SUMMARY OF THE INVESTIGATION OF THE MAY 10, 2008, BELDEN, MISSISSIPPI EARTHQUAKE PONTOTOC, LEE AND UNION COUNTIES MISSISSIPPI

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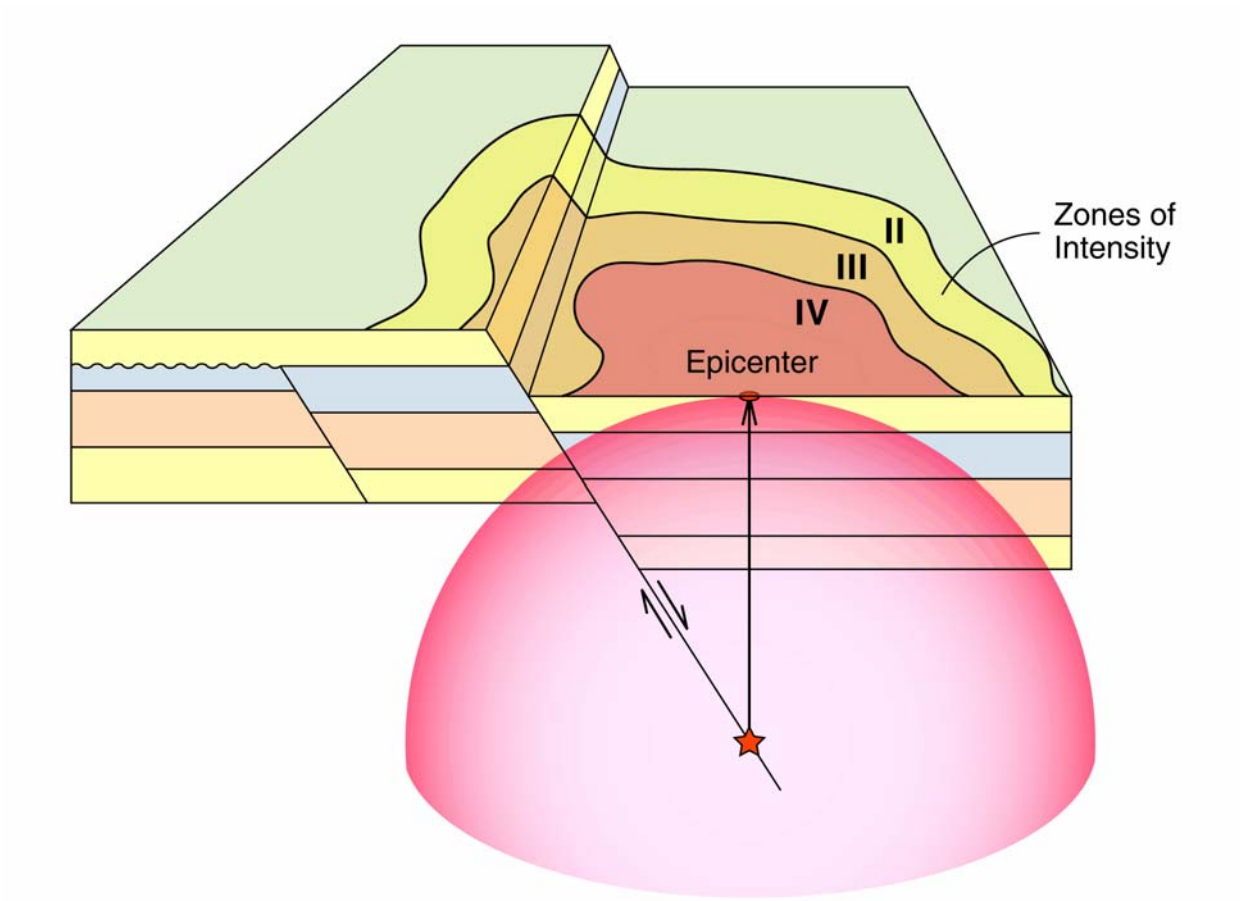

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Charles T. Swann, R.P.G.
Mississippi Mineral Resources Institute
310 Lester Hall
University, MS 38677

Introduction - Although Mississippi is not generally associated with earthquakes in the public's perception, there is historical record of earthquake epicenters (the ground surface location directly above where the earthquake originated in the subsurface) in 24 of Mississippi's counties including Mississippi's Gulf Coast. Many are small - some so small that they were detected only by instrumental methods. The largest Mississippi earthquake we have record of occurred in 1931, was a magnitude 4.7 event, and was felt in Arkansas, Louisiana and Alabama as well as Mississippi.

Earthquakes are the result of movement along faults. Many of Mississippi's earthquakes cannot be readily assigned to a known fault. The reasons for this situation include: 1) vegetative cover in Mississippi makes faults extending to the surface difficult to identify, 2) many of the geological maps of the state were constructed prior to modern topographic maps so vertical control needed to identify faulting was lacking, 3) the modern geological mapping with vertical control is available only for selected areas of the State, and 4) only recently has the potential damage posed by the earthquake hazard been fully appreciated in Mississippi government and the scientific community.

Among many of the general public, the perception is that the New Madrid Seismic Zone (NMSZ) is the only source of earthquake hazard in Mississippi. This idea is not totally correct because Mississippi has a number of faults that are not associated with the NMSZ. Local faults may have movement histories that are not tied to the same processes that govern NMSZ faults and so the knowledge we have gained from the NMSZ may not apply to local faults. Another consideration is that damage resulting from an earthquake is often tied to the distance from the epicenter. The closer to the epicenter, the greater the shaking, and the greater the potential damage to surface structures. Although the southern end of the NMSZ is only approximately 100 miles from Mississippi, a local Mississippi earthquake could occur virtually beneath a metropolitan area. Very nearly the case with this, the May 10, 2008, earthquake.

Goals of the Investigation - The characteristics of Mississippi earthquakes are poorly-known and each earthquake presents the unique opportunity to learn more about them. The goals for this investigation were: 1) to produce a map illustrating the distributions of Modified Mercalli Intensity (MMI) grades throughout the area, 2) to determine the area of maximum intensity, 3) to

determine overall felt area for the event, and 4) to make recommendations regarding earthquake mitigation and awareness.

Regional Seismicity - Historical records exist of earthquakes occurring in 24 Mississippi counties including Mississippi's coastal counties. Lee and Pontotoc Counties are in an area of Mississippi that has had few recorded earthquakes (Bograd, 2005). There is no historical record of earthquakes having previously occurred in Lee County. Adjoining Pontotoc County has an instrumentally-recorded earthquake that occurred on October 12, 1980. This earthquake was a 2.1 magnitude event and there is no record of it being felt on the surface. There have been two earthquakes recorded in Prentiss County. The first occurred on January 29, 1983, and had a magnitude of 2.4. This earthquake was not felt. Then on February 5, 1983, there was a 2.9 magnitude earthquake at the same location that had a maximum MMI intensity grade of V.

The Saturday, May 10, 2008, Event - Components of the Advanced National Seismic System (ANSS) recorded an earthquake event in northern Mississippi at 12:52:50 Central Daylight Savings Time. The epicenter of the event was fixed at latitude 34.350 N, longitude - 88.830 W, which is less than a mile south of the town of Sherman, Mississippi (Pontotoc County). The earthquake's magnitude was determined to be 3.1 on the duration magnitude scale. No damage was reported from the earthquake, although it was felt over a rather large area. Accounts of the earthquake referred to the event as centered in or near Belden, Mississippi (Lee County) although the instrumentally determined epicenter was near Sherman. This discrepancy obviously became an issue to investigate further during the field studies.

Accounts of the earthquake were published in Tupelo's newspaper, the Daily Journal (see Castens, 2008; Daily Journal, 2008; Johnson, 2008), the Clarion- Ledger of Jackson, Mississippi, (see Clarion-Ledger, 2008) and in the Pontotoc Progress, the newspaper for Pontotoc County (see Butler, 2008). The local electronic media also carried reports of the earthquake.

Characteristics of the Event - There are two factors that were consistently noted during the field interviews regarding the event. The seismic vibrations, of course, were of concern, but the noise associated with the event seemed to be of equal concern. The noise was likened to a sonic boom, dynamiting of stumps or beaver dams, or thunder, but louder or as a airplane crash. An article in the Daily Journal (Castens, 2008) reported that one Tupelo resident described the noise as "...rumble ...like somebody had thrown a cherry bomb in the sewer system."

Earthquake noise is not uncommon when the depth of the fault movement is shallow. The seismic vibrations of the soils couple with the air above and causes it to vibrate. This vibration of the air is perceived as earthquake noise. The May 10 earthquake's depth is listed as approximately 0.1 mile (528 feet), however it is noted that the depth is poorly constrained. Discussions with the ANSS seismologist (Withers, 2008) pointed out that the epicenter is on the eastern edge of the ANSS network with the closest stations (Oxford Station and the station at Pickwick Lake) located to the west and north, respectively, of the epicenter (one station in central Alabama was also used to derive earthquake characteristics). Without the epicenter being well within the network, accurate determination of depth is problematic. The suggestion was to consider the earthquake a shallow event and not to attach much reliability to the instrumentally-derived depth.

An earthquake's assigned magnitude is the result of a mathematical equation that produces a unique value (the magnitude) for a given earthquake. The values used to "plug into" the equation are derived from the seismic stations in the local network. In this case, the network is the ANSS. The assigned magnitude value is the same for each earthquake and does not change. A magnitude 4 earthquake, remains a magnitude 4 throughout the felt area. There are several earthquake magnitude scales that measure different components of the seismic event. The duration magnitude scale was used in this event. With lower value magnitudes, the differences among magnitude scales are small. The measured magnitude for the May 10 earthquake is 3.1.

Earthquake intensity is a measure of the severity of earthquake effects (Reiter, 1990) at a particular location on the surface of the earth. Intensity grade values, (unlike magnitude values) are more subjective than magnitude values, requires interpretation by the analyst, and typically vary with distance from the epicenter. The intensity grade within an earthquake's felt area is usually higher surrounding the epicenter (although exceptions have been noted) indicating more severe vibrations and a greater potential for damage. There are several intensity scales, but the one most commonly used is the Modified Mercalli Intensity Scale (MMI) that was set up in 1931. Intensity grades vary between I (felt only by a few people) and grade XII which is described as total damage. An earthquake Intensity grade I is felt only by a few people, so it is typically not mapped. Isoseismal lines divide a map into intensity grades by connecting points of equal intensity. The isoseismal line separating MMI grades II and III, for example, is interpreted as everywhere having a value of grade III with grade values higher on one side of the line (grade values above III, but below IV) and lower on the other (grade values below III, but above II).

A news account of the earthquake (Clarion-Ledger, 2008) reported that at the Belden liquor store, vibrations were sufficient to cause bottles to fall from the shelves. Vibrations sufficient to cause this type of damage are characteristic of intensity grade V or VI. Since this article seemed to indicate the liquor store experienced rather strong vibrations, it was identified during the interview process (NT's Wine and Spirits) in order to verify the news account. The interview indicated that unlike the news account, there was no damage due to the earthquake. The vibrations did cause the bottles to rattle and the sensation was likened to a vehicle running into the building (a prior experience). The occupants were sufficiently concerned to vacate the building. Another case of occupants evacuating a building was identified only a short distance from the liquor store. Although vibrations sufficient to cause the evacuation of buildings are typically associated with grade V, the lack of damage, and other characteristics typical of grade V, led to the decision to assign a grade IV (perhaps at the high-end of the grade) to this area. Southwest and west of Belden, however, small items were knocked from shelves and people vacated their homes -- the criteria for grade V. This grade V area is just west of Belden and had the highest intensities identified in the investigation (see attached map).

The area experiencing MMI grade V is relatively small and the intensity values quickly diminish to MMI grade II. Of those feeling the earthquake, by far, most experienced MMI grade II intensities. The grade II lower boundary defines the felt area of the earthquake. Intensity grade II was reported from all interviewees in Pontotoc County (*i.e.* Sherman, Endville,

Chesterville, and Furrs) and extends westward beyond Old Natchez Trace State Park and to within a few miles of the city of Pontotoc. Northward, Sherman was near the edge of the felt area which extends into the southeast corner of Union County. As can be seen in the attached map, the felt area is not symmetrical and extends further to the west than to the east. For this reason, only the western portion of Tupelo and parts of downtown Tupelo were affected by the event. The felt area is defined by the area within the MMI grade II isoseismal line. Using the area inside this isoseismal line as the criteria for defining the felt area, the earthquake was felt over 97.06 square miles in Pontotoc, Lee, and Union Counties.

There were several reports from residents in the vicinity of the Tupelo airport and all seemed to describe typical grade II effects. The residents in this area were concerned not only about the vibrations but also about the noise that accompanied it. Many likened it to an airplane crash. Pets from throughout the area were disturbed by the earthquake, although none exhibited any behavior that would indicate they sensed the event prior to it occurring.

As can be seen on the attached map, the areas of highest intensities are in and near Belden, although the instrumental epicenter was located near Sherman; approximately 4.5 miles to the northwest. The discrepancy between the area of highest intensities and the instrumentally-derived epicenter (high intensity MMI values and the epicenter should coincide) was discussed with the Center for Earthquake Research and Information. The fact that the event was on the edge of the ANSS network and most of the network is to the north, suggested that some inadvertent error in epicenter location could be included in the calculations causing a northward displacement of the epicenter. Since there are no known geological factors that could cause the intensities to be shifted to the south, it is suggested that the epicenter is actually in Lee County near Belden, or approximately 3.37 miles to the south and 1.73 miles to the east of the instrumentally-derived location (or at latitude 34.298158^0, and longitude -88.798944^0). If the epicenter is moved to this location, this represents the first earthquake recorded in Lee County.

Geological Implications - A review of the literature has not identified any known faulting in the vicinity of the earthquake. Examination of topographic maps does not suggest any preferred drainage directions for the local fluvial systems or anomalous drainage patterns that could be the surface expressions of faulting at depth. The causative fault is new to us and so we know virtually nothing about it. Characterization of the fault is an obvious recommendation that could help reduce the risk of earthquake-related damage to the built environment.

The lack of information regarding this fault also points out the need for a broad study of faults in Mississippi that may have on-going movement. Active faults could pose a significant earthquake hazard to the near-by built environment, particularly if their presence is not anticipated. Their identification and the time and nature of their movement would be useful information to model the characteristics of potential earthquakes generated by the fault and what economic loss could potentially be caused by the event. Earthquake modeling also aids the local and State emergency managers as they plan for future contingencies.

The asymmetrical felt area may be influenced by local effects reflecting the underlying shallow stratigraphy. The area of highest intensity near Belden (assumed epicenter) is located along the western edge of the outcrop belt of the Cretaceous Demopolis Formation (chalk). A

few miles to the west (at Sherman) is the outcrop belt of the Ripley Formation (Cretaceous) which extends westward to the vicinity of Pontotoc. The Ripley is composed largely of clastics *i.e.* fine- to medium-grained sands. From Belden, the felt area is much better developed to the west than to the east (although the felt reports are also few to the east) which coincides in large part with the outcrop belt of the Ripley Formation. It is suggested that local site characteristics associated with the Demopolis chalk outcrop belt may be damping the transmission of the seismic waves to east producing the asymmetry of the felt area. This suggestion is supported by a thesis completed by Snodgrass (1998) which was conducted on the Mississippi State University campus. He concluded that the chalk on which the campus was constructed met the shear-wave velocities required to be considered seismic bedrock. The important point to be derived is that the seismic waves will not be as highly amplified in this "bedrock" terrain and will also damp more quickly. The seismic waves damp more quickly over the out crop belt of the chalks in the Demopolis (smaller felt area), but are amplified over the out crop area of the clastics in the Ripley Formation (larger felt area). The final result is an asymmetrical felt area.

Seismic Hazard - There are many faults that have been identified in Mississippi, but to date, none have been identified that could correlate to the fault that moved on May 10 near Belden. With very little known about the fault, it is difficult to characterize the seismic hazard it may pose to the built environment. The few earthquakes recorded from this area suggests a minimal seismic hazard; however the historic record is too short to adequately characterize the seismic activity of a fault. The classical example of this situation is the Meers Fault of Oklahoma, (Ramelli and Slemmons, 1990) that exhibits geomorphological features typical of recent movement, but is virtually aseismic. It is estimated that the Meers Fault is capable of generating significant earthquakes (magnitude 7 or greater), and has been active during the last few thousand years.

The May 10 event demonstrated that the Belden fault is active and is capable of generating at least a magnitude three earthquake. No geomorphological features were identified that would suggest the fault plane extends to the surface. Unfortunately, the paucity of subsurface information on the fault, such as fault length, makes it difficult to evaluate its potential to producer larger earthquakes. The major concern is the fault's close proximity to Tupelo - an increasingly urbanized area with a high population density. Perhaps the best strategy for addressing the earthquake hazard is to anticipate a larger magnitude earthquake and prepare accordingly. This preparation will serve equally well for an event from the NMSZ.

Recommendations - The following recommendations include scientific studies as well as more applied emergency management recommendations.

1) It is recommended that the legislature of the State of Mississippi require the local adoption and enforcement of building codes, including the seismic provisions, for northern Mississippi (International Residential Code of 2006 and the International Building Code of 2006). Code implementation should go beyond mere adoption and include review, inspection, and quality control provisions. Putting this recommendation into practice would provide better earthquake performance for new buildings and provide the public a more uniform, minimal level of safety in the more earthquake-prone northern end of the state. One of the lessons learned from Hurricane Katrina is that relying on the

voluntary adoption and enforcement of building codes results in a patch work of compliance and provides less than adequate provisions for the public's health and safety.

2) It is recommended that the governing bodies of the municipalities in or near the felt area adopt the latest building codes (International Residential Code of 2006 and the International Business Code of 2006) including the code's seismic provisions as described above.

3) From field work in Pontotoc and Lee Counties, it is obvious that there is considerable interest in the earthquake among those that felt it and those that did not. It is recommended that the Mississippi Emergency Management Agency (MEMA) be the lead agency in holding educational meetings in the Tupelo / Belden / Sherman / Pontotoc area to discuss potential earthquake implications to the built environment, and potential earthquake mitigation.

4) With this earthquake occurring near the urbanized Tupelo area with its high population density, additional geological information on the causative fault would be useful. A geological study is recommended to determine fault depth, length, displacement and to develop any other geological information to help evaluate the seismic hazard it poses to the Tupelo / Pontotoc area. Similarly, geotechnical characteristics (such as soil amplification) of local soils during an earthquake event have been determined for very few areas of Mississippi. A set of maps depicting soil amplifications and potential areas of liquefaction should be prepared for the Tupelo area.

5) It is recommended that a tabletop exercise be held (perhaps a joint Lee / Pontotoc County exercise) to explore emergency management implications of a significant earthquake event.

6) It is recommended that Tupelo undertake a study to identify the structures that are likely to be vulnerable to damage during an earthquake event (such as unreinforced masonry) and adopt mitigation measures to minimize potential damage. The mitigation should include structural as well as non-structural measures (such as the installation of seismic gas shut-off valves). Schools in the Pontotoc and Lee County area should be a high priority for earthquake mitigation. We should learn from the tragic earthquake losses recently experienced in the Sichuan Provence of China and seek to not repeat the situation that led to them.

7) With an earthquake hazard from both the NMSZ and from local, Mississippi earthquakes, it is recommended that a Mississippi seismic council be established. The Mississippi Office of Geology, Mississippi Mineral Resources Institute, and the Center for Community Earthquake Preparedness (University of Mississippi) have earthquake expertise in Mississippi and could form the technical base for the council. The council should be lead by the Mississippi Emergency Management Agency and could include academia, private industry as well as other State and Federal agencies with

responsibilities (or interest) in the area of earthquake mitigation and emergency management.

Although these recommendations were discussed with several State agencies, they remain the considered opinion of the author. Others may or may not agree.

Acknowledgments - I would like to acknowledge all that gave me a few minutes of their time to fill out the forms and discuss their earthquake experience. These interviews are the basic data on which this report is based. I would like to particularly acknowledge the help of Mr. Jim Littlejohn, Pontotoc Fire Chief, for his help with the obtaining information from Pontotoc County regarding the earthquake and Mr. Paul Harkins, of Lee County E-911 for his help with the Lee County information. Mr. M..B.E. Bograd of the Mississippi Office of Geology and Ms. Suzanne Lewis of the Mississippi Emergency Management Agency also assisted with the investigation. Thanks to Dr. Darrel Schmitz of Mississippi State University for pointing out the work done at MSU and providing a copy of the Snodgrass thesis. Carol Lutken, MMRI Interim Director, improved the manuscript by her editing and constructive criticism. My sincere thanks to all at the Sherman City Hall. Everyone's help and enthusiasm in Sherman was greatly appreciated and it makes an investigation much more enjoyable.

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FELT AREA MAP OF THE MAY 10, 2008, EARTHQUAKE LEE AND PONTOTOC COUNTIES MISSISSIPPI

Charles T. Swann
Mississippi Mineral Resources Institute
310 Lester Hall, University, MS 38677

R 3 E
R 4 E
R 5 E
GUNTOWN
R 6 E
T 8 S
T 9 S
T 10 S
BLUE SPRINGS
LEE CO.
UNION CO.
PONTOTOC CO.
SHERMAN
SALTILLO
BELDEN
TUPELO
PONTOTOC
PLANTERSVILLE
VERONA
Old Natchez Trace Lake
Lake Lamar Bruce
Lake Wilhelmina
Brown Creek
Tishomingo Creek
Yonaba Creek
Town Creek
Coonewar Creek
Chiwapa Creek
Mogue Chitto
II
III
IV
V

LEGEND

- Location of report (was felt)
- Location of report (was not felt)
- Instrumental earthquake epicenter
- Proposed new epicenter
- Isoseismal Lines
- IV Modified Mercalli Intensity values

MS
Location of Study Area

N

0 1 2 3 4 Km
0 1 2 3 mi.