Assessing Earthquake Risk in the Western Ohio Seismic Zone

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Abstract

Outside of several isolated areas, such as the New Madrid, Missouri area or Charleston, S.C., the mid-continent of the United States is not typically recognized for earthquakes. Western Ohio, and more specifically Anna, OH, has historically experienced seismic activity. Future earthquakes here will be especially dangerous, because the general public is not prepared for a high magnitude event to occur there. There is research being done, notably by the OhioSeis Network, which is a division of the Geological Survey of the Ohio Department of Natural Resources, to study the causes of these earthquakes and to create awareness and spread knowledge about them. There are also various geologic and seismologic organizations that are working to predict the maximum earthquake that is possible to occur in a given area. If a high magnitude earthquake were to strike in western Ohio today, transportation, buildings, and pipelines would all be in jeopardy. If the earthquake in L'Aquila, Italy was able to create so much damage there, then one of a similar size here, which is possible, could surely be just as devastating in Ohio. The most important and easiest way to prepare for future seismic activity is to spread awareness regarding their effects and the dangers they could present.

Introduction

For the purposes of this report, the Western Ohio Seismic Zone is defined as the areas of land in the following counties: Allen, Auglaize, Champaign, Logan, Mercer, Miami, and Shelby. This region has historically had earthquakes, with over 40 having been recorded here since 1875 (Hansen, 2003). The majority of these earthquakes have been at a low enough magnitude so as not to cause serious damage or concern. Two earthquakes occurred seven days apart in Shelby County in 1937, with the first having a recorded magnitude of 4.9 and the second of 5.6. These earthquakes were of intensities VII and VIII, respectively, on the Mercalli scale (figure 4). The sources for such earthquakes in the Western Ohio Seismic Zone, as well as many other mid-continental areas, are poorly understood, and many studies and theories are debated for why they occur in particular regions. Since earthquakes have historically occurred in western Ohio, it is likely that they will continue to strike there in the future. How big can an earthquake be here? What could possibly go wrong if a high magnitude earthquake were to strike in western Ohio today? These are questions that can be analyzed to better prepare ourselves for such an event and to perhaps create awareness regarding mid-continental earthquakes. Conceivably the most dangerous aspect of this situation is the ignorance of the general public to the dangers of earthquakes in their area.

Background

Local Geology

Western Ohio is located in the Central Lowland physiographic province, which is characterized by relative flatness and low-lying topography (Fenneman, 1928). Most of Ohio is covered by glacial deposits, left behind by ice sheets from the Wisconsinan and Illinoian glaciations. The area defined as the Western Ohio Seismic Zone is primarily covered by glacial deposits from the Wisconsinian glaciation. This includes unconsolidated sediments such as till, boulders, gravel, sand, silt, clay, and organic debris. This material was deposited in the form of ground moraines, terminal moraines, and ridge moraines, with some outwash plains in Shelby and Miami counties. All of the glacial material lies on top of old, flat-lying or gently dipping bedrock, with few large structural features of note. The sedimentary rock in Western Ohio ranges from the Cambrian System (510 million years ago) to the Devonian system (407 million years ago).

Based on Rb-Sr dating techniques, the basement rock in central Ohio is 1 billion years old, and becomes older west of the Grenville Boundary in Ohio (Bass, 1960 and figure 3). Hypocenter depths place Ohio's earthquakes in the basement rocks at depths of a few kilometers. The earthquakes presumably occur along zones of weaknesses, such as faults, margins of intrusions, and the failed Fort Wayne Rift (figure 3). The reason earthquakes are poorly understood in regions such as Western Ohio is because these structures are covered by sedimentary rocks and thus must be studied mostly by geophysical means.

Causes of Earthquakes

The earthquakes in this region are poorly understood, although the study of stress in intraplate regions, as well as knowledge of deeply buried faults can provide clues to the causes of earthquakes in the Western Ohio Seismic Zone. Midcontinent earthquakes are difficult to study because there are long periods of time where there is no seismic activity, and when earthquakes do occur, the observed offsets of the earth are typically small.

Ohio is in an area characterized as undergoing relative east-west horizontal compression due to ridge push (Zoback and Zoback, 1981). The stress is relatively uniform and occurs on a broad-scale, which gives clues to the source of the stress. As a result, earthquake stress can be explained by a combination of ridge push and basal drag from the Mid-Atlantic Ridge.

The basement where earthquakes originate in Western Ohio is over 1 billion years old, brittle, and has subjected to considerable horizontal compression. Basement structures like faults, intrusion margins, and other localized zones of weakness in crustal rocks concentrate the earthquake activity. This helps to explain why intraplate earthquakes are seemingly happening on specific fault zones, rather than randomly in the crustal stress field (Zoback and Zoback, 1981).

Figure 3 shows basement structures in Ohio derived from various geologic studies. Some of these structures have been studied in more depth than others, as some of the smaller faults are strictly speculative and based on seismic activity. All of the associated structures in the Western Ohio Seismic Zone are deep, and none of them are visible at the surface of the earth. The Precambrian basement of Ohio is covered by 750-4500m of sedimentary rocks and glacial deposits (Baranoski *et al.* 2009). Figure 1 shows that the earthquake epicenters generally trend in a NW-SE direction, which roughly follows the trend of the Fort Wayne Rift (figure 3). The Fort Wayne Rift was caused by the Grenville Orogeny in Ohio. First, continental collision and crustal shortening made its way to eastern Ohio, then extensional rift basin complex was developed in the west, first as the Fort Wayne Rift, then later as the East Continent Rift System (Branoski, *et al.* 2009). Some of the earthquakes in western Ohio are also thought to come from smaller faults that also run NW-SE and are adjacent to the Fort Wayne Rift. These faults include the Logan Fault and the Anna-Champaign Fault, the latter which is thought to have caused the 1986 earthquake in Auglaize County (Hansen, 1999). It is thought that the Anna-Champaign Fault was created by the failed Fort Wayne Rift (Hansen, 1999). Despite the many theories and studies regarding Ohio earthquakes, including localized weak bedrock and rift zones, the definite causes for earthquakes in the Western Ohio Seismic Zone continue to be tentative and speculative.

Methods

Maximum Size of Potential Earthquakes

The sizes of potential earthquakes in intercontinental regions can be estimated using a variety of methods. The magnitude of the largest earthquake thought to be possible in one of these regions is labeled *Mmax* (Wheeler, 2009). Different experts, teams, and organizations have used a combination of different methods to find estimations of *Mmax* for eight locations in North America. Wheeler compiled these data in his report published in 2009. There have been three major assessments of *Mmax* estimation by different groups. One such project was conducted by experts from the Lawrence Livermore National Laboratory (LLNL), which ran from 1983-1993. Another project was produced by teams from the Electric Power Research Institute-Seismicity Owners Group (EPRI-SOG), which consisted of geologists and seismologists, from 1983-1986. Finally, USGS has released a series of *Mmax* estimation maps from 1976-2008.

Several methods were used to estimate *Mmax* values, each of which has respective advantages and disadvantages. The numerous experts and groups used different combinations of these methods, with some researchers using only one method, and others using as many as four. The most used method, and perhaps the simplest has *Mmax* being equal to the largest observed magnitude in a specified region, also called *Mobs*. This method is simple to use, and can be employed just about anywhere. It also gives us a definite lower bound for the *Mmax* of an area (Wheeler, 2009). This method is problematic however, considering the relatively short period of time that we have records of earthquake magnitudes. It is very likely the largest earthquake to have occurred in a specific region happened before its magnitude was able to be recorded. The second most used method to estimate *Mmax* was based on study of the local seismicity rate of an area. This technique used the observed frequency of smaller earthquakes to predict *Mmax*. The reason this method is effective is because when earthquakes happen faster in a seismic zone, it is more likely that larger earthquakes will occur there. This is a qualitative approach, where it is observed that fault zones will mature faster and grow when they are more seismically active. The issue with using the seismicity rate is that it is questionable whether it can be applied to mid-continental regions as well as it can be applied to plate boundaries. Also, the seismicity rate method is not valid for *Mmax* values lower than about 7.0. The third most used method uses local geological and geophysical properties of an area, such as details of fault zones and geophysical anomalies to estimate *Mmax*. This method is great for areas with distinct faulting and geophysical anomalies, but relatively problematic for areas in the mid-continent such as Anna, OH, where the crust producing earthquakes is hidden under a cover of glacial and bedrock materials. Geologic explanations are still weak and poorly understood regarding why earthquakes occur in the Western Ohio Seismic zone.

Mobs, seismicity rates, and local geologic features are the three most used techniques by all of the studies done. There are other techniques that were used, though not as extensively. One such method involves adding a chosen constant to Mobs. This solves the historical record problem, but then there is an issue with how to choose the constant. The increments likely vary between regions, and it is hard to quantify the changes in the increments. Another method estimates *Mmax* by "extrapolation of a magnitude-frequency graph of the area's seismicity" to 1,000 years (Wheeler, 2009). This method is also simple to use and can easily be reproduced by different investigators. The problems with this method are that it is dependent on the size of the study area, and there is no quantitative explanation to why you extrapolate over a 1,000 year period. *Mmax* estimation facilitates studies of intercontinental earthquakes where the geological constraints are so poorly understood. *Mmax* studies are not as effective at plate margins where *Mmax* can be easily computed. At these regions, tectonics and faulting can be more directly observed and studied as the causes of earthquakes.

Of the twenty studies that were analyzed by Wheeler (2009), the most used techniques to estimate *Mmax* were based on Mobs, the seismicity rate, and local geologic features. The overall average value of *Mmax* for the Anna, OH region as calculated by LLNL experts, EPRI-SOG teams, and the USGS, was 6.3, with a median of 6.2, and a range of values between 5.2 and 8.4. The overall average for *Mmax* was equal to 6.3, which also was the magnitude of the earthquake that occurred in L'Aquila, Italy in 2009. As seen in figure 4, the *Mmax* estimation for the Western Ohio Seismic zone lies within category IX of the Modified Mercalli scale. As seen in the figure, this translates to serious structural damage to buildings, underground pipes, and other structures.

Implications

To analyze the hazards that are likely from an earthquake occurring in the Western Ohio Seismic Zone, an earthquake of magnitude 6.3 will be assumed for this area, applicable anywhere in the seven counties previously noted. In the following sections, problems that could arise from a large magnitude earthquake will be examined, including transportation, buildings, oil and gas pipelines, hospitals, and anything else that could fail and thus pose a threat to the people of Western Ohio.

Transportation Systems

According to the 2000 U.S. Census, the average population of the seven counties in the Western Ohio Seismic Zone is 57,540 people, with the total population of these counties together being 402,780 people. For the total area this covers, about 3,000 square miles, this is not an overly populated area, which at first thought is a positive thing in case of an unforeseen natural disaster. The opposite can be argued however, especially regarding transportation and other such infrastructure. Because of the relatively low population in central-west Ohio, there is only one interstate highway, I-75 that runs through the Western Ohio Seismic Zone. There are also two U.S. highways, routes 33 and 36, that run East-West through this region. When bridges or overpasses fail on these roads, emergency services are essentially cut off from the population.

Primary airports are non-existent in this region. The closest primary airport, as seen in figure 1 is in Dayton OH, which is 42 miles from Anna, OH, and even farther from Allen, Auglaize, and Logan counties.

Damage to railroads is another problem worth examining. There is a railroad hub in Lima, OH, and figure 1 shows that 6 railroad lines meet here in Lima. In the late 19th century and early 20th century, the railroad industry was booming in Lima, with over 100 trains passing through the town daily. Although not what it once was, especially considering there are no more transportation railways that pass through Lima, there are still several freight trains that pass through Lima on a regular basis. This freight service would be disrupted by a strong earthquake.

Oil and Gas Pipelines

As discussed earlier, the *Mmax* of Anna, OH correlates to IX on the Mercalli scale, which indicates "ground cracked" and "underground pipes broken". This could pose problems for the oil and gas pipelines in the area. As seen in figure 5, there are several oil and gas pipelines, distribution centers, and refineries that pass through the Western Ohio Seismic Zone. Several of these oil gas pipelines converge in Allen County. An earthquake could disrupt the distribution and production of oil and gas in the area, which could lead to bigger problems involving companies and industries that rely on these pipelines. Another potential hazard could involve the Rockies Express Pipeline (REX) that passes through Lebanon, OH, which is south of Dayton and north of Cincinnati. This pipeline was just completed in 2009, and is one of the biggest natural gas pipelines in the United States. This pipeline, which stretches from Colorado to Monroe County, Ohio, has 1.8 billion cubic feet per day capacity. This pipeline is somewhat south of our seismic region, but would be affected by a strong earthquake in Anna, Ohio. This could potentially be a very expensive problem, as the development and construction of the REX pipeline cost about 5 billion dollars.

Additional Impacts

Another potential problem that is exacerbated by the relative low population of the Western Ohio Seismic Zone is the number of hospitals in the area. Due to the lack of large cities, there is only one hospital in five of the seven counties of the Western Ohio Seismic Zone, and Allen County has two hospitals and Miami County has three hospitals. Plumbing and electricity would surely be disrupted during a large magnitude earthquake, and more severe damage is likely, depending on the exact magnitude. According to the Mercalli Scale, an earthquake with a magnitude of 7 to 7.5 has considerable capacity to destroy buildings and other structures.

In 2006, Allstate Corp. dropped earthquake insurance across most of the U.S., including in Missouri, home of the New Madrid seismic zone. The losses an insurance company would endure over an unexpected natural disaster such as an earthquake could be crippling to the company. Earthquakes are considered a low risk, high impact event, especially in the mid-continent, meaning that although it is unlikely and uncertain if/where an earthquake will strike, its damage could be catastrophic. Allstate's actions highlight two important aspects about our society's viewpoint on mid-continent earthquakes. First, it shows that many people and businesses do not treat mid-continental earthquakes as a real threat. Second, and oppositely, they are recognizing the fact that if an earthquake were to occur in mid-continental regions, it could potentially be so catastrophic that it would financially devastate their business.

Discussion

Western Ohio vs. L'Aquila, Italy

Considering the similarities between the 6.3 magnitude earthquake in L'Aquila, Italy in April, 2009 and the *Mmax* estimation for Anna, OH, a comparison of the two regions can be done to predict the earthquake damage in Ohio. Comparing the two regions with regards to earthquakes can also possibly catch the attention of the general public and create awareness of the hazards of earthquakes. There are several aspects of the L'Aquila earthquake that can be investigated and then compared to the potential situation in western Ohio. The population of L'Aquila, Italy is 72,948, with a daily presence in the city of about 100,000 people (US Census Bureau). The total death count from the earthquake was 307, with 1,500 people injured, and 65,000 people left homeless. The average population in Shelby, Auglaize, Allen, Logan, and Mercer counties, Ohio is 57,540, with a total population in these counties over 400,000 people. There was noticeable damage to between 3,000 and 11,000 buildings in L'Aquila, many of which conformed to seismic-safety standards. On the other hand, some buildings were reportedly poorly constructed, and there is an on-going investigation regarding the degree to which these safety standards were followed. Although building codes and zoning laws in Ohio are enforced and effective, buildings here are not designed or constructed to be able to withstand a high magnitude earthquake. The fact that thousands of buildings experienced significant damage should be noticeable, if not a warning to people that live in areas with a history of seismic activity.

According to a Geo-engineering Extreme Events Reconnaissance (GEER) report in L'Aquila and the surrounding areas, some small villages outside of L'Aquila experienced heavy damage to buildings. The villages that experienced the heaviest damage were located on Pleistocene soils. Although the causes of the western Ohio earthquakes are much different than Italy, the geology is similar based on the fact that there are unconsolidated sediment at the surface of both regions. This amplifies the effect of an earthquake, and that is evident based on the damage seen in these small villages in Italy. According to a USGS map of the L'Aquila earthquake, in figure 6, there was an intensity of at least V on the Mercalli scale for a circle surrounding L'Aquila with a 30 mile radius. In the center of the circle, L'Aquila, the Mercalli intensity was equal to IX and X. The size of this circle shows that damage is felt over a large area, which would be the same for an earthquake in western Ohio.

Conclusion

If a 6.3 magnitude earthquake were to strike somewhere in the Western Ohio Seismic Zone, many problems would arise regarding infrastructure and damage to buildings. The damage could be especially severe considering the glacial deposits that exist in much of Ohio. The reason an earthquake would be so dangerous here, is because of the fact that people are not ready for such an event. There are simple things Ohioans can do to ensure a safe future, including securing large bookshelves, appliances, and other large furniture items in their homes, and buying earthquake insurance, which is currently available in Ohio.

Recommendation for Future Work

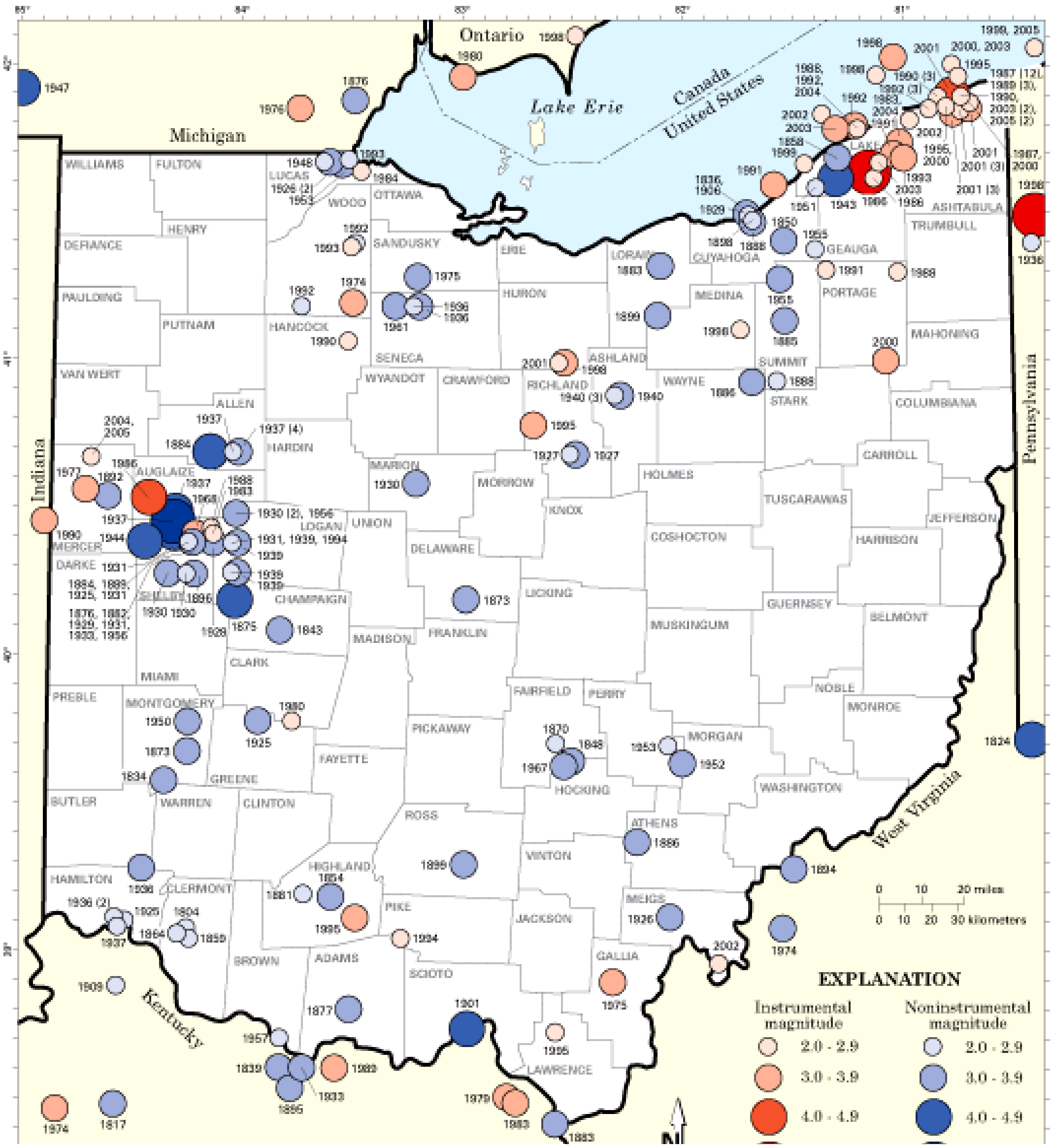
The most important work that can be done in the future is to continue to spread awareness regarding earthquakes in Ohio. The Ohioseis Network is a great start, and if Ohioseis could grow and gain more attention, they could have an even better effect on the future. Progress is being made toward learning about causes of mid-continental earthquakes. In the future, geo-scientists will know more about the origins of these earthquakes, and those of the Western Ohio Seismic Zone.

Acknowledgements

I would like to thank the OhioSeis Network for all of the work they have put in regarding Ohio earthquakes. Their maps, earthquake descriptions, and supplemental information were of great help while completing this project. I would also like to thank Ralph von Frese for all of his help and guidance.

List of Figures and Tables:

Earthquake Epicenters in Ohio and Adjacent Areas



The Ohio Seismic Network: http://www.dnr.state.oh.us/geosurvey/html/fltmap/tabid/8306/Default.aspx

Figure 1

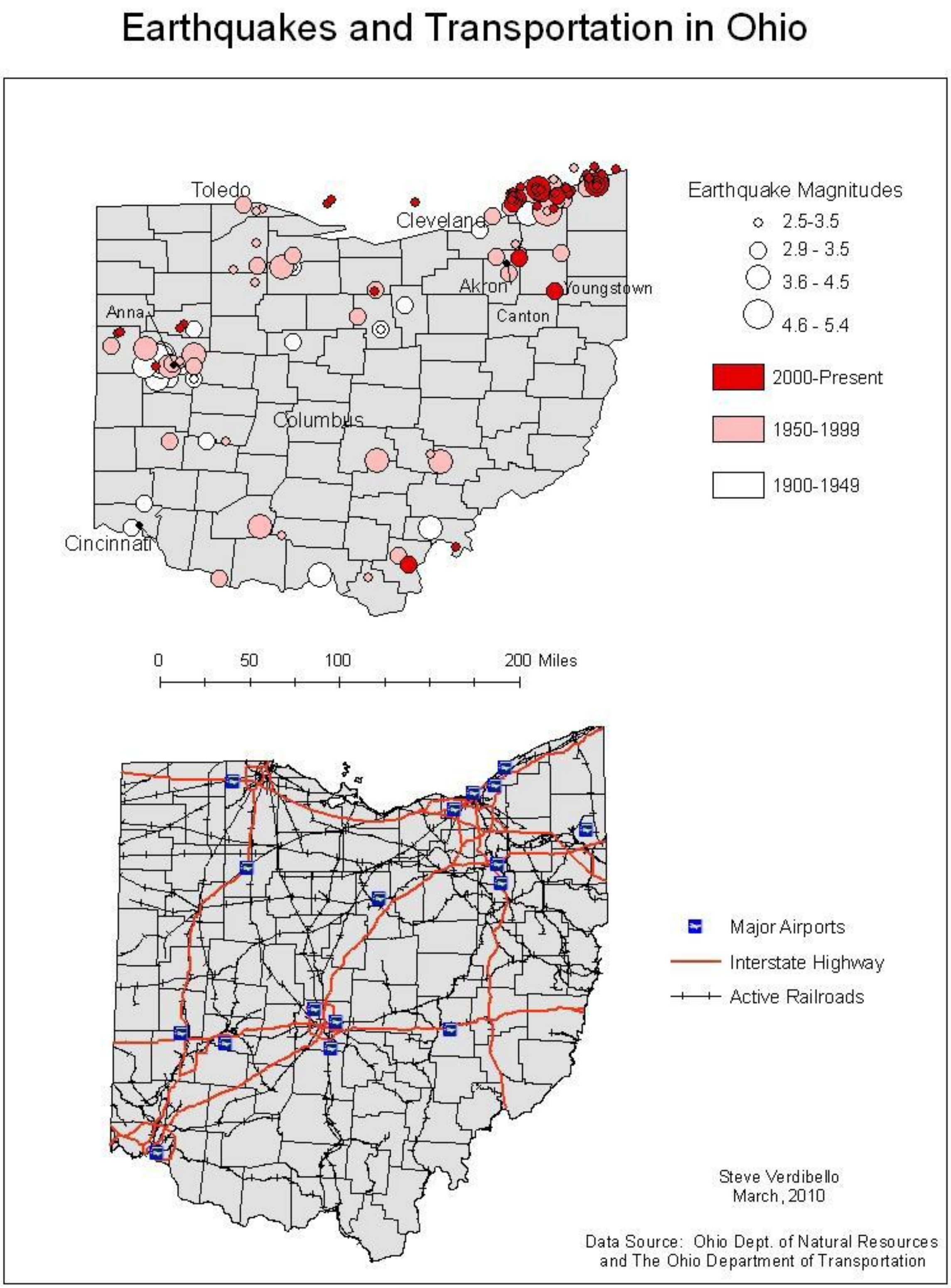
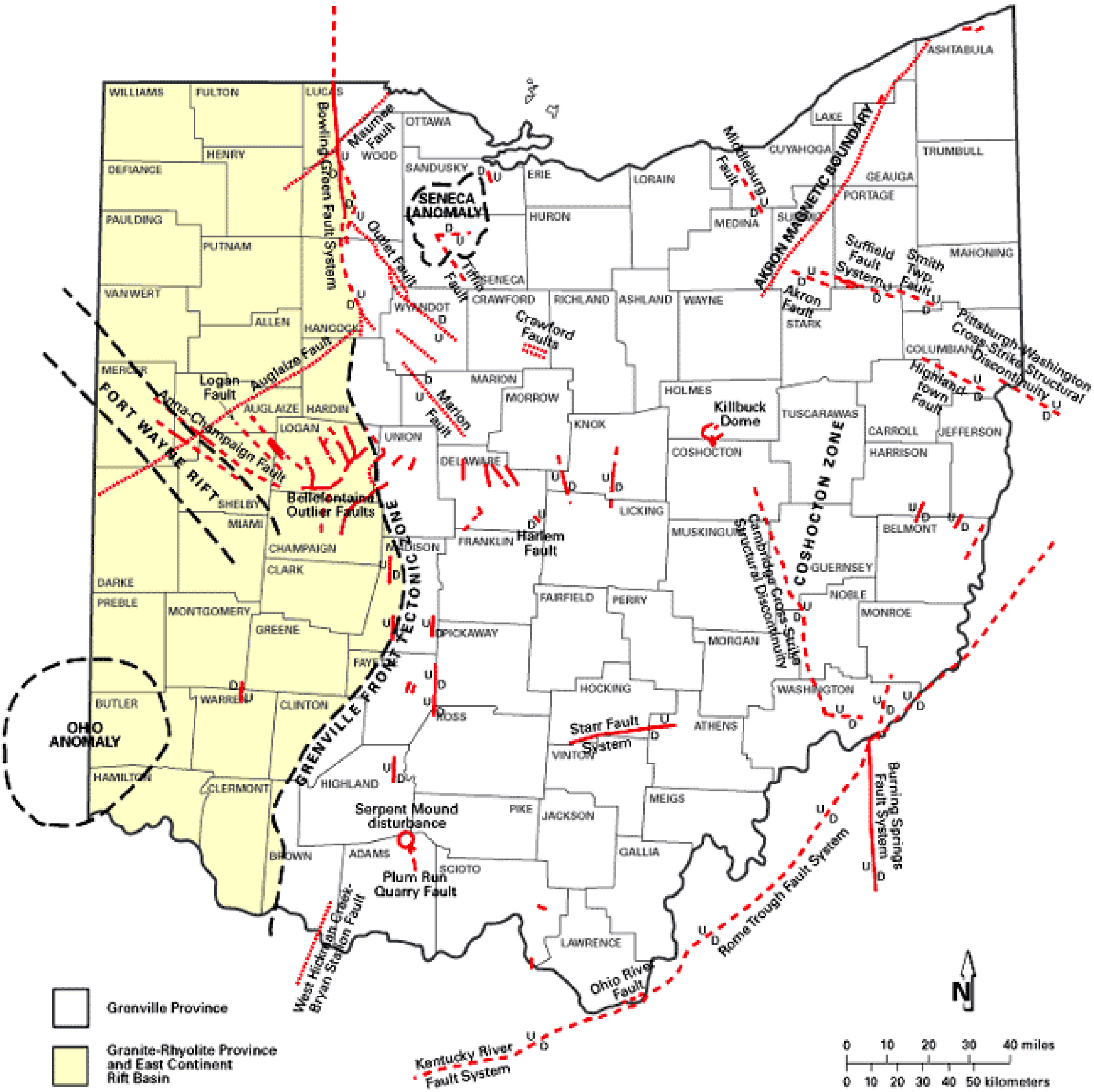


Figure 2: Created in ArcGIS

Map of Deep Structures in Ohio



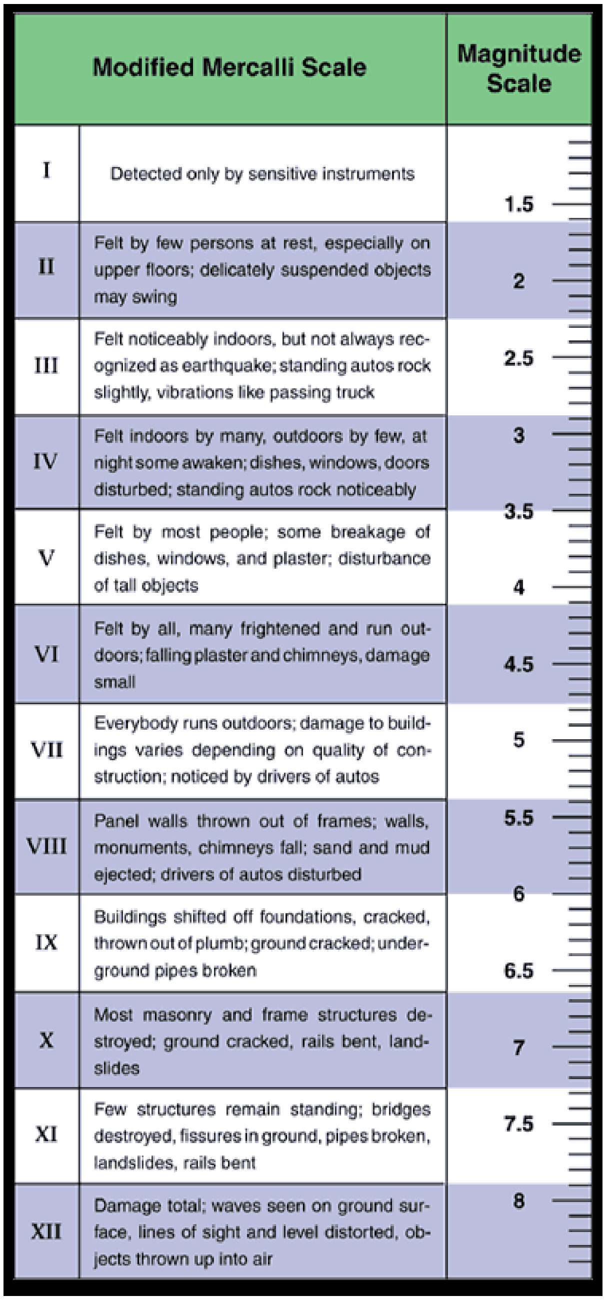
The Ohio Seismic Network: http://www.dnr.state.oh.us/geosurvey/html/fltmap/tabid/8306/Default.aspx

Figure 3

Mmax Estimation, Anna, OH:

Research Group	LLNL Experts	EPRI-SOG Teams	USGS	Overall Avg.
Mmax Avg.	6.29	6.20	6.44	6.31

Table 1



← **Avg. Mmax for Anna, OH**

Figure 4

The Mercalli Scale: The Ohio Seismic Network:
http://www.dnr.state.oh.us/geosurvey/html/scales/tabid/8313/Default.aspx

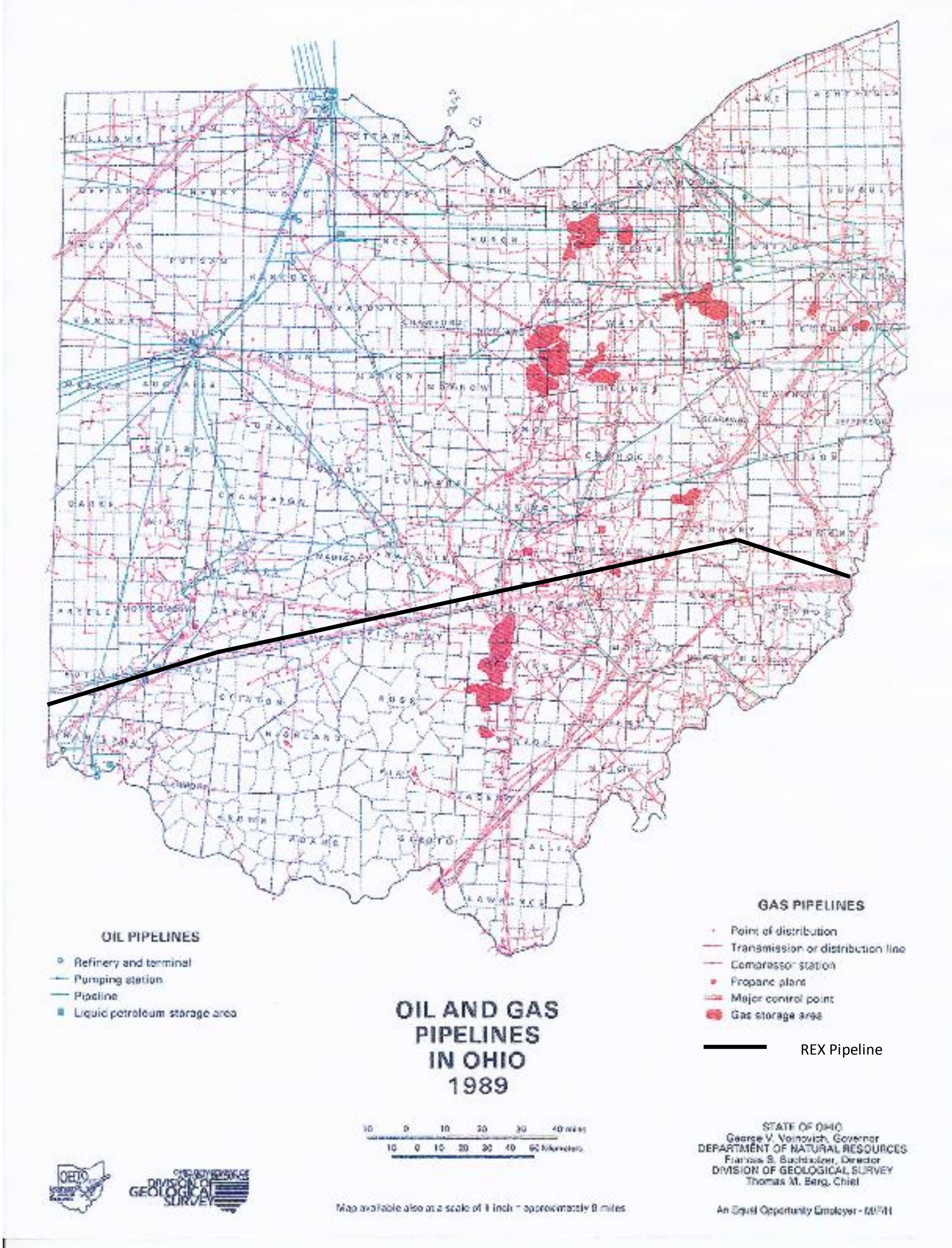
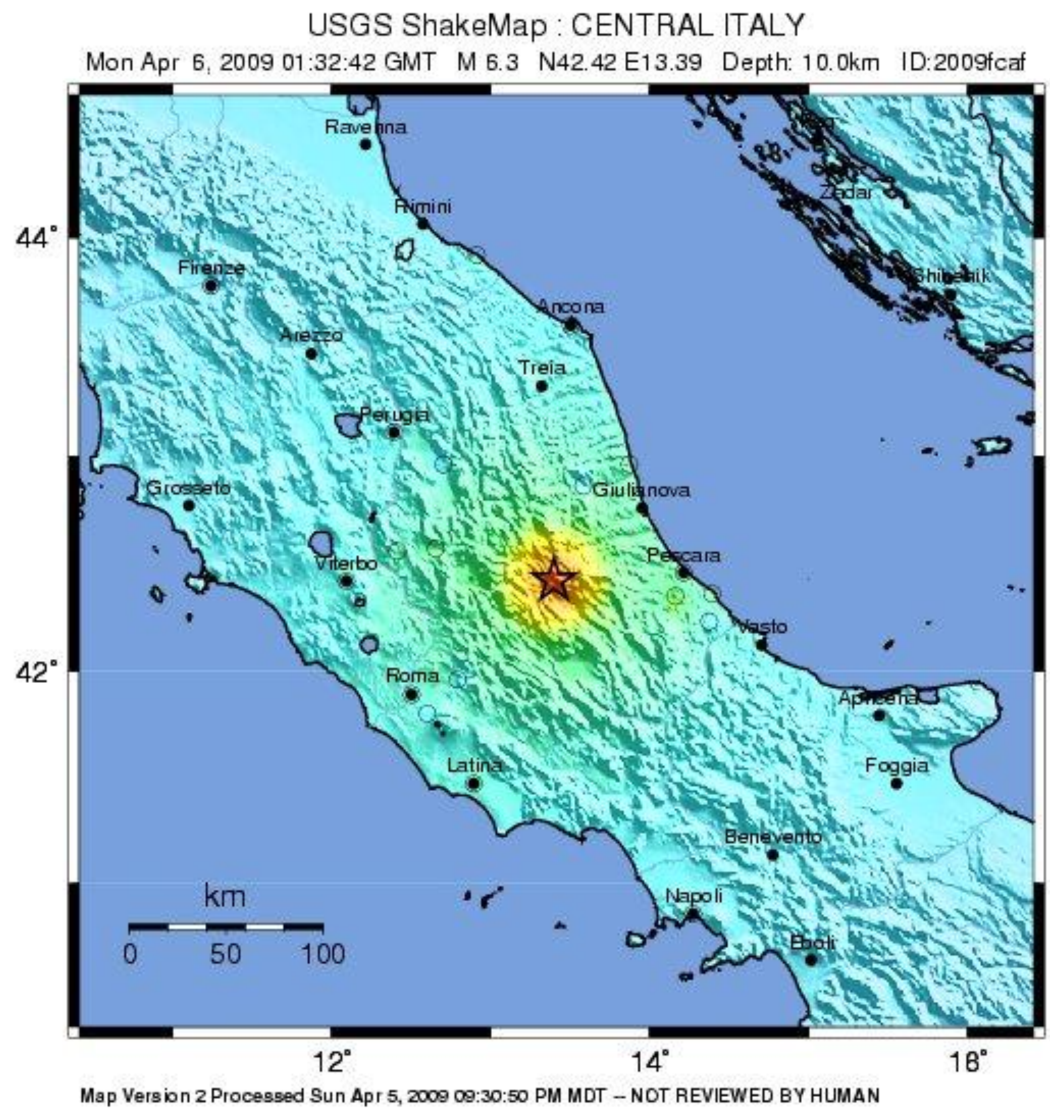


Figure 5: ODNR



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Figure 6: USGS

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