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Various Opinions On the Seismic Hazards of the New Madrid Seismic Zone
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Abstract
Significant earthquakes have happened in the New Madrid Seismic Zone (NMSZ) creating concern over the potential hazard of the region. Ten representative academic articles were chosen that focused on the observations of physical aspects of the NMSZ such as fault movement, sand blows, and paleo seismic data. All the opinions were widely varied as there was no general consensus on the probability of another major earthquake happening. The conclusion is that more research is needed and for now and there is no sure way to predict the time of the next large earthquake in the NMSZ.

Introduction

Ever since the 1811-1812 large earthquakes in New Madrid, MO the question of when the next significant earthquake will occur has been the question. Earthquake prediction is still in the early stages of development and has a long way to go. However, a question that dozens of scientists have tried to answer over the last fifty years has been, when will the next large one occur.

To better understand the NMSZ some background is needed. It is located on the Reelfoot Rift which is a failed rift zone created about 180 million years ago when the Atlantic Ocean was beginning to form. However, the North American continent failed in breaking apart. The Reelfoot Rift extends for 150 miles through Tennessee Arkansas Missouri and Illinois which causes earthquakes frequently.

The main reason for concern is that while large earthquakes do not occur as often as in some other plate boundaries areas such as the San Andreas fault, some large earthquakes with magnitudes as large as 8.0 could occur in the interior of tectonic plates such as the NMSZ. The 1811-12 earthquakes caused significant damage as was felt as far as New York. However, at the time Missouri was only starting to be colonized and so few people were significantly affected. Now large cities such as St. Louis, Nashville, and Memphis have all been built near the fault zone. If even a 6.0 earthquake occurred millions of people would be affected by the earthquake. A joint assessment by the Mid-American Earthquake Center of the University of Illinois and the Federal Emergency Management Agency predicted that a major New Madrid event could cause an economic loss of over 300 billion dollars. For reference, the damage cost by Hurricane Katrina was around 161 billion dollars.

To explore how much potential hazard the NMSZ has, ten opinions were selected covering the potential for significant earthquakes that could occur in the NMSZ.

Basis of research

The research was conducted by using Scopus and Georeference to find all the articles. In finding all qualified opinions several criteria were set. First, all papers had to be published after 1980 to ensure that the information was relevant and used the most recent data. Second, all authors had to be accredited in the geophysical world. Third, all papers chosen had to have data interpreted to an estimated amount of time of when the next earthquake would happen based on the physical evidence found in the Reelfoot Rift. Fourth, all papers had to use observational methods and any that only used mathematical modeling methods were excluded. With these criteria, ten opinions were selected to give an overview of the hazards of the NMSZ.

How the research was conducted

In reading the papers the key sections that I focused on were the Abstract, Introduction, and Discussion sections as these were the sections most likely to describe the study method and give the necessary results. However, all papers differed in their research methods and as a result, the way of finding information varied. To know the criteria for earthquake prediction the article, *Can you predict earthquakes?*, by the USGS was used to make the selection of papers and check the validity of them.

Additionally, research was conducted as to the criteria of seismic hazards (explained in the previous section) and compared it to all the papers to make sure that the methods were the most accurate and up to date. In conclusion of my research, I grouped similar methods discussed in the papers to analyze the overall interpretations of the hazards of the NMSZ.

Discussion

Earthquake Hazard in the New Madrid Seismic Zone Remains a Concern

United States Geological Survey (USGS)

The first paper is the most cited of all the opinions listed here. The USGS in 2018 complied data of the recorded and dated earthquakes and created a statistic of the probability of the next one happening.

"(1) the evidence indicates that we can expect large earthquakes similar to the 1811-12 earthquakes to occur in the future with an average recurrence time of 500 years and (2) magnitude 6 earthquake, which can also cause serious damage, can be expected more frequently than the large 1811-12 shocks.

"Based on this history of past earthquakes the USGS estimates the chance of having an earthquake similar to one of the 1811-12 sequence in the next 50 years is about 7 to 10 percent and the chance of having a magnitude 6 or larger earthquake in 50 years is 25 to 40 percent." USGS et al. (2009).

Hence, the USGS concludes that there is a low probability of another earthquake happening.

2018 One-Year Seismic Hazard Forecast for the Central and Eastern United States from Induces and Natural Earthquakes.

Mark D. Petersen and others (2018)

This is a specific report from the USGS. This article was included as this is the most recent paper published for the NMSZ. By looking at the past earthquakes in the region and taking into account other ones in nearby regions it was discovered that the earthquakes had increased, "In this analysis, we found that M>= 3.0 earthquakes near NMSZ have increased for the past 5 years." Petersen et al. (2018). The article does not conclude on whether that means the next significant earthquake is coming or not.

Significant Motions between GPS sites in the New Madrid Region: Implications for Seismic Hazard.

Arthur Frankel and other (2012)

The last article by the USGS referred to here uses the fault rate of the Reelfoot Rift to gauge the risk in NMSZ. "Our analysis of the limited GPS data in the New Madrid region clearly shows that there is significant motion between some of the stations. The amount of observed motion is consistent with a model of creep at depth along the Reelfoot fault. The amount of creep consistent with the GPS data may not conflict with geological evidence of M 7-8 earthquakes with 500-year recurrence times." Frankel et al. (2012). Frankel concludes that there is significant motion in the fault that most likely corresponds with the recurrence time of a magnitude 7 earthquake to occur every 500 years.

The Earthquake Potential of the New Madrid Zone

Martitia P. Tuttle and others (2002)

Based on previous earthquakes (900 ± 100 AD and 1450 ± 150 AD yrs.) show that the earthquakes could be as short as every 200 years to as long as 800 years. Some of the variability comes from the uncertainty in radiocarbon dating in itself and in dating horizons that pre and

post-date sand blows. At 95% confidence dating the estimated recurrence interval for M>7 NMSZ earthquakes range from 162 to 1196 yrs.

The New Madrid Zone: Not Dead Yet
Morgan T. Page and others (2014)
Analysis of prehistoric sand blows in NMSZ shows that protracted sequences, with multiple large main shocks, seem to be normal for the NMSZ. “At 95% confidence, no set of direct Omori parameters is consistent with all three of our constraints: early clustering, current seismicity rates, and the rate of M>=6 events after the first year.” Page et al. (2014). Does not show that these earthquakes are a result of aftershocks of the 1811-1812 earthquakes. “If current seismicity in the New Madrid region is not composed predominately of aftershocks, there must be continuing strain accrual.” Page et al. (2014). A strain rate of 4mm/yr. which is consistent with the change of stress that would be caused by an earthquake on Reelfoot Rift.

Significant Options Between GPS Sites in the New Madrid Region: Implications for Seismic Hazard.
Arthur Frankel and others (2012)
Note that sand blows as old as 2400 BC were found showing that earthquakes have been happening for at least 4000 years. Controversy arises over the GPS data that has been collected 16 years before this paper. Motions are at 0.4 mm/yr with a creep of 4 mm/yrs. on the deeper portion of the Reelfoot Rift. This amount of creep produces enough slip for earthquakes to occur about every 500 yrs. On the shallow part of the Reelfoot Rift.

Time Variable Deformation in the New Madrid Seismic Zone
Eric Calais and others (2009)
By using strain rates of the Reelfoot Rift and the earthquakes produced it was determined an occurrence of <1000 years. However, it was inconclusive whether the model could form a basis for earthquake prediction. "The upper bound is consistent with steady-state behavior, in which strain accumulates at a rate consistent with repeat time for magnitude-7 earthquakes of about 600 to 1500 years, as seen in the earthquake record. However, the lower bound cannot be reconciled with the record implying that the recent cluster of large-magnitude events does not reflect long-term fault behavior and may be ending.” Calais et al. (2009).

Seismic Hazard Uncertainty Analysis For The New Madrid Seismic Zone
Chris H. Cramer and others (2001)
This paper covers the scientific issues related to the earthquake sources in the NMSZ has led to the development of a logic tree of possible alternative parameters. A variability analysis, using Monte Carlo sampling of the logic tree, is shown in this paper. By doing an analysis using the logic tree it shows that for, “2%-exceedence-in-50-year hazard, the best-estimate seismic hazard map is similar to previously published seismic hazard maps for the area. For peak ground acceleration (PGA) and spectral acceleration at 0.2 and 1.0 s (0.2 and 1.0 s Sa), the coefficient of variation (COV) representing the knowledge-based uncertainty in seismic hazard can exceed 0.6 over the New Madrid seismic zone and diminishes to about 0.1 away from areas of seismic activity.” Cramer et al. (2001). He continues to state that, “PGA, 0.2 and 1.0 s Sa seismic hazard variability is the uncertainty in the location of future 1811–1812 New Madrid sized

earthquakes." Cramer et al. (2001). Hence while using the logic tree Cramer was unable to provide any statistics, but he shows the potential hazard in the NMSZ.

Estimating Earthquake Magnitude from Reported Intensities in the Central and Eastern United States.
Oliver S. Boyd and others (2014)
Deriving a macro seismic intensity prediction equation to estimate the earthquake magnitude of the 1811-12 earthquakes to then predict the future of the NMSZ. By using the hypo-central distance as a function of magnitude intensity can be predicted.
"The increased range of possible earthquake magnitudes in the New Madrid seismic zone increased the coefficient of variations of hazard estimates by 27%-42% in Memphis Tennessee." Boyd et al. (2014).

Uncertainties in Seismic Hazard Maps for the New Madrid Zone and Implications for Seismic Hazard Communication.
Andrew Newman and others (2001)
This paper compares the California earthquakes to the NMSZ earthquakes. Since the California earthquakes are better studied than the NMSZ earthquakes this paper demonstrates how more research is needed. But it also shows that the statistics behind California compared to the NMSZ are similar to each other even though the last 6.0 magnitude earthquake to have happened in the NMSZ was in 1811-12 and all the following earthquakes have not been as large and caused as much damage.
Even taking the previous earthquake sequences of 1811-12 it is hard to tell with paleo-seismic data what future earthquakes would look like. The California earthquake records illustrate a large variability of the magnitudes of the earthquakes which before 2019 was 7-51%. Current NMSZ maps show a Mag 6 earthquake happening on average less than once per 100 years.

Results
By taking the ten articles and comparing the various conclusions reached, the opinions were split into four categories to conclude whether it is possible to predict the next significant earthquake in the NMSZ. The first category was the three USGS papers that used past earthquakes to build statistics of the next possible one. They concluded that it is not possible to predict the next one and only a probability can be made. The second category was dating sand blows to see past earthquakes, but this method was also unable to conclude on predicting earthquakes and the authors were only able to create a statistic. The third category was using fault rate to see, if possible, when the next earthquake happened. Again, this method was inconclusive. The fourth category involves all the other methods of using a logic tree, macro seismology rate calculation, and comparing the hazard of the NMSZ to the California earthquakes. The overall conclusion was that it is not possible to predict the next earthquake.
However, six of the ten opinions provided estimates for the next possible 6.0-7.0 magnitude earthquakes. For Turtle and Calais since they provided ranges the average was taken to have a line chart. Here the most common estimate was 500 years with Newman giving the lowest estimate of 100 years and Calais giving the highest of 1050 years (on average).
The rest gave no estimate as they claimed there was no way using their method to be sure of the next earthquake.

The overall result shows that it is not possible to predict the NMSZ's next big earthquake. Six authors provided opinions on the probability of the next significant earthquake happening and four said that it was not possible to predict or provide a probability of the next one happening.

Nomenclature

Earthquake Prediction- According to the USGS this requires three criteria: date and time, location and magnitude in order to know precisely the next earthquake is happening.

Coefficient of Variation (COV)- Ratio of standard deviation to the mean.

Sand blows- form where continued earthquake shaking has wet and loose soil to consolidate turning the sand into a liquid. When pressure beneath increases enough the sand explodes leaving craters.

Logic Tree- an organizational tool used to create a diagram of all possible causes of a failure event.

Macro Seismic Prediction Equation- created specifically to estimate the magnitudes of the 1811-12 NMSZ earthquakes by comparing magnitude and intensity to each other.

Magnitude- measures the amount of shaking of an earthquake. Most common scale used the Richter Scale a logarithmic diagram.

Intensity- measures the amount of damage caused by an earthquake. Directly proportional to the magnitude of an earthquake.

Monte Carlo Sampling -samples the probability log distributions of random variables.

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Reflection on the Learning Experience (Please submit as an attachment)

1. Describe your foundational understanding of how research is conducted in your discipline.
   For this report research was conducted by looking up academic articles and then reviewing selected ones in order to reach a conclusion as to the hazards of the New Madrid Seismic Zone (NMSZ)
2. How have you expanded your understanding of the informational resources available and how to best use these resources?
   I have learned how to sort through academic articles and to know how to decide which ones will work best with the paper. Also learned how to use Scopus and Georeference efficiently.
3. Describe the knowledge you have gained regarding the fundamentals of experimental design.
   By taking multiple opinions and putting them together to create an overall view on whether there is an earthquake hazard potential in the NMSZ.
4. Describe how you have learned to interpret the results of your research project.
   By gathering all the estimated of the occurrence of the next possible earthquake and using them to show that earthquakes can only be estimated and that for the time being accurate prediction is not possible.