THE SUBSURFACE ANATOMY OF THE BOOTHEEL'S SAND BLOWS:
REMNANTS OF THE NEW MADRID EARTHQUAKES

R. S. Freeland, Ph.D., P.E. J. T. Ammons, Ph.D.
Professor, Agricultural Engineering Professor, Soil Science
The Department of Biosystems Engineering & Soil Science
The University of Tennessee
2506 E. J. Chapman Dr., Knoxville, TN 37996-4531
phone: 865.974.7140; fax: 865.974.4514
e-mail: rfreelan@utk.edu.

Abstract

Earthquakes have repeatedly shattered the alluvial landforms about the Missouri Bootheel—most recently the 1811-1812 New Madrid earthquakes. During the four greatest of earthquakes, long fissures opened across the surface and volcanic-like sand blows erupted, venting subterranean sands onto the surface. Left embedded within the subsurface were sand-filled vents channeling between the water table and surface; as such, are today influencing the interaction and movement of ground and surface waters.

Nearly a century of mechanized agriculture and erosion has all but erased the evident surface features of the past great earthquakes. Thus, fields significantly impacted by past seismic shocks appear today as normal; yet still hidden beneath the surface remain the sand-filled seismic vents. Impacted fields may drain much more rapidly than farmers expect during artificial winter flooding, or require greater volumes of irrigated water. Thus, the project’s objective was to develop a large field-scale mapping protocol to pinpoint any sand-filled subsurface features existing beneath the surface that may allow rapid, voluminous water movement between the surface and groundwater.

We have developed a non-intrusive survey methodology for precisely mapping the locales of seismic features across large acreages using mobile ground-penetrating radar combined with precision satellite-positioning technologies. When located, we either earmark the features for remediation or recommend excluding the impacted area from flooding and irrigation practices.

Introduction

In the early morning of December 16, 1811, a three-month long sequence of powerful earthquakes began within the northernmost Mississippi embayment. Nearly continuous earthquake activity, which included four record-setting earthquakes, devastated a region of middle North America about the Mississippi River. A series of aftershocks would continue another five years. Survivors reported that it was impossible to walk upright as the ground heaved and rolled in waves, easily toppling large trees. Some swells would split along their peaks, opening long and deep fissures across the ground surface. Blackish water gushed from the earth. Lands subsided and flooded, forming shallow lakes. Lowlands uplifted and drained. During the four great earthquakes of 1811-1812, sand geysers erupted; vomiting into the sky great volumes of subterranean sands mixed with sulfurous steam and prehistoric charcoal. From these sand volcanics, approximately 60,000 ha of future farmland (fig. 1) about the Missouri Bootheel were left torn by fissures, and pockmarked with craters surrounded by mounds of spewed sands. The term “sand blows” refers to the surface remnants of these strewn sands.

Geologists trace this event back approximately 500 Ma. Beneath what is today are the sediments of the Mississippi River Valley, tectonic forces started to separate the landmass that was to become North America. For some reason it stopped, leaving a rift (Reelfoot Rift) as an active 240-km long fault. Periodically, (some scientists suggest approximate 400 - 800 year cycles) the fault releases energy in the form of major earthquakes that have few of greater magnitude on Earth.
**Fig. 1.** Highlighted (hatched) area of significant sand blow and fissure occurrence due to past seismic episodes about the Missouri Bootheel (adapted from Obermeier, 1989). Research site is near Bogota, Tenn.

**Fig. 2.** Aerial photography comparison of the NMSZ research site near Dyersburg, Tenn. illustrating impact of 60 years of erosion, flooding, and intensive mechanized agricultural activity on vented sands on a site having > 10% sand blows across the surface -- (a) 1941 and (b) 1998.
Today, the rich sediments of the Mississippi River alluvial plains encompass some of the richest, most fertile farmlands of the Nation. The lands within the New Madrid Seismic Zone (NMSZ) follow a 60-km wide region of numerous faults following the Mississippi River southward extending just south of St. Louis, Mo. toward Memphis, Tenn. Farmlands are typically devoted to row crop production—cotton, soybeans, rice, and corn. Water for irrigation, if ever needed, is bountiful, as the water table along the Mississippi River is but a few meters beneath the surface.

The practice of winter field flooding is growing in popularity throughout the lower Mississippi River Delta. Rice farmers in Mississippi, Arkansas, and Louisiana are increasingly devoting more acreage to winter flooding in order to accelerate degradation of field stubble and to retard growth of cool-season weeds. Winter flooding of rice fields is a best management practice that supports soil conservation, enhances groundwater recharge, profits farming operations, and benefits wildlife. Its popularity is also increasing, in part; due to the revenues gained from managed migratory duck hunts, as these flooded fields lie directly along the a major migratory waterfowl route, the Mississippi Flyway. As part of the recreational sporting venue, the Tennessee Wildlife Resources Agency (TWRA) purchased 200 ha of waterfowl habitat wetland alongside a tributary of the Mississippi River, the Obion River, for managed duck hunts.

Objectives

Our research involves assisting the Tennessee Wildlife Resources Agency in determining the suitability of fields for waterfowl impoundment areas near Bogota, Tennessee (fig. 1). As this area is within the NMSZ, the initial hypothesis was that unseen sand blows existing within the field might attribute to major water loss, as an early soil survey denoted the fields having sand blows (USDA, 1965). However, extensive mechanized agriculture and land forming had obscured any obvious surface features typifying sand blows (fig. 2). Soil investigations using both hand augers and a truck-mounted soil probe failed to detect any breakages or non-uniformities of the clay gleyed horizon serving to perch water, which apparently occurred at an approximate depth of 1 m stretching beneath the surface across the entire site.

The objectives of this project were to:

1. Establish a rapid geophysical mapping protocol for spatially mapping the continuity of the gleyed horizon over large acreages.

2. Establish pattern signatures of any sand blows occurring unseen beneath the surface.

Materials and Methods

Site Description

The study was located in a 40-ha field on a 600-ha wildlife management area in northwest Tennessee near Bogota, Tenn. in the Southern Mississippi Valley Alluvium MLRA 131 (N 36° 8′ 8″, W 89° 27′ 28″) (fig. 1). The ground surface has less than one percent slope, was bare and smoothly tilled, as it was recently planted with waterfowl feedstock. Extensive tillage operations have all but erased surface-apparent seismic features (fig. 2). The USDA (1965) soil survey outlined approximately 90% of the area as Forestdale-Crevasse complex and the remainder as Crevasse sandy loam. (The Forestdale-Crevasse complex soil series is referred to as “sand blow land”.) A typical soil profile is ½- to 1-m thick loamy sand and sand over a gleyed horizon. The gleyed horizon, which serves to perch water, is approximately 1-m beneath the surface, capping clean, coarse, unconsolidated medium-grained sands and a gravel substratum. This region is along a depositional terrace of the Obion River and is susceptible to flooding. The field surveyed has previously served as a flood chute, the oxbow of an abandoned meander of the Obion River
Fig. 3 Flood chute originating from the oxbow of an abandoned Obion River meander.
traversing the northern perimeter of the field (fig. 3).

A trench in the adjacent field was opened to approximately two meter depth with a backhoe (fig. 4). This trench was opened due to a precursory GPR survey that highlighted this area as a potential “sand blow”. Three soil profiles were described perpendicular to the northeast-southwest oriented trench, and sampled for laboratory analysis according to the Soil Survey Manual (Soil Survey Staff, 1993). Particle size analysis was determined using the pipette method (Kilmaer and Alexander, 1949).

Ground-penetrating Radar

Ground-penetrating radar data were collected using a SIRveyor-20 mainframe and a Model 5106 200-MHz antenna that are manufactured by GSSI, Inc. (North Salem, NH, USA). The 200-MHz antenna is connected to the radar system unit by the 30-m control cable. Using an all-terrain vehicle, the antenna was towed across the test plots while mounted within a protective fiberglass skid (Freeland et al., 2002). Real-time positioning data of the antenna was obtained using a WAAS-enabled GeoXT differential GPS receiver (Trimble Navigation, Ltd., Sunnyvale, CA). Its external antenna was mounted directly above the GPR antenna. (fig. 5).

Survey Protocol

Targeting the largest horizontal feature of the sand blow—the lateral sills extending outward tens of meters from the vent—the first survey traverses were widely spaced to determine the general locales of sand blows as distributed across the field. Subsequently, more closely spaced traverses about the sand blows would determine the locale of the smaller dimensioned vents. A preliminary survey in a nearby field revealed that the initial traverse spacing as too widely spaced to resolve the smaller-dimensioned sand blows, as the subsurface shape was ellipsoidal rather than circular. Thus, a 5-m spaced traverse was selected as a more optimal spacing, while also balancing the time required for data collection and the amount of data recorded for subsequent interpretation. The average speed of the survey was 6.5 km/hr, with the route visually tracked by the operator using time-encoded event markers overlaid in real-time using GPS inputs to ESRI ArcPad 7.0 (fig. 6). The operator screen displayed an aerial photograph base map to aid the operator in real-time GPS tracking of the survey route and traverse spacing. The 200-MHz antenna was operated over a 100-ns depth range, giving an approximate 6-m depth of survey for the soil conditions of this site. Using this protocol, data collection and storage were intense. For example, over 3 GB of data were collected while surveying 20.5-ha.

Results

Major Profile Descriptions

Figure 4 shows a cross-section of the fissure structure elements found within an excavated trench. The soil morphology changed drastically in Profile 2, showing an opening of sand to the surface. Some stability is present on both sides of soil Profile 2. Profile 2, on the other hand, shows how the disruptive nature of the earthquake alters the soil profile.

The site was found to contain four major characteristic GPR pattern signatures, and numerous minor signature patterns. Thick bright-white reflectors typified high concentrations of sands. The radar signal weakened as it passed through the gleyed horizon, thus static appears beneath the highly-conductive gleyed horizon within the image. Shown in Fig. 7a, is the GPR signature deformed gleyed layer with backfill of spewed sands.
Fig. 4. Soil morphological cross-section of an earthquake fissure, Dyer County, Tenn. 36° 8’ 17.138” N, 089° 27’ 35.174” W

Fig. 5. The University of Tennessee mobile GPR platform
Fig. 6 Route of survey taken by mobile GPR platform. Serpentine lines denote major fissures occurrences within field, and white traverses (a-d) are locales of GPR segments illustrated in fig. 7.
Fig. 7 Ground-penetrating radar profiles of four traverses at designated locales in fig. 6: (a) large depression of gleyed layer adjacent to fissure containing great volume of back-filled spewed sands and charcoal, (b) cross-profile of fissure with sunken gleyed layer and back-filled spewed sands, (c) alluvial deposition of sands, and (d) typical profile showing no earthquake features or alluvial sands. Dashed line indicates gleyed layer.
Shown in Fig. 7b is the cross-profile of a fissure near the center of the structure. Above and adjacent to the fissure are spewed sands.

Shown in Fig. 7c, alluvial sand sediments, characterized by a mixture of wavy, short horizontal bands denote alluvial sands deposits. These regions typified Crevasse-series soils.

Shown in Fig 7d, is the GPR signature profile of the predominate landform across the site possessing a uniform non-deformed gleyed layer, which is capable of perching water. This profile has not been altered by seismic activity.

**Excavated Fissures**

Three fissures were excavated at the site. The fissure’s major axis were oriented parallel to the channel of a flood chute from an oxbow of an abandoned meander of the Obion River. The fissures oriented north-northwest, which from the site first appeared directed toward New Madrid, Mo., the reported epicenter of the largest of four catastrophic earthquakes occurring on February 8, 1812. Obermier (1989) in his conclusions cautioned against making this presumed relationship, as he reported:

> "The orientation and intensity of long fissures (greater than 0.8 km) are largely controlled by very localized geologic and topographic factors; in meander-belt and braided-stream alluvial deposits, where concentrations of fissures are greatest, the orientation is generally parallel to former stream channels and has no relation with the probable direction of shaking."

The fissures found on this site varied from 100 to 200 meters in horizontal length, and of serpentine shape. The fissures top-down view at the top of the gleyed horizon was most apparent, up to one-half meter wide at the midpoint, gradually tapering to a thinning crack at opposing ends (fig. 8). At the midpoint, the fissure opening was the widest. The gleyed horizon had deformed to the deepest depth lowest within its midsection as the gleyed layer elevation sank; thus having the deepest and widest overlaying of spewed sands. Charcoal was embedded in the spewed sands. The loose sands within the fissure structure itself as it passed through the gleyed layer were colored reddish brown at the widest and deepest section; turning gray as the fissure tapered and the gleyed horizon rose in elevation at opposing extents. Although initially dry immediately following excavation, within a few hours the trench filled with water entering from the trench sides along the top of the gleyed horizon.

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**References**


Fig. 8 (a) Excavation of serpentine fissure to gleyed interface (b) top-down view of sand-filled fissure within the gleyed interface.