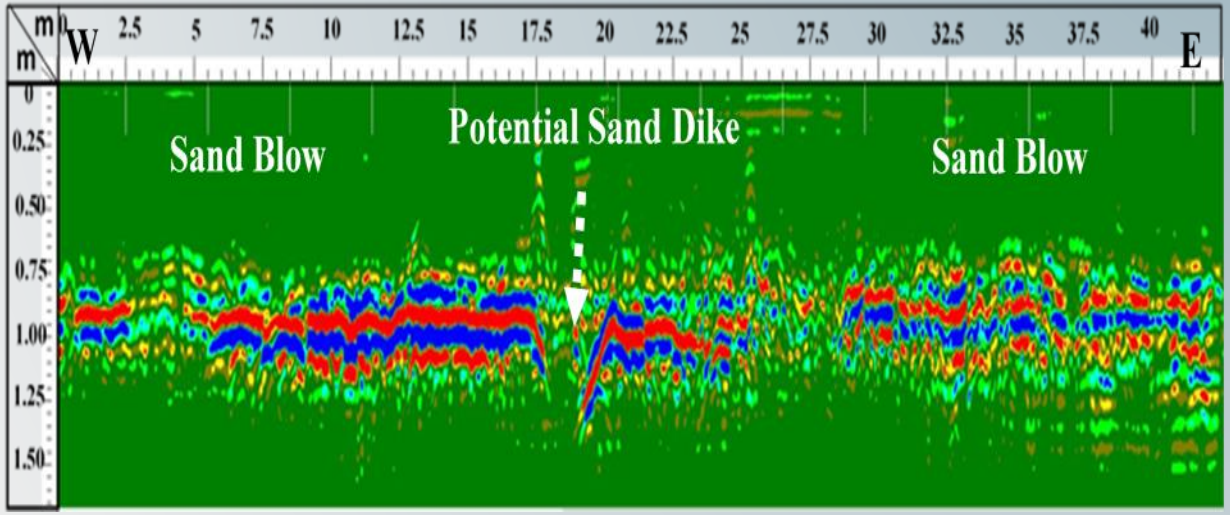
▶ Trenching at Site 3 (DBNW3):



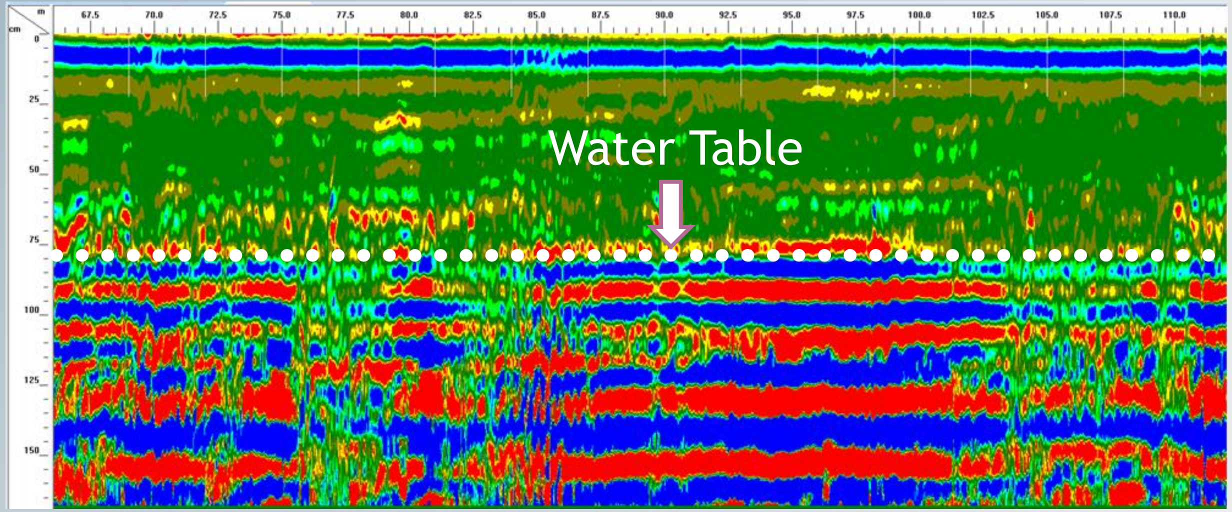
Photographs showing the trenches that were excavated at DBNW3: a) The southern trench (DBNW3S), and b) The northern trench (DBNW3N). The photographs point to the west.

Photograph showing the strike direction of the sand dike at DBNW3.

▶ Trenching at Site 4 (DBNW4):

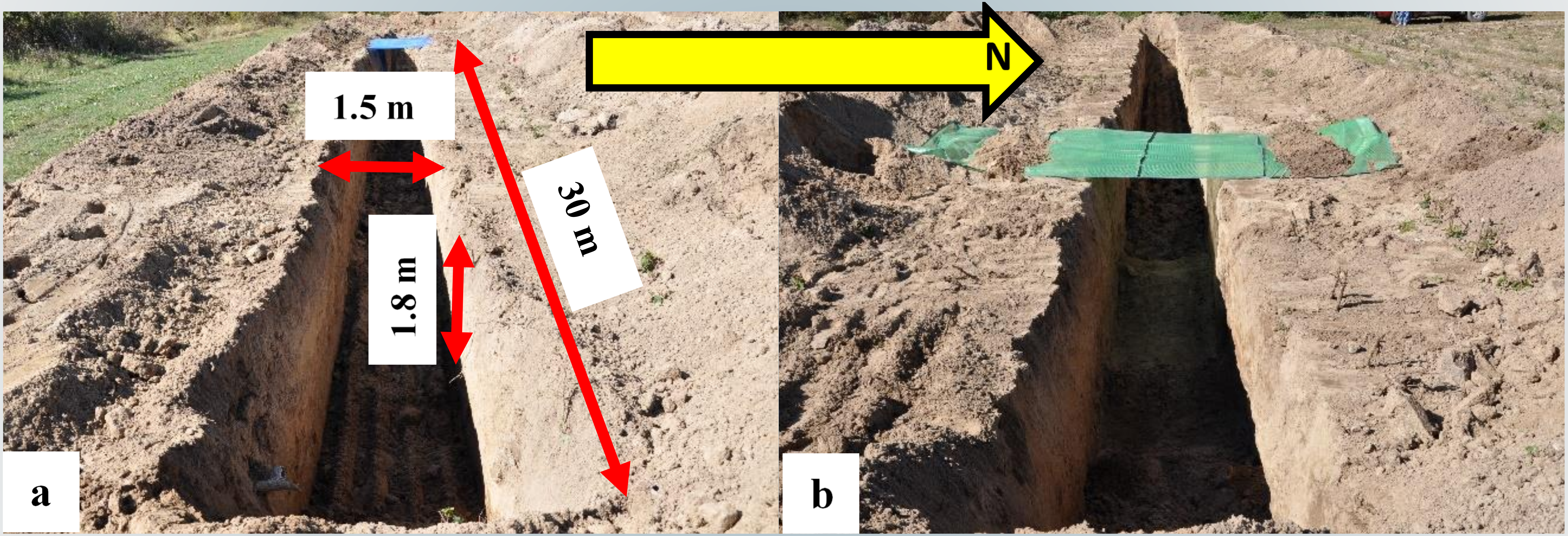


GPR data collected at Site DBNW4 before heavy rain on the region.



GPR data collected at Site DBNW4 after heavy rain on the region.

▶ Trenching at Site 5 (DBNW5):

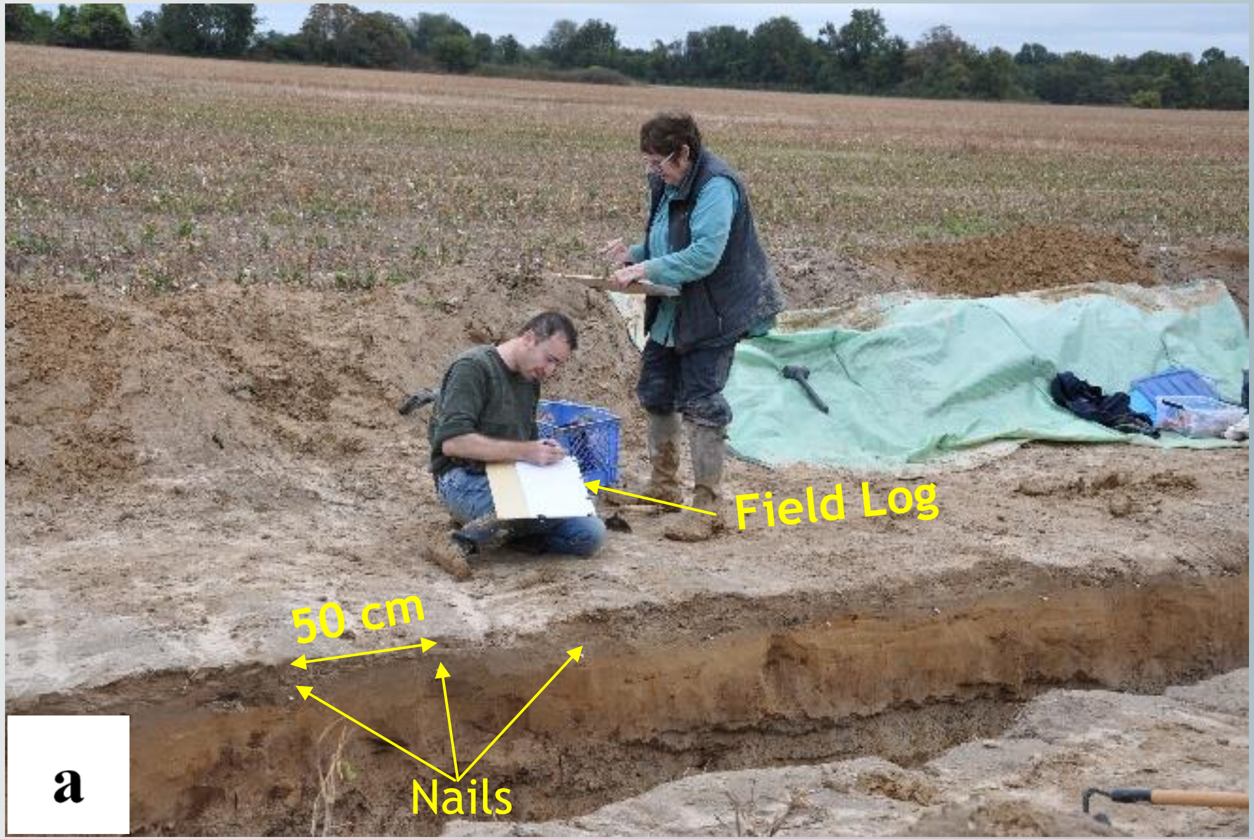


Photographs showing the trenches that were excavated at DBNW5: a) The southern trench (DBNW5S), and b) The northern trench (DBNW5N).

Photograph showing a large sand dike in the southern trench (DBNW5S).

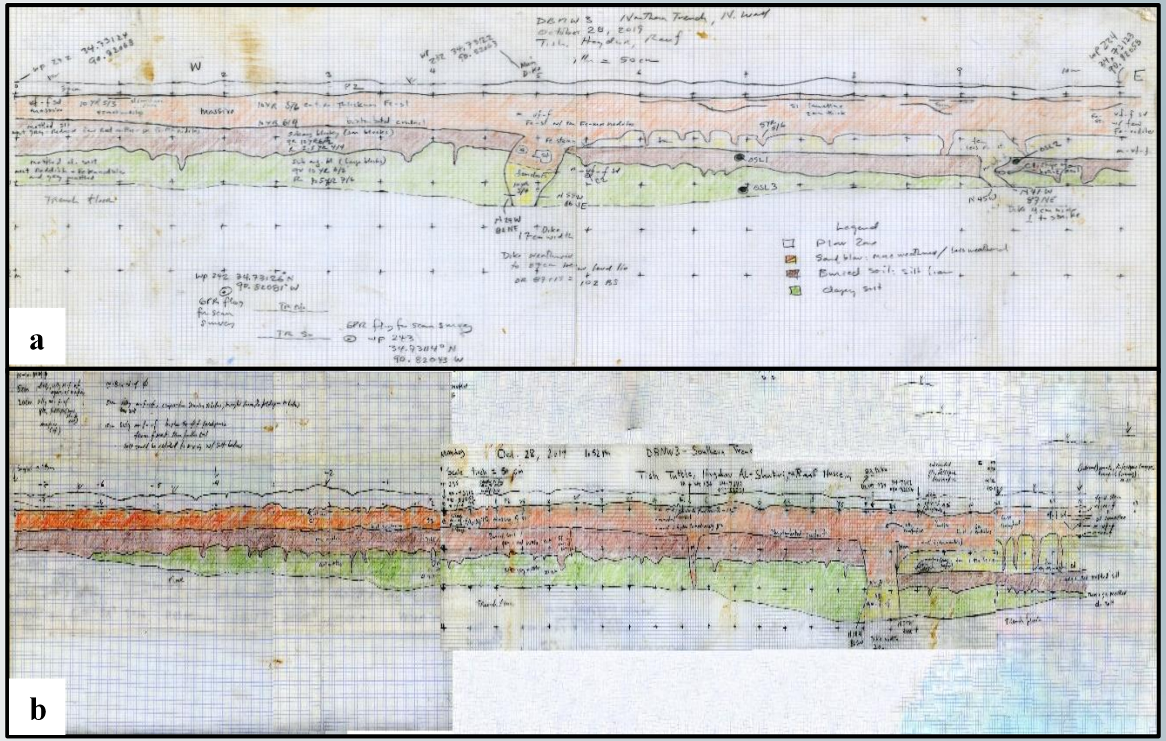
3.2- Logging:

Logging at Site-3 (DBNW3)

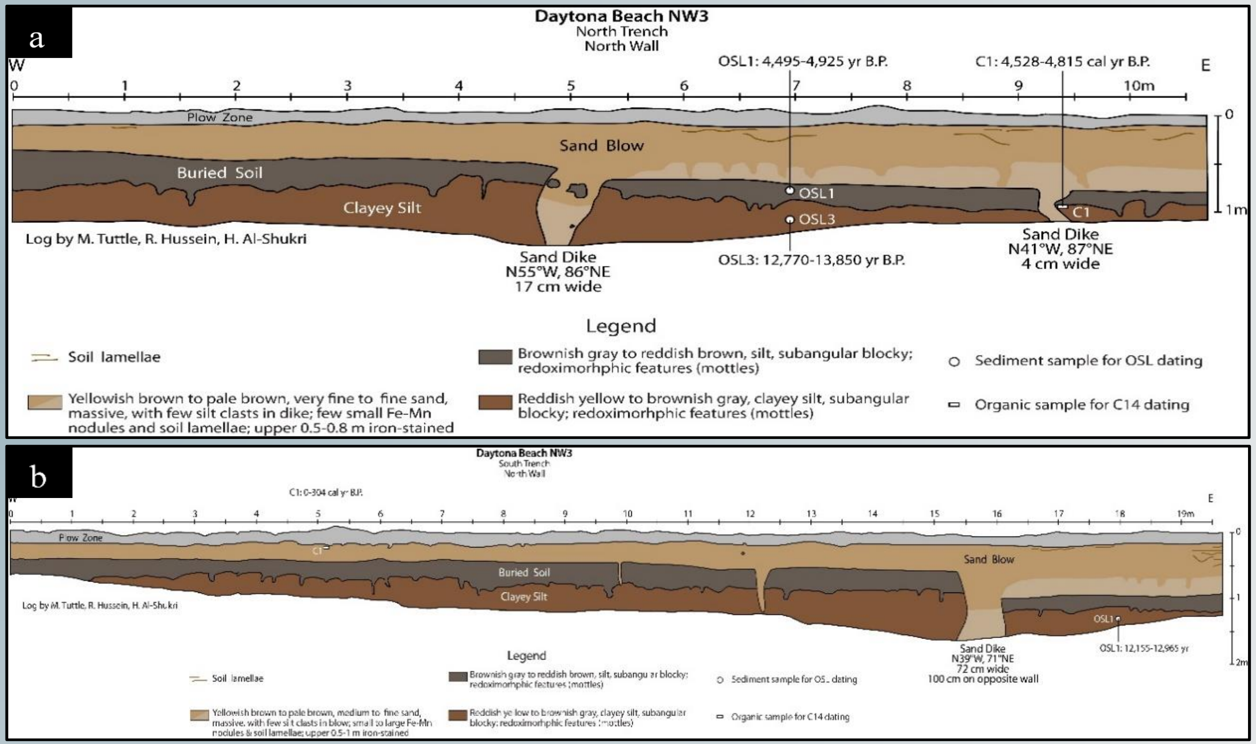


Photographs showing the logging work at DBNW3: a) Logging at the northern trench (DBNW3N), and b) Logging at the southern trench (DBNW3S).

Paleoseismological logs of Site-3 (DBNW3)

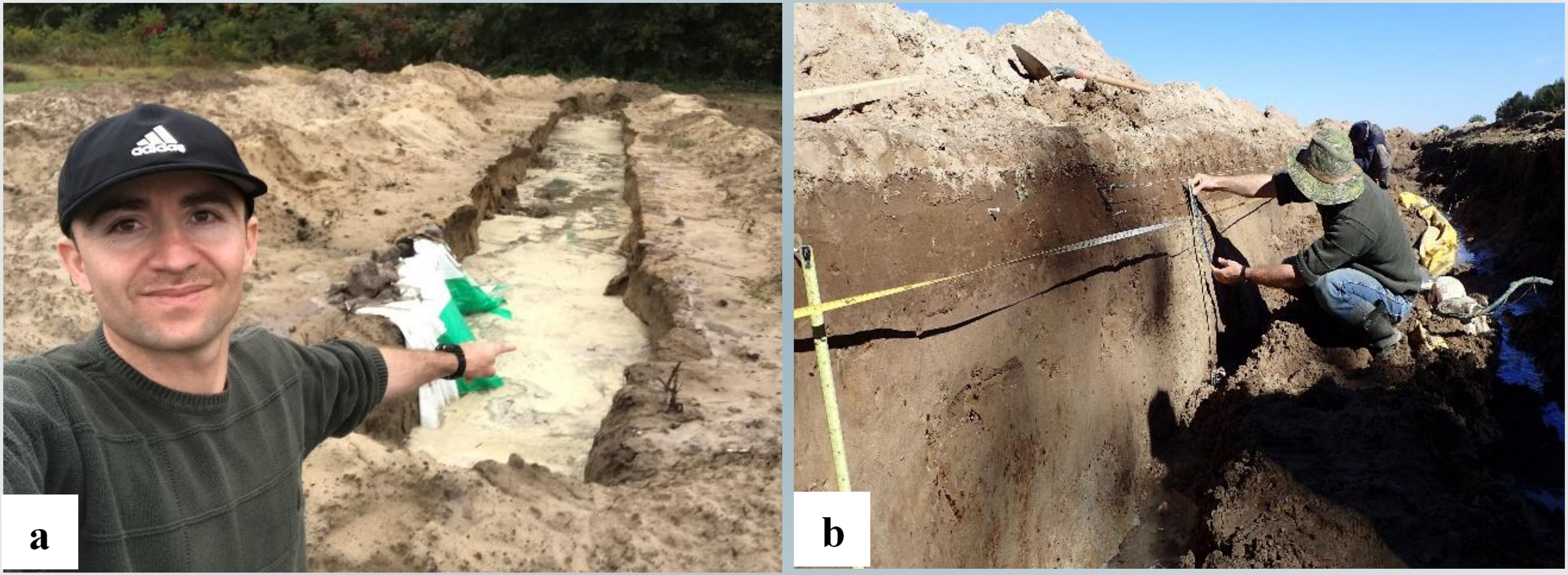


Capture images showing the recorded and drawn logs in the field for site 3 (DBNW3): a) Log of the northern trench (DBNW3N), and b) Log of the southern trench DBNW3S) by (M. Tuttle, R. Hussein and H. Al-Shukri).



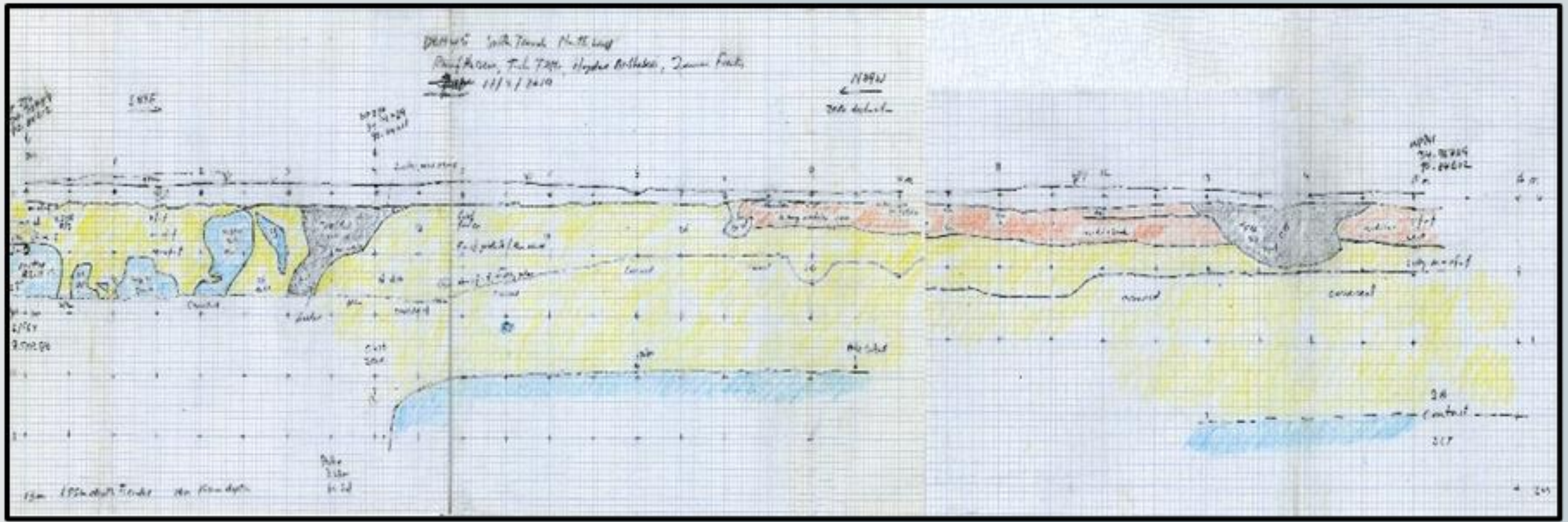
Adobe Illustrator figure showing paleoseismological logs of DBNW3: a) Results from the logging at DBNW3N, and b) Results from the logging at DBNW3S.

Logging at Site-5 (DBNW5)

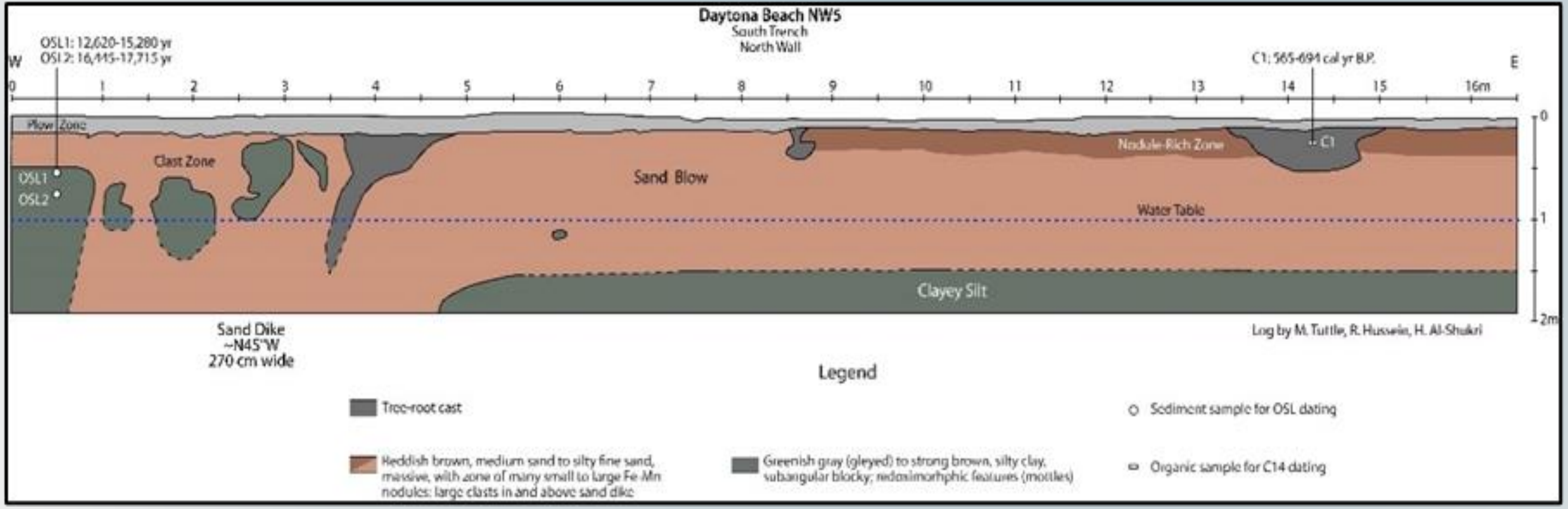


Photographs showing the logging work at DBNW5: a) The northern trench that was completely flooded and collapsed, and b) Logging work at the southern trench.

Paleoseismological logs of Site-5 (DBNW5)



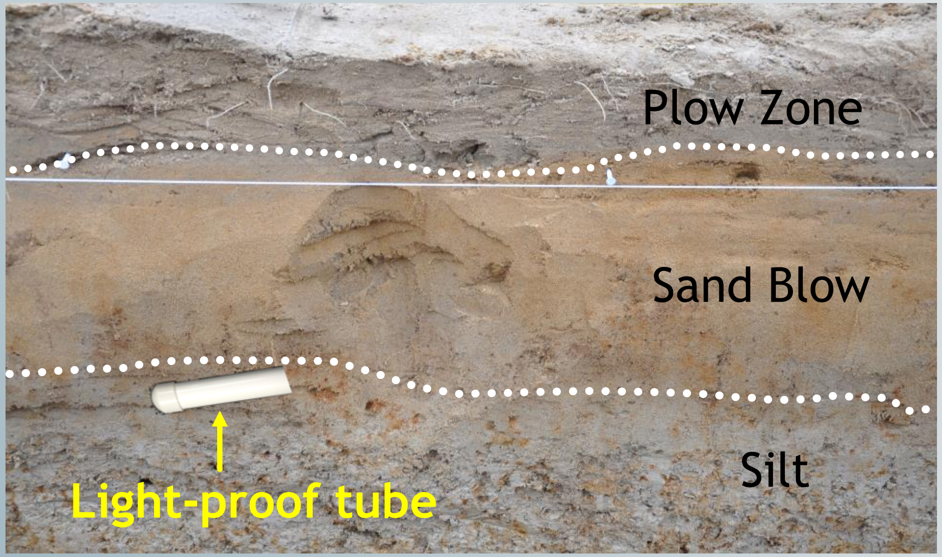
Field log of DBNW5S by (M. Tuttle, R. Hussein and H. Al-Shukri).



Adobe Illustrator figure showing a paleoseismological log of DBNW5S.

3.3- Charcoal, OSL, and Grain Size Sampling:

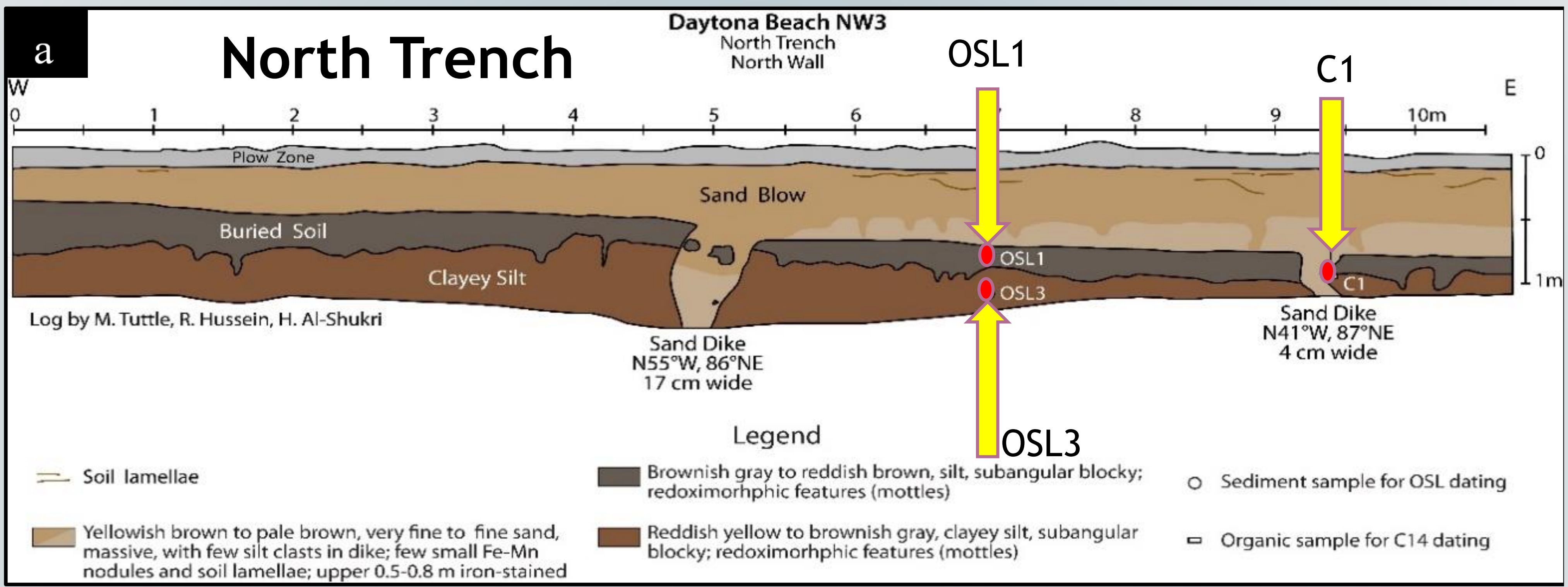
Charcoal samples for event dating. Radiocarbon dating technique.

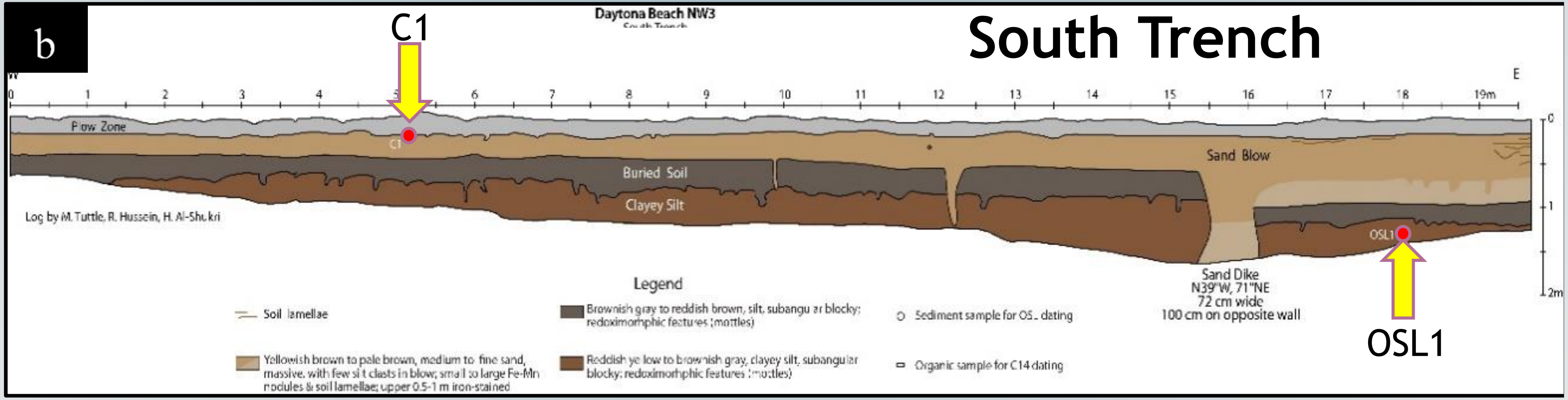


Sand samples for event dating. Optically Stimulated Luminance (OSL) technique.

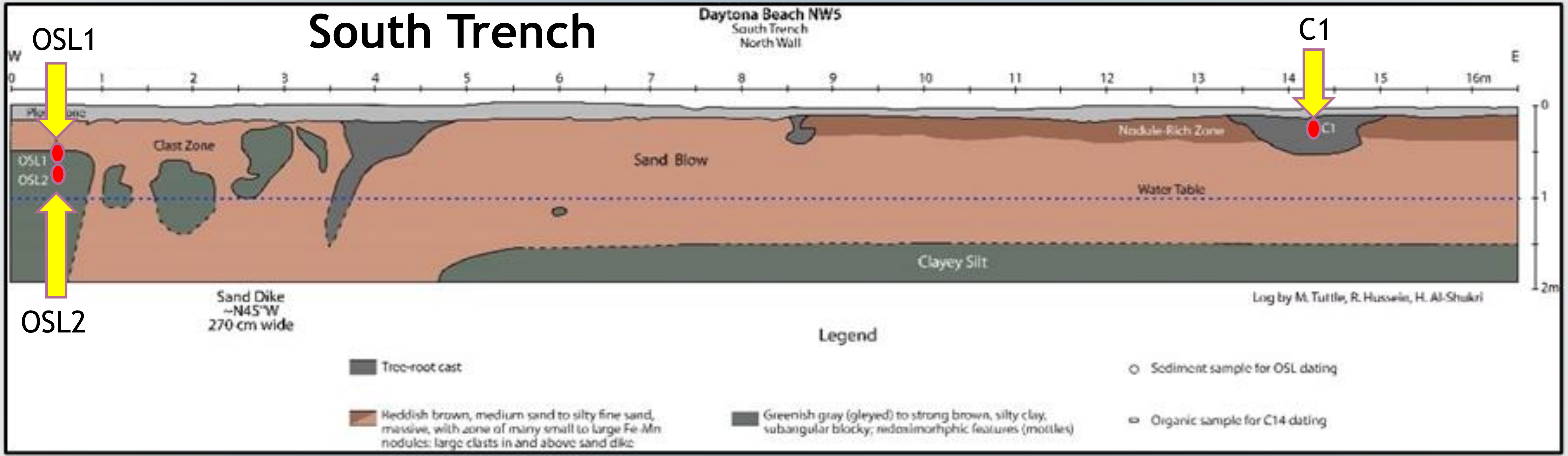
Sand samples for grain size analysis. Laser Diffraction technique.

3.3.1- Charcoal and OSL Samples collected from Site-3 (DBNW3):

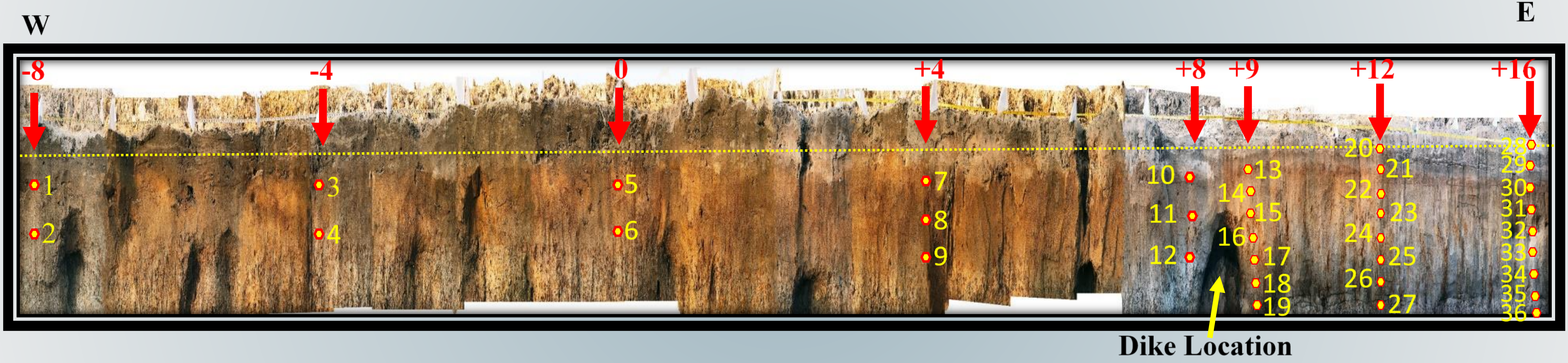




3.3.2- Charcoal and OSL Samples collected from Site-5 (DBNW5):

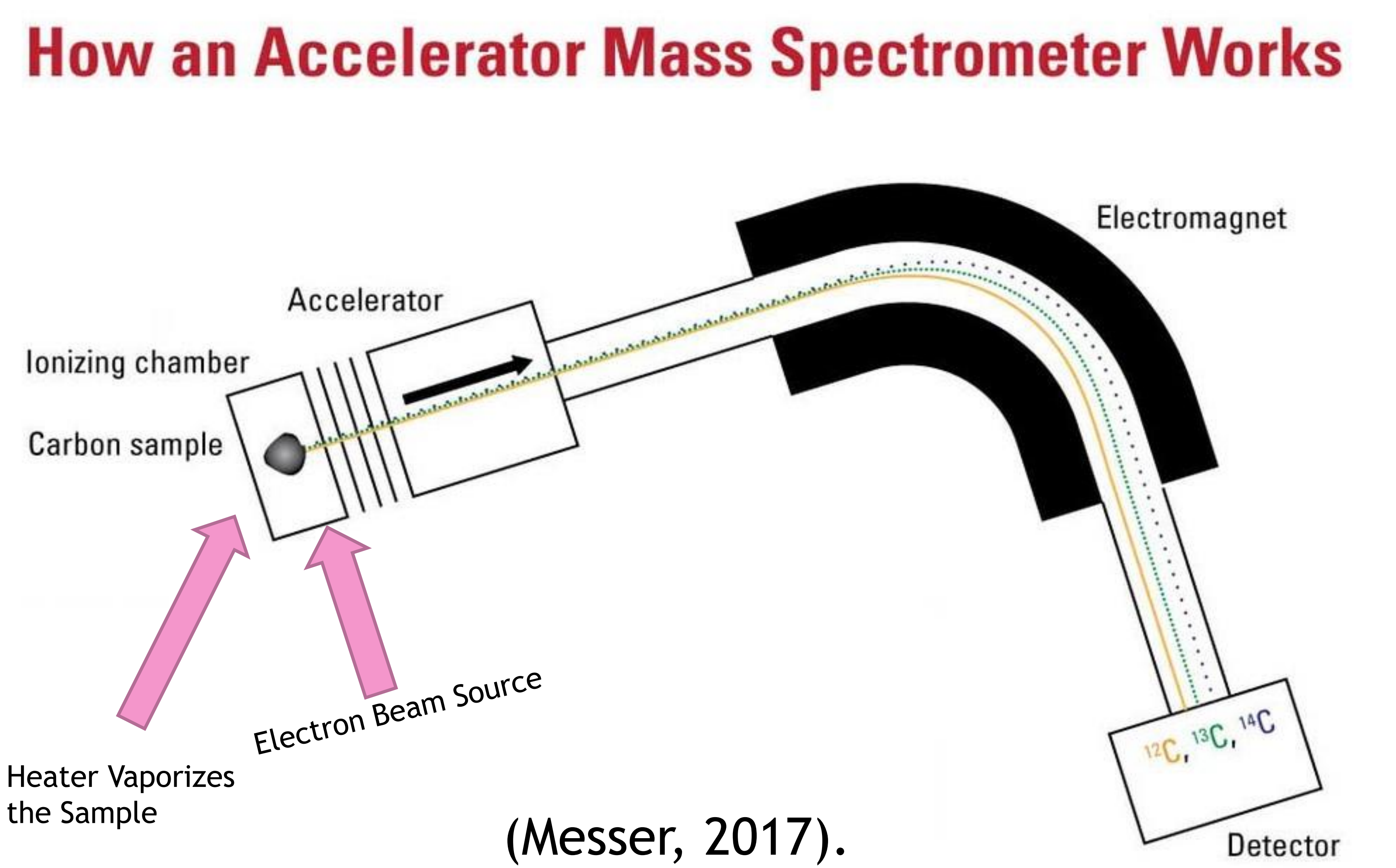


3.3.3- Sand samples collected from Site-3 (DBNW3) for grain-size analysis:



3.4- Dating and Grain Size Techniques:

- 3.4.1- AMS Radiocarbon Dating Technique



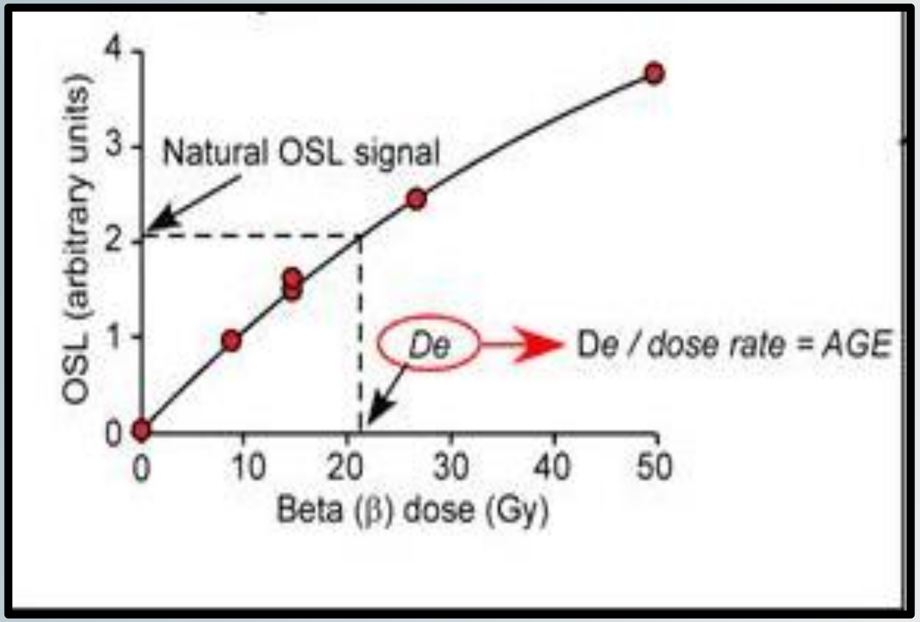
(Messer, 2017).

▶ 3.4.2- Optically-Stimulated Luminance Dating Technique

- 1- Measuring natural OSL Signal.
- 2- Calculating equivalent dose (De).
- 3- Measuring dose Rate.
- Calculating Sample age.

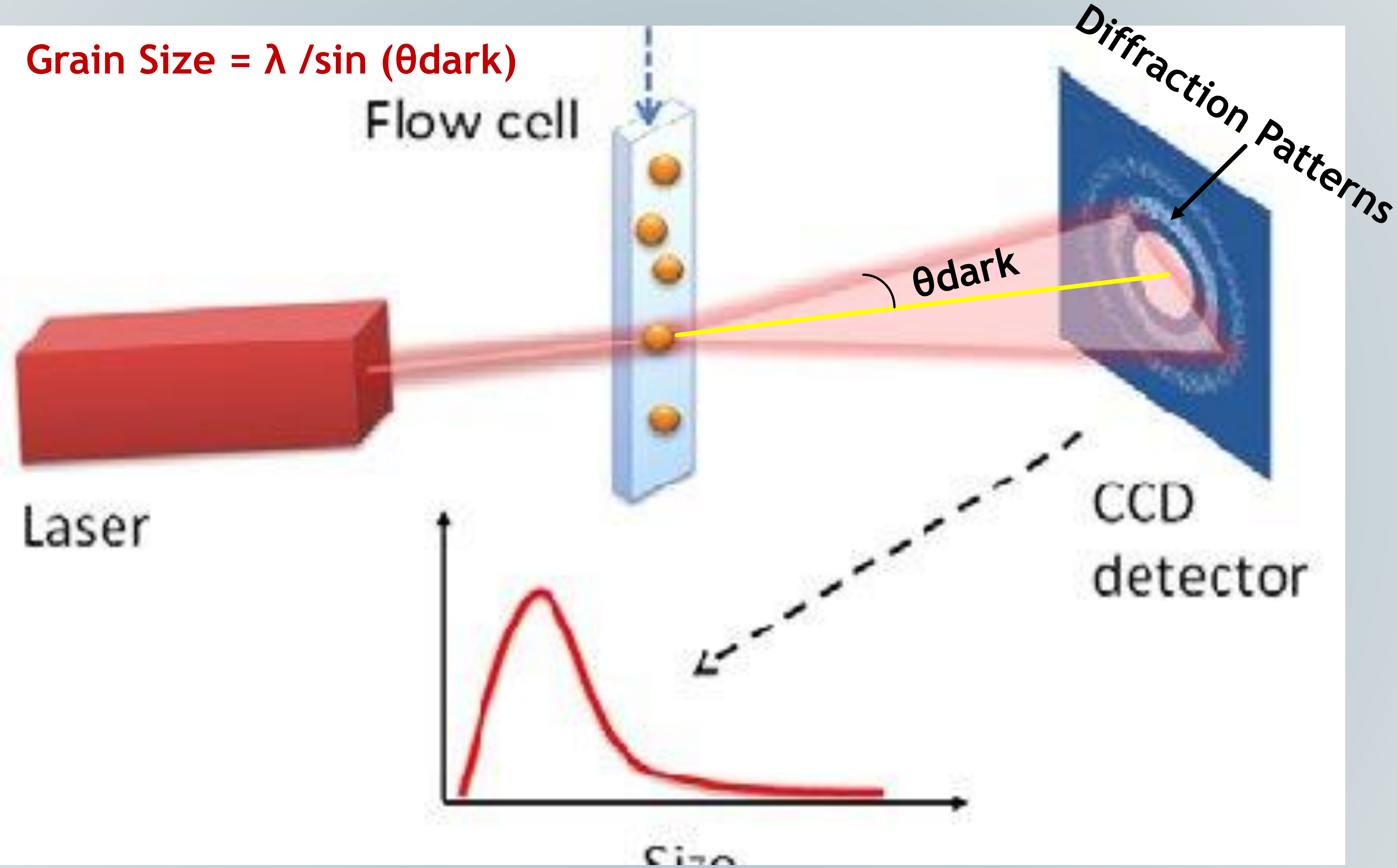
Quartz grains in sand (Munroe, 2017) .

Blue light injected onto a sand sample (Duller, 2020).



Signal-dose plot for one aliquot of one sample (Rittenour, 2017).

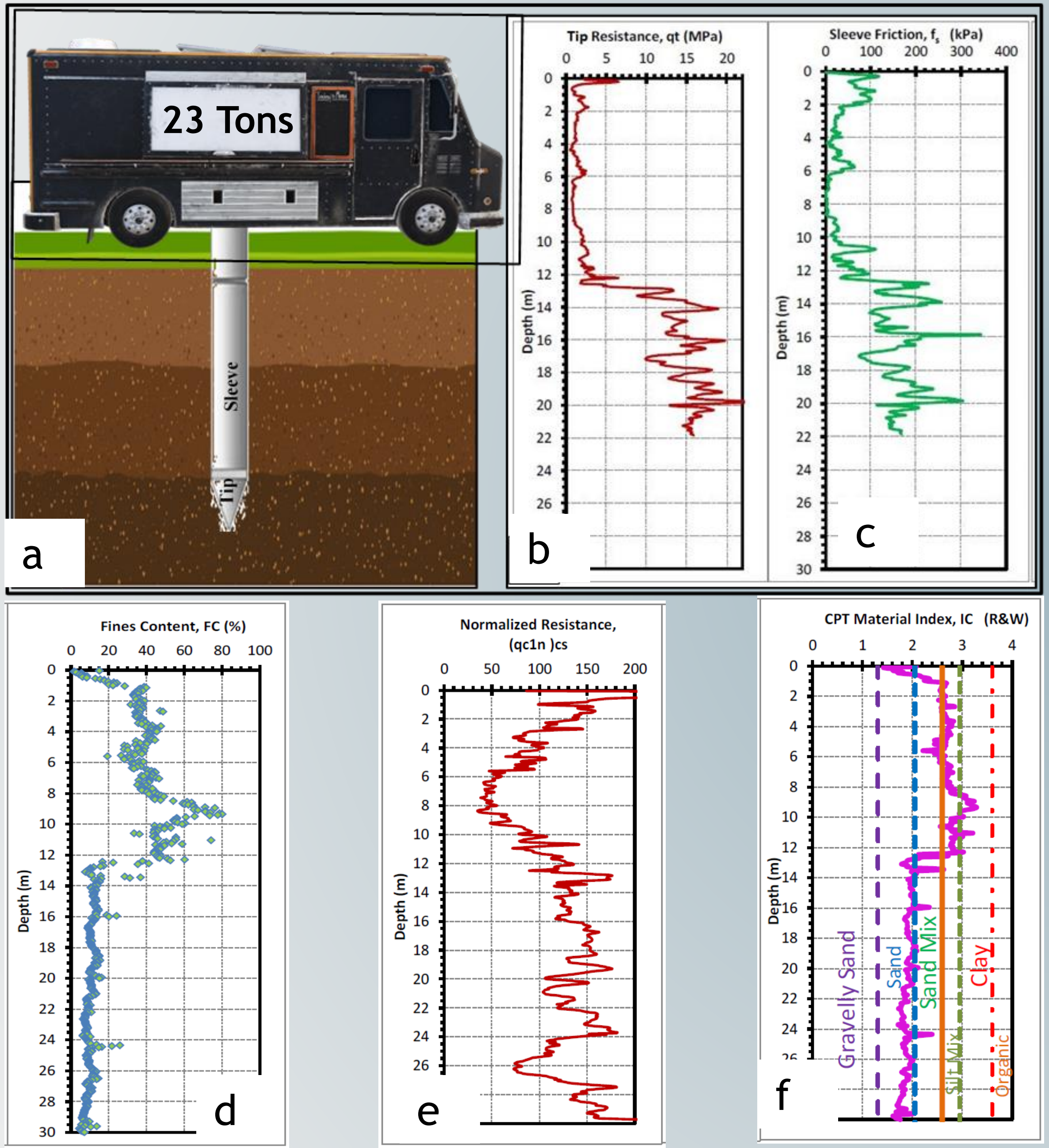
▶ 3.4.3- Laser Diffraction For Grain Size Measurements:

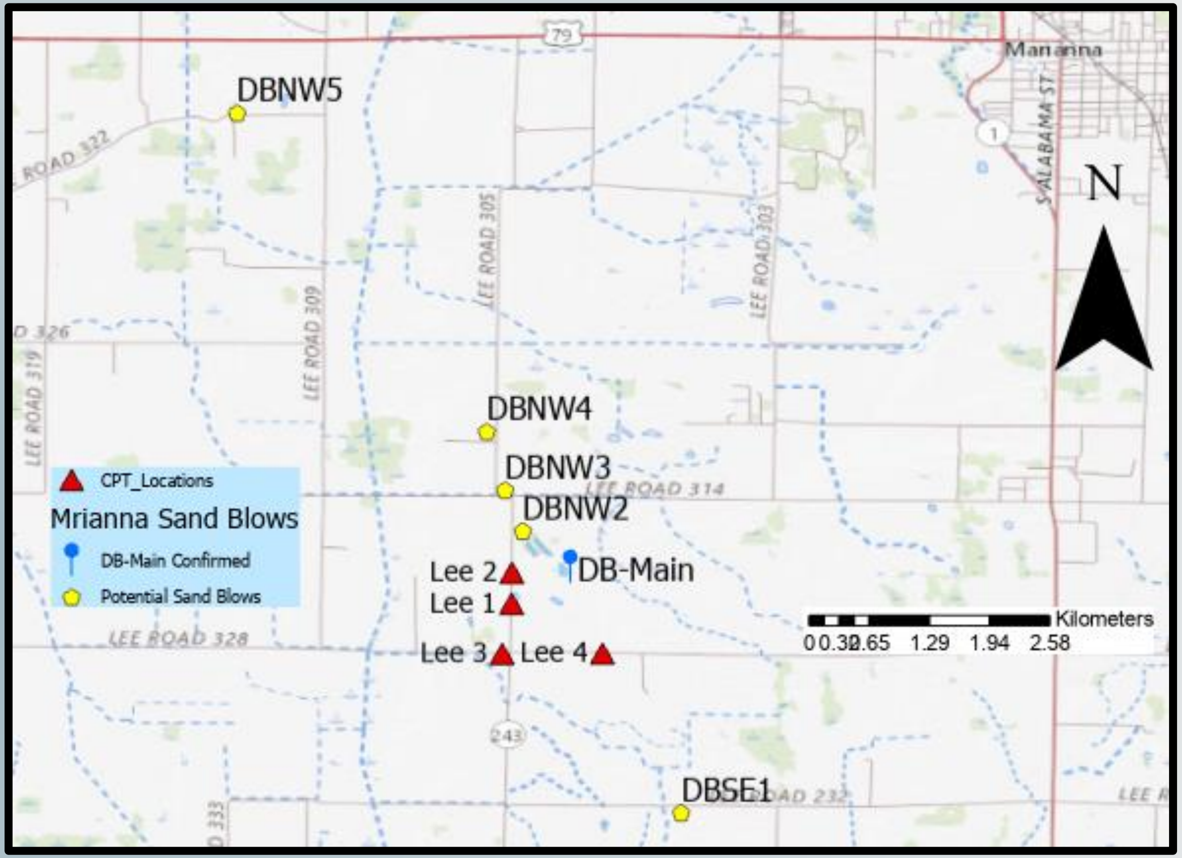


Principles of laser diffraction measurements (Hyll, 2015).

3.5- Magnitude Estimation:

3.5.1- Cone Penetration Testing (CPT) Method:



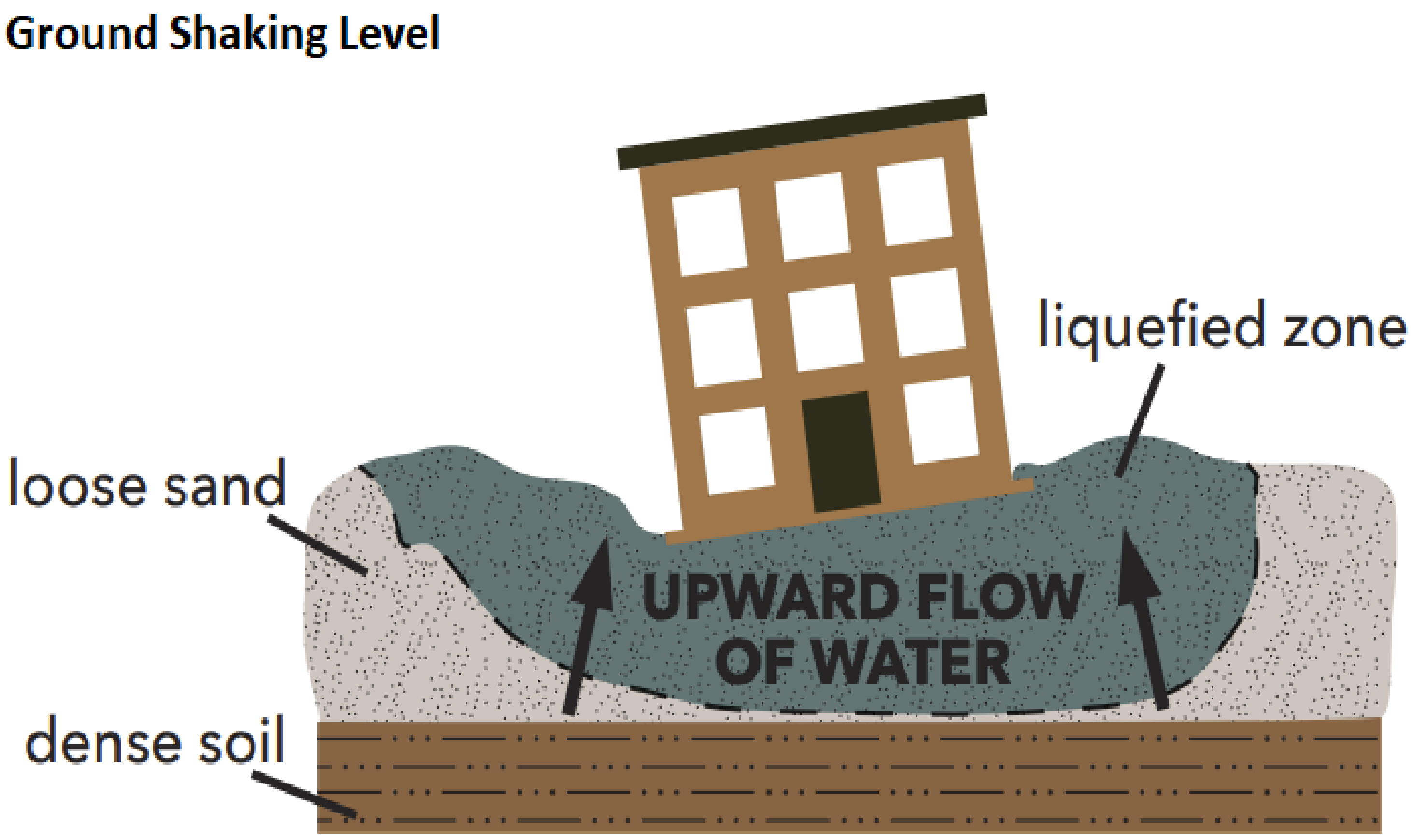


GIS Map Showing CPT Site Locations

The capacity of soil to resist liquefaction is represented by Cyclic Resistance Ratio (CRR).

3.5.2- Cyclic Stress Method :

Cyclic Stress Ratio (CSR): is the level of ground shaking from seismic loading



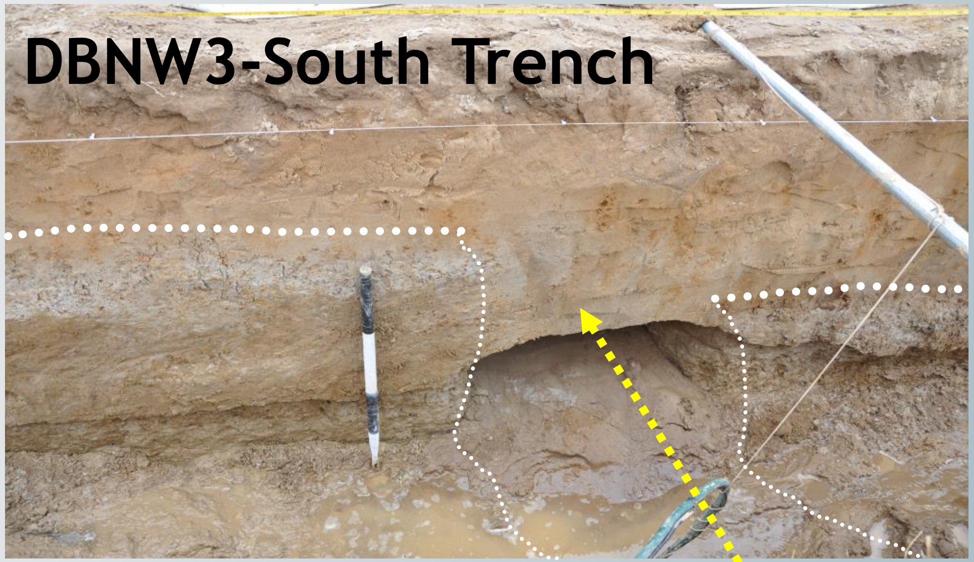
(Dougherty, 2019)

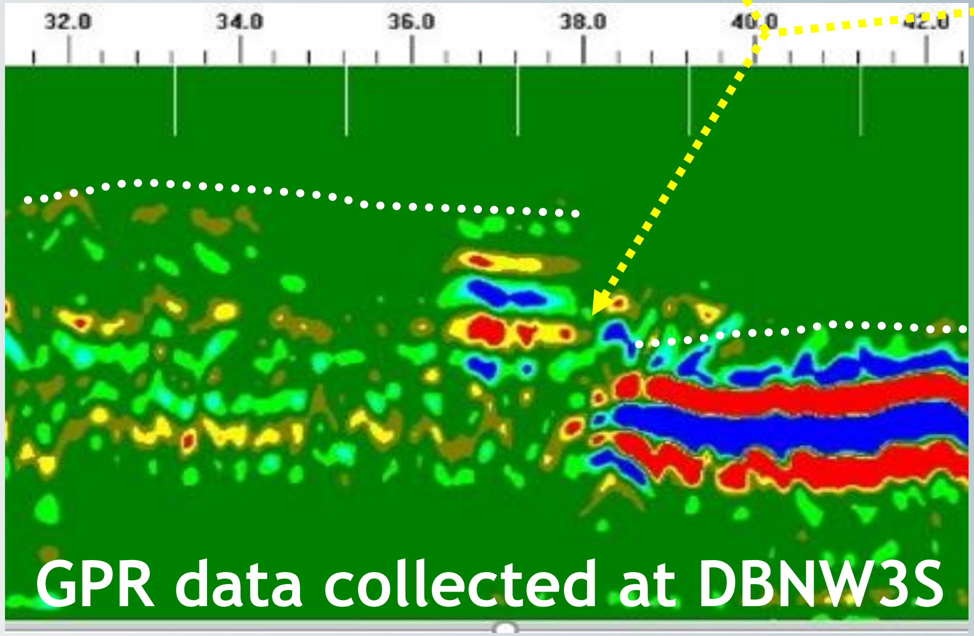
Liquefaction Potential Analysis

- If CRR > CSR = Soil Will Not Liquify
- If CSR ≥ CRR = Soil Will Liquify

4- Results and Discussions:

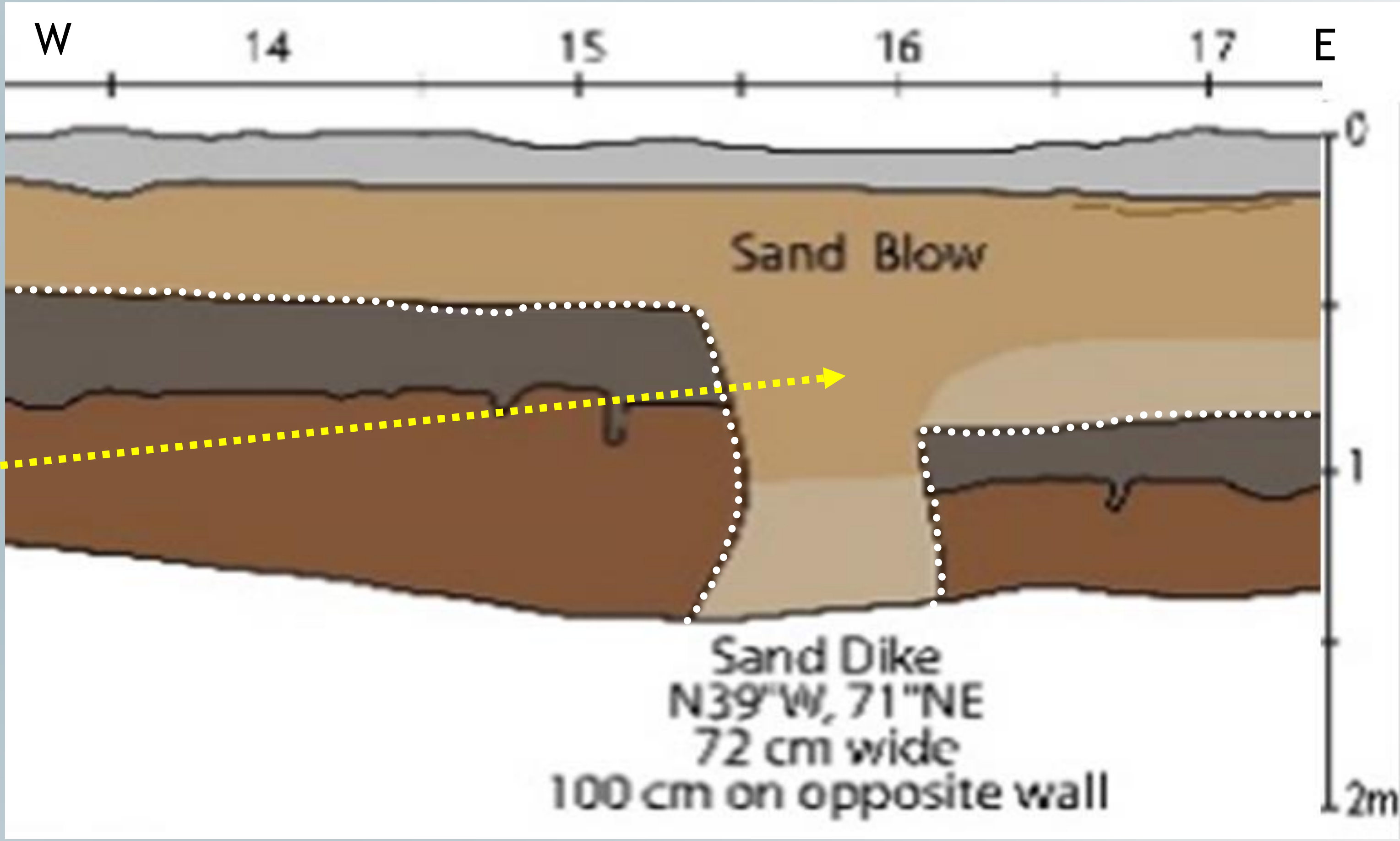
4.1- Trenching and Logging Results:





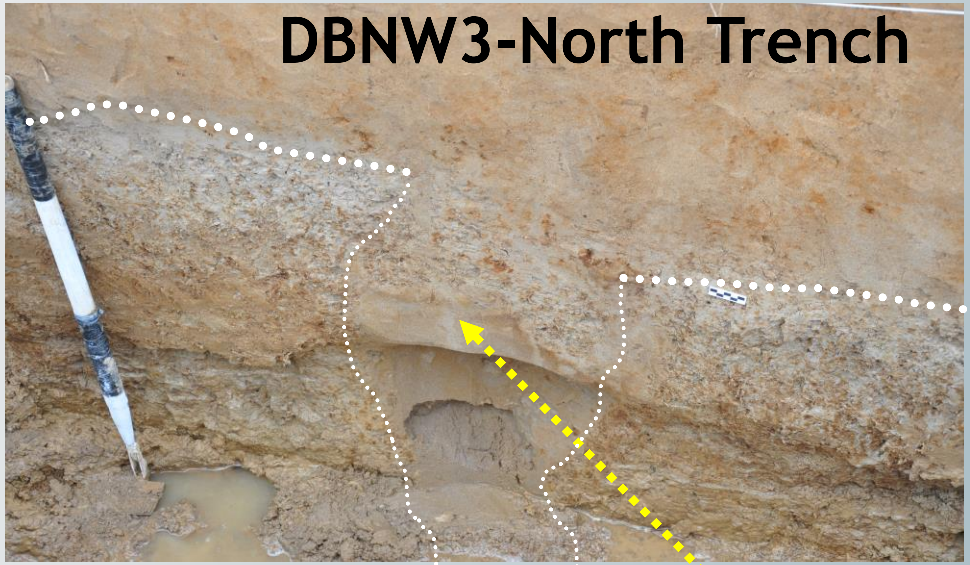
GPR data collected at DBNW3S

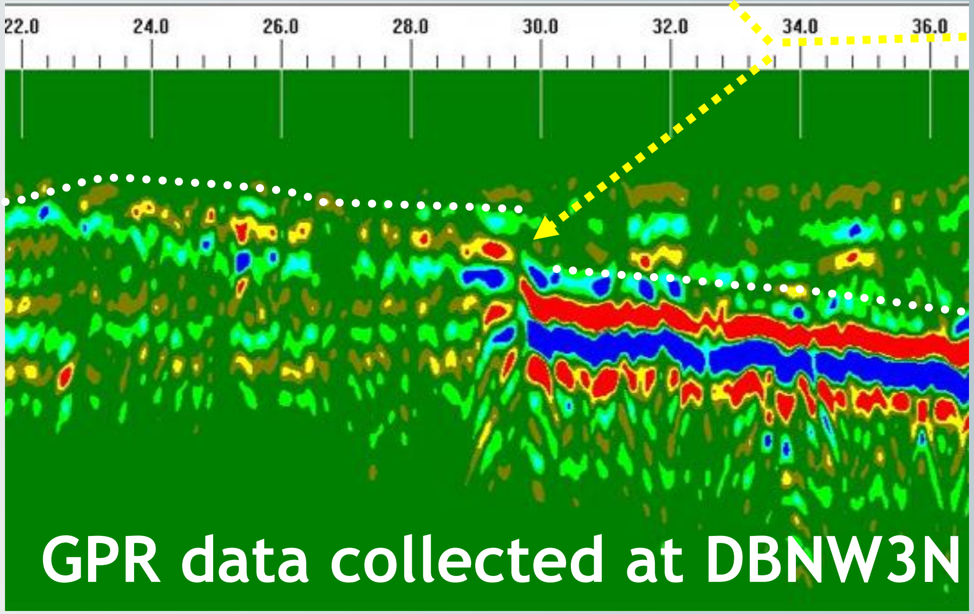
4.1.1- Trenching and Logging Results from DBNW3S:

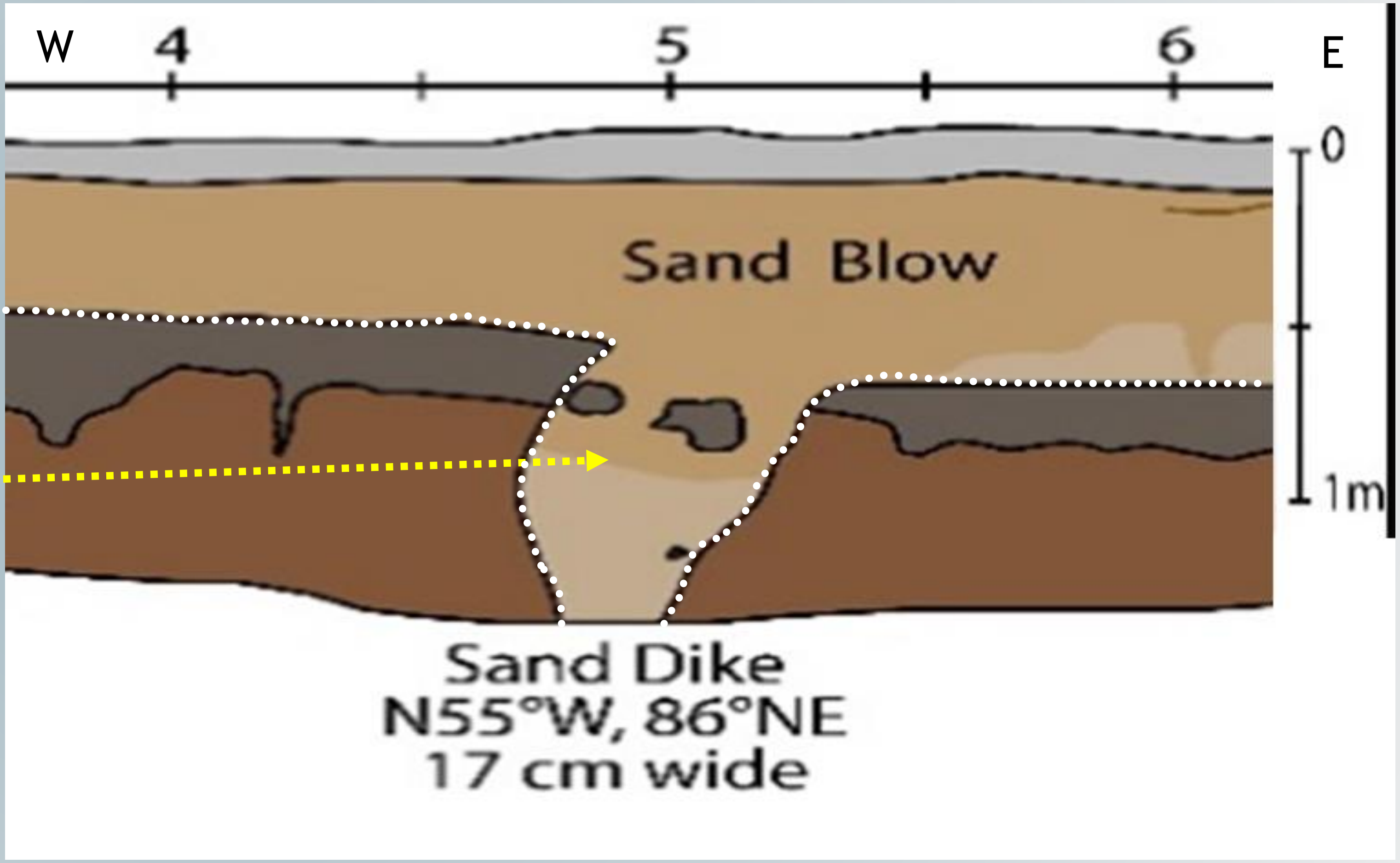


Paleoseimological log of DBNW3S

4.1.2- Trenching and Logging Results from DBNW3N:

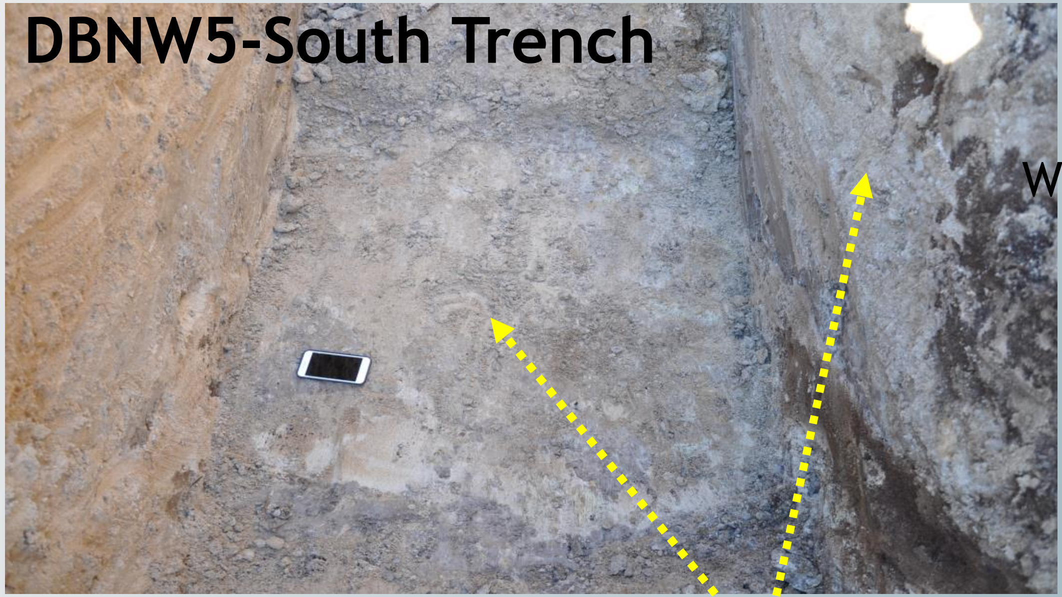


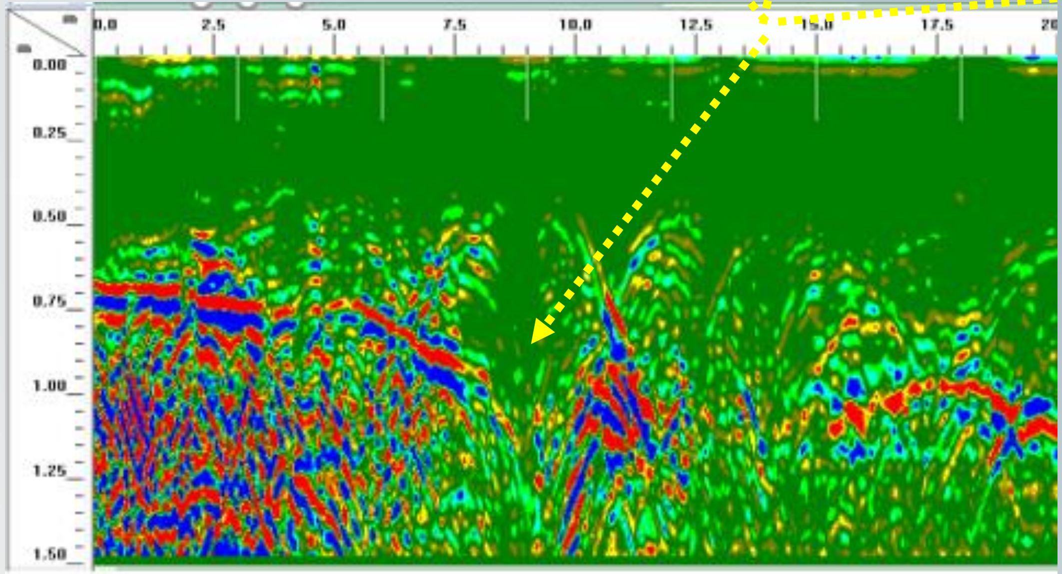




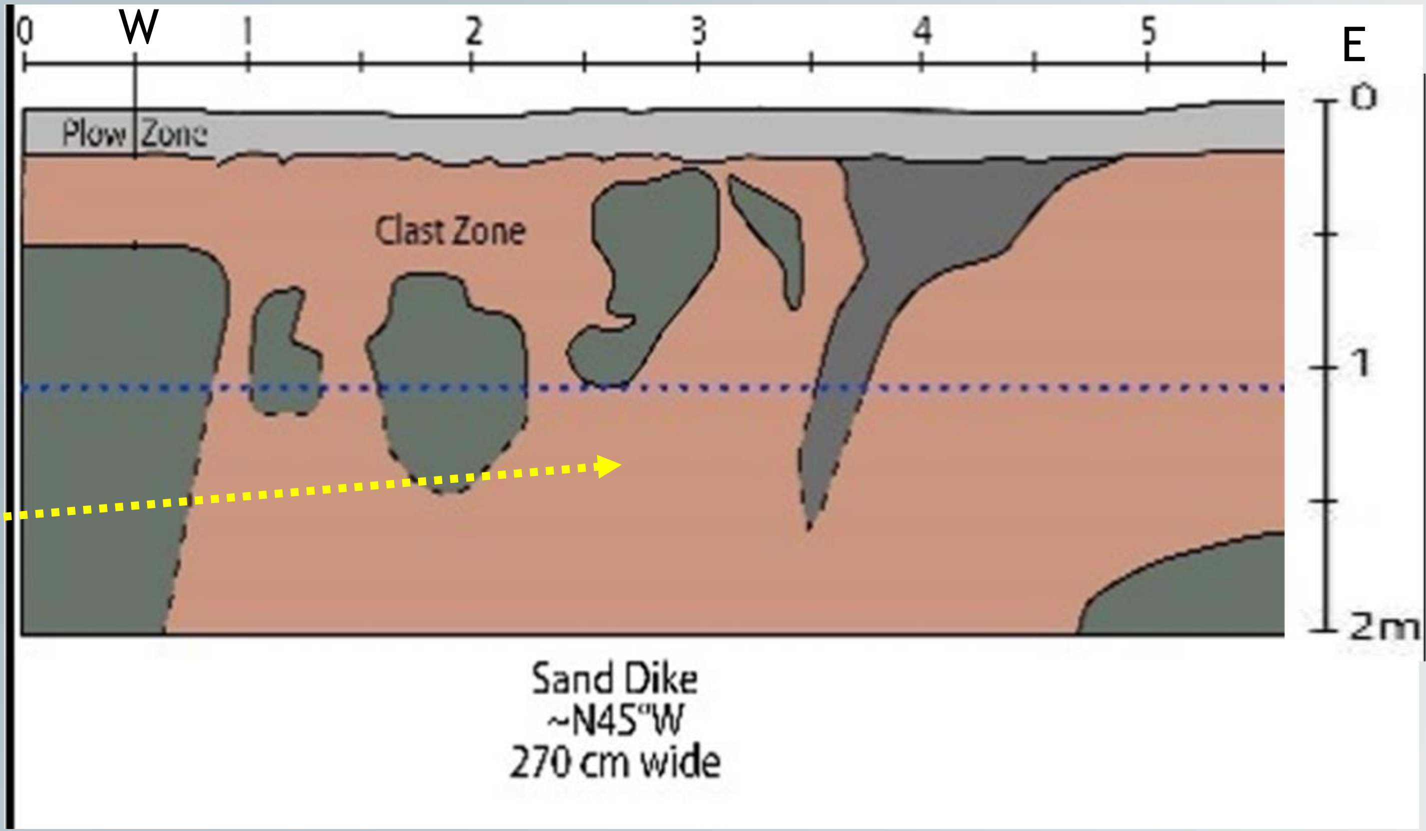
Paleoseimological log of DBNW3N

4.1.3- Trenching and Logging Results from DBNW5S:





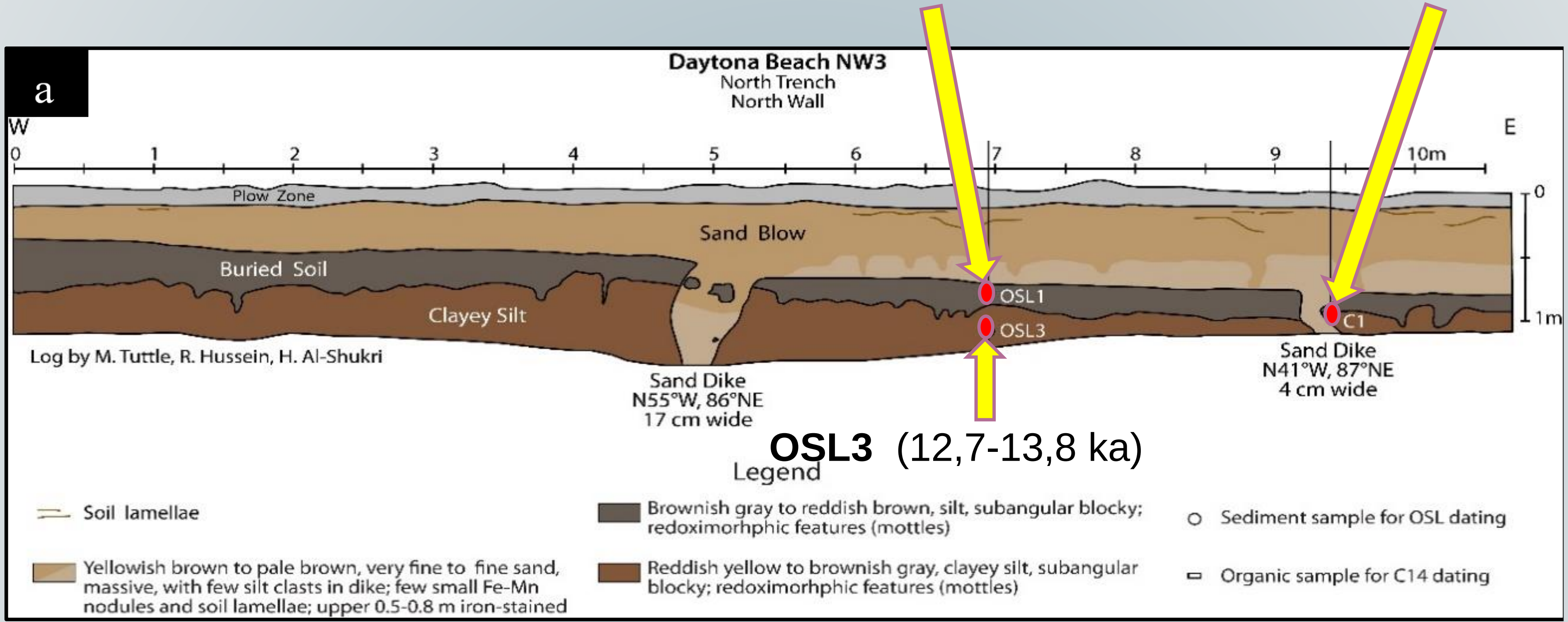
GPR data collected at DBNW5S

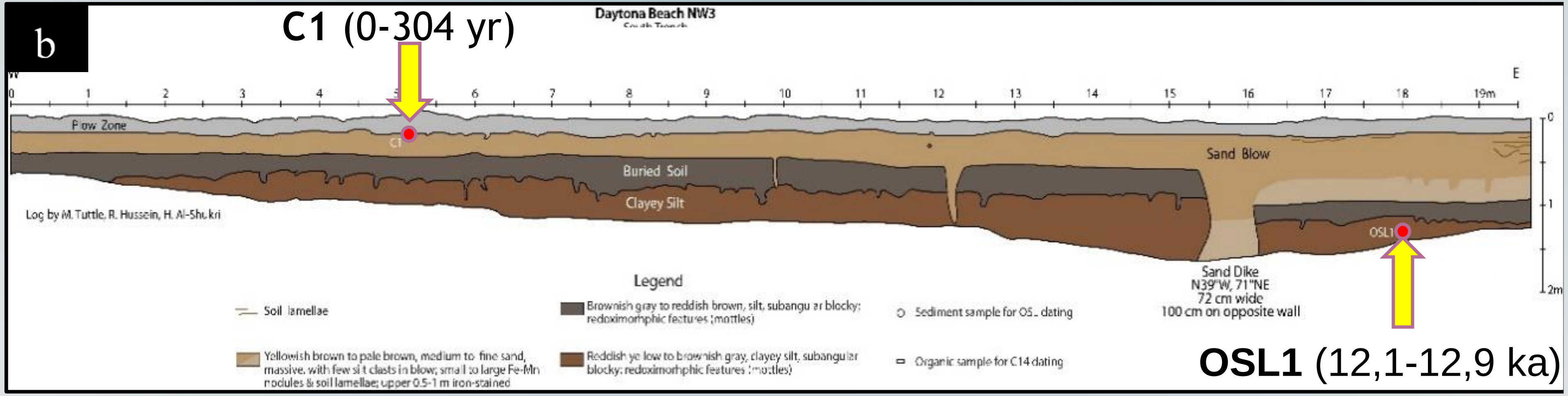


Paleoseimological log of DBNW5S

4.2- Dating Results:

4.2.1- Dating Results from DBNW3:

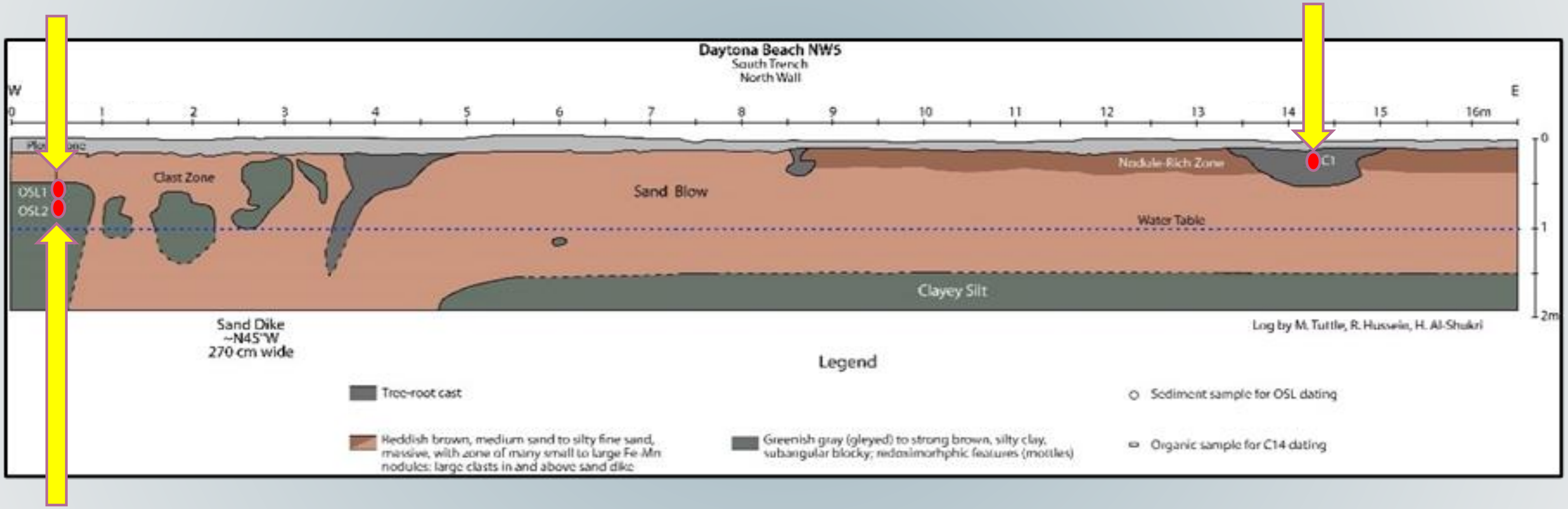




4.2.2- Dating Results from DBNW5-South Trench:

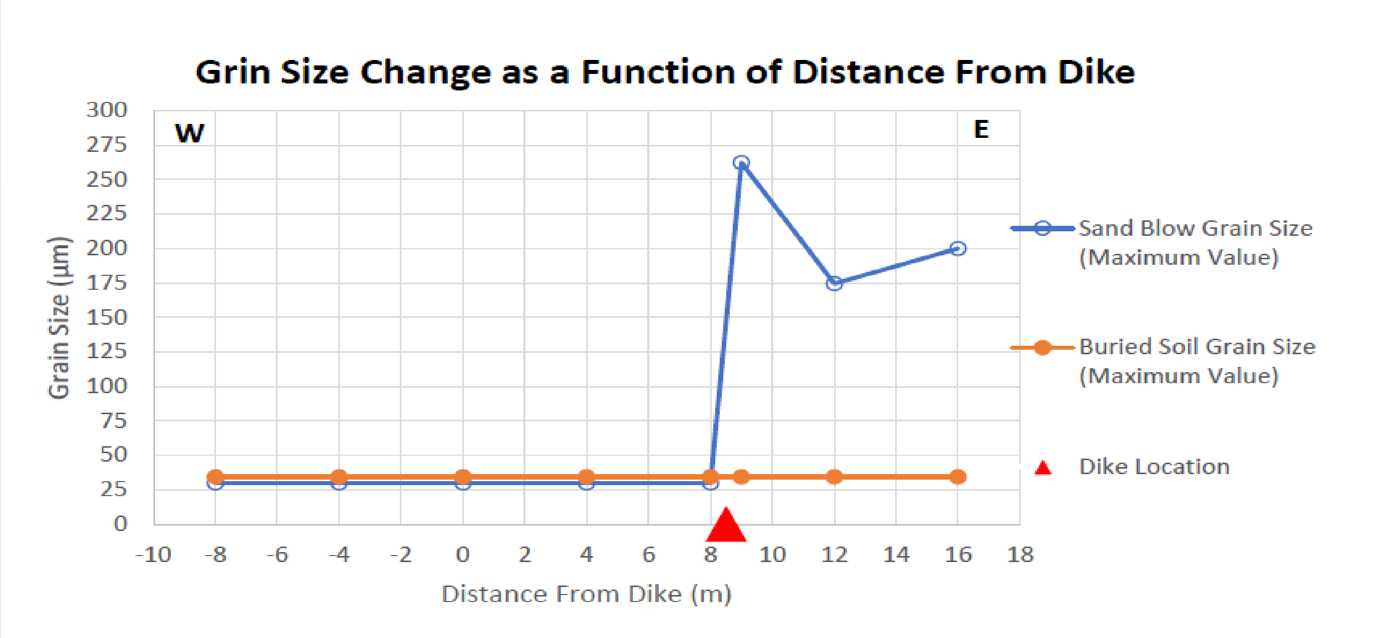
OSL1 (12,6-15,2 ka)

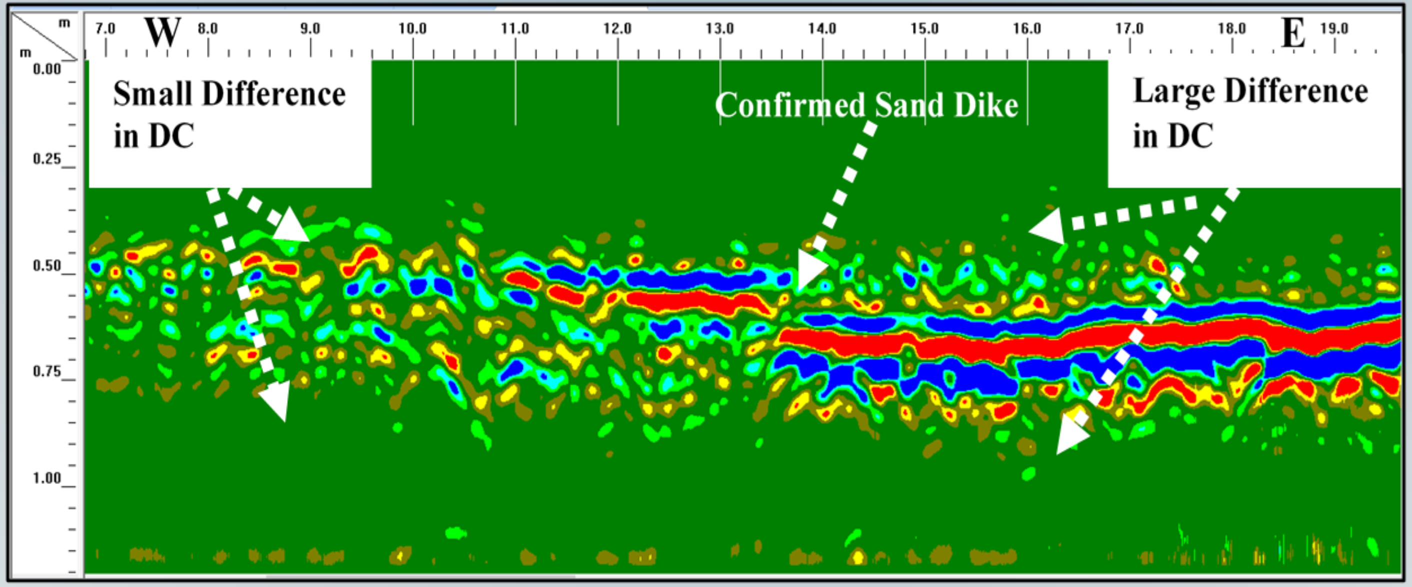
C1 (565-694 yr)



OSL2 (16,4-17,7 ka)

4.3- Grain-Size Analysis Results From DBNW3S:





4.4- Magnitude Estimation Results:

Moment Magnitude (M_w)	Liquefaction (Water Table Depth 1.5 m, and Distance to Fault 5 km)	Liquefaction (Water Table Depth 1.5 m, and Distance to Fault 10 km)	Liquefaction (Water Table Depth 5 m, and Distance to Fault 5 km)	Liquefaction (Water Table Depth 5 m, and Distance to Fault 10 km)
5.0	N	N	N	N
5.5	N	N	N	N
6.0	L	N	L	N
6.5	L	L	L	L
7.0	L	L	L	L
7.5	L	L	L	L

Table Showing results of potential liquefaction analysis for site Lee 1 and site Lee 3.

5- Conclusions, Recommendations, and Future Work

5.1- Conclusions:

- GIS is a promising tool in selecting suitable locations for SBs.
- GPR has proven to be a powerful tool in selecting the most suitable area for trenching.
- Trench observations have confirmed the information collected from the GPR data.
- Marianna sand blows are of large sizes and this is most likely due to a local seismic zone which is the **Marianna seismic zone (MSZ).**
- Trench logging reveals the existence of many sedimentological features (lamellae and nodules).

- Dating results indicate that the Marianna sand blows formed prior to 4.8 ka.

- DBNW3 is on the younger side for the Marianna sand blows, whereas DBNW5 is on the older side for the Marianna sand blows.

- The MSZ produced at least three large paleoearthquakes about (4.8, 5.5, 9.9, and possibly 13.9 Ka).

- The Marianna sand blows were formed by at least a magnitude of 6 earthquake.

- Sand blow investigations have shown that sand blow long axes and sand dikes' strike are southeast-northwest orienting and parallel to a lineament. The lineament is 12-km long above a strike-slip fault and this is most likely the Marianna fault.

5.2- Recommendations:

- For optimal OSL results, it is recommended to collect samples immediately below the sand blow-buried soil contact.
- For smaller sand dikes, It is also recommended to use the 900-MHz antenna.

5.3- Future Work:

- Intensive GIS work will be conducted at the Marianna area.
- The north-south orienting cotton-field rows at site 1 (DBSE1) will be leveled.
- Prior to excavation work is performed at site 2 (DBNW2), shoaring will be prepared.
- The planned trench at this site 4 (DBNW4) will be excavated.

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