Earthquake Education Workshops

September 2014

Charlotte, Candler, and Winston-Salem, NC

"Earthquake History of North Carolina"

presented by

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Magnitude 5.8 VIRGINIA
Tuesday, August 23, 2011 at 13:51:04 EDT

Largest earthquake to shake the eastern U.S. since 1944 and the 2nd largest in Virginia history.

Shaking was felt from Georgia to Canada, caused light damage and panicked hundreds of thousands of people to evacuate buildings in New York, Washington and other cities.

There were no reported deaths, and scattered reports of minor injuries.

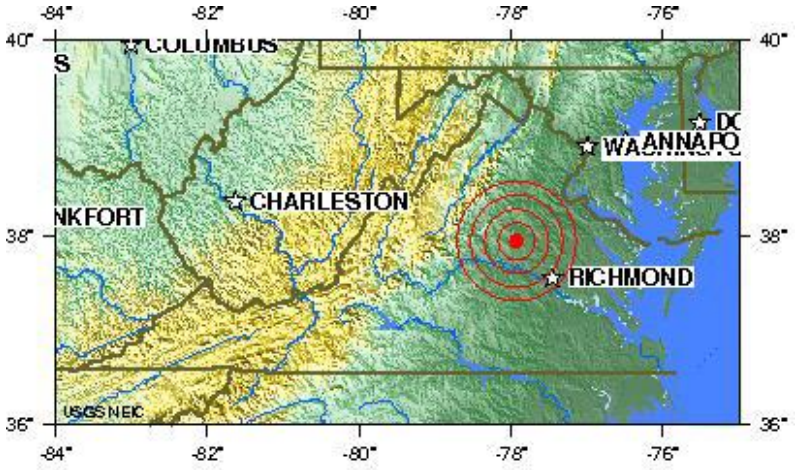


Image courtesy of the US Geological Survey

Police tape is seen in front of the National Cathedral in the Washington after a piece of the left spire fell off during earthquake shaking in the Washington area. The magnitude 5.8 earthquake centered in Virginia forced evacuations of all the monuments on the National Mall in Washington and rattled nerves from Georgia to Massachusetts.

(*AP Photo/Pablo Martinez Monsivais*)

Magnitude 5.8 VIRGINIA
Tuesday, August 23, 2011 at 13:51:04 EDT

Intensity scales were developed to standardize the measurements and ease comparison of different earthquakes. The Modified-Mercalli Intensity scale documents the perceived level of shaking from I (lowest) to XII (highest – total destruction).

Modified Mercalli Intensity	Perceived Shaking
X	Extreme
IX	Violent
VIII	Severe
VII	Very Strong
VI	Strong
V	Moderate
IV	Light
II-III	Weak
I	Not Felt

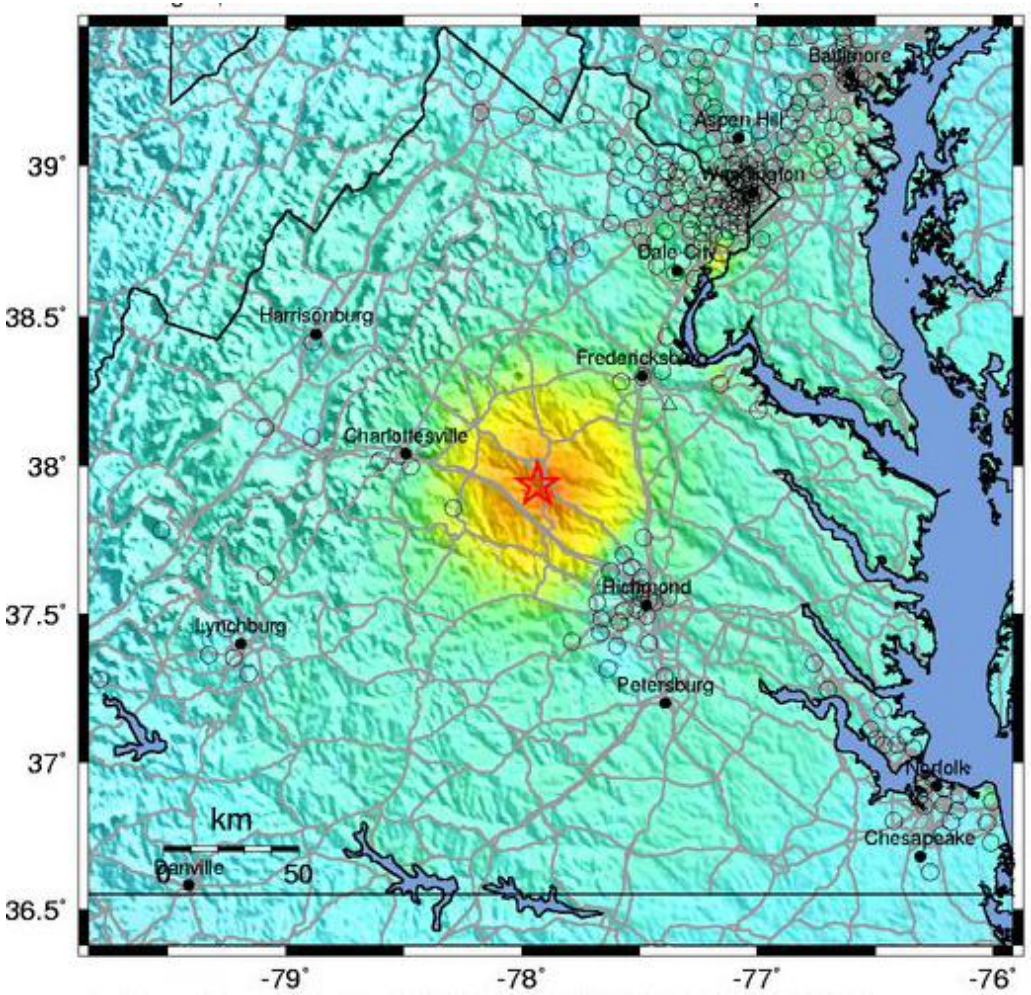
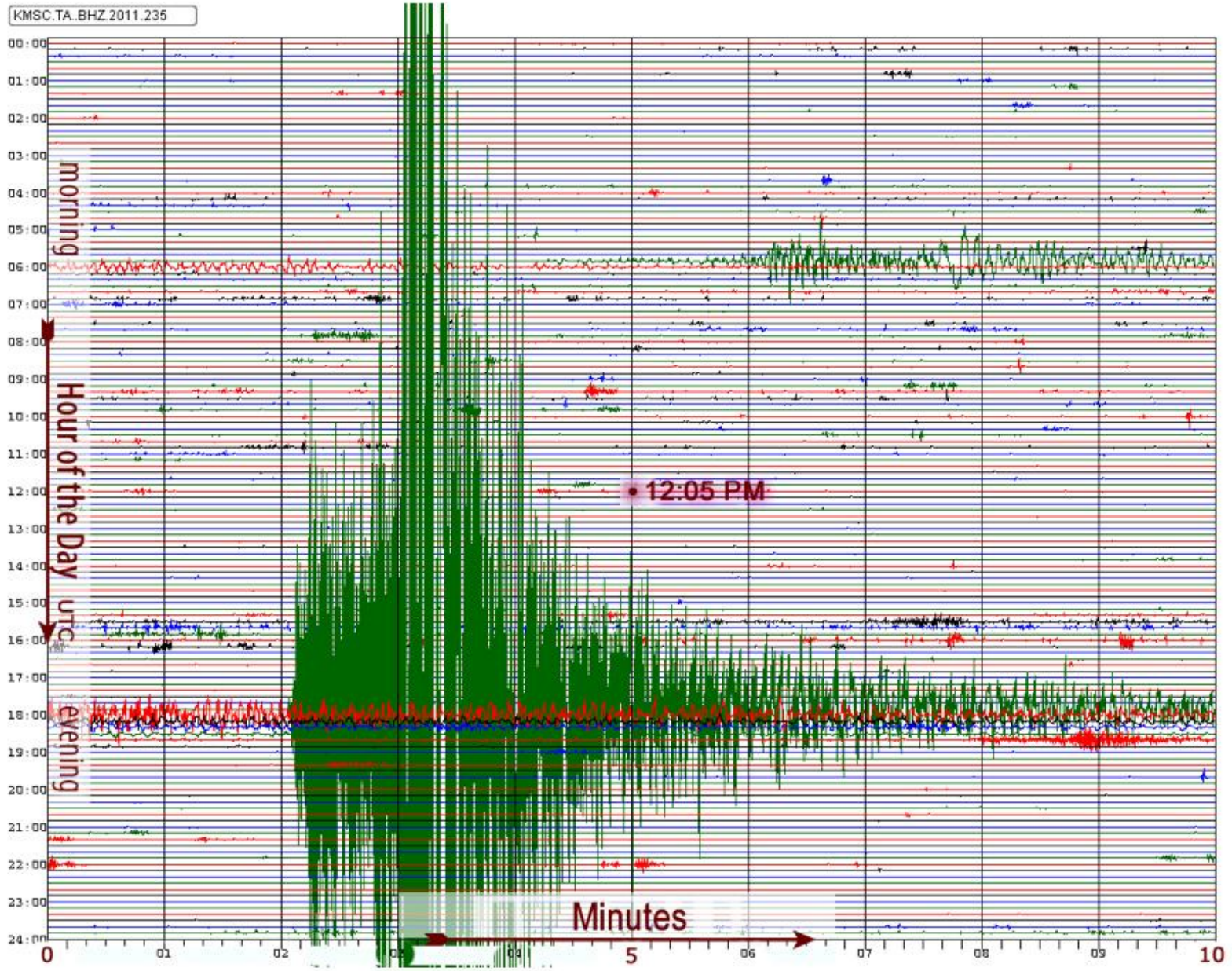
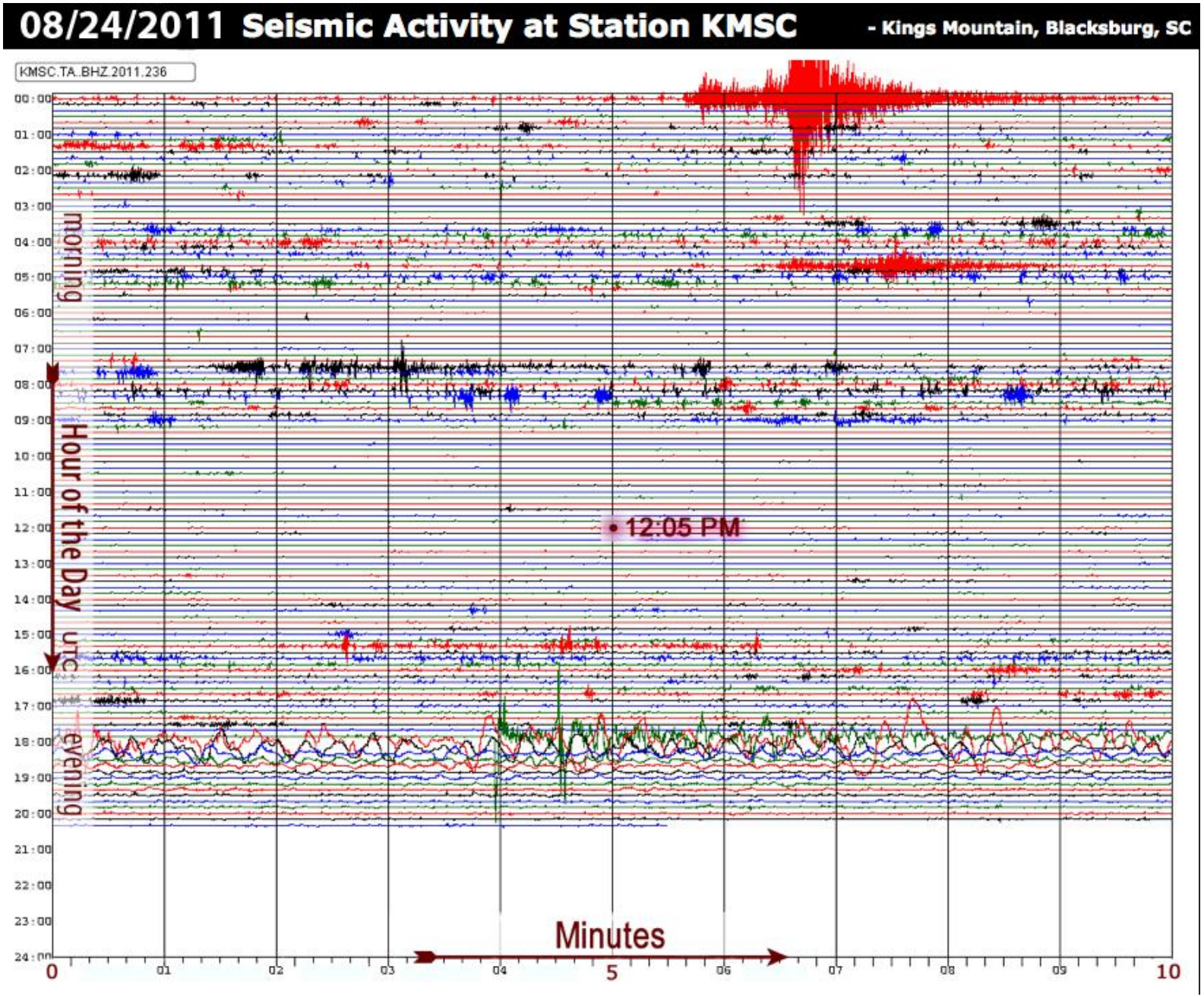


Image courtesy of the US Geological Survey

USGS Estimated shaking Intensity from M 5.8 Earthquake

08/23/2011 Seismic Activity at Station KMSC- Kings Mountain, Blacksburg, SC




08/24/2011 Seismic Activity at Station KMSC
- Kings Mountain, Blacksburg, SC
KMSC.TA..BHZ.2011.236
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
24:00
morning
Hour of the Day UTC
evening
• 12:05 PM
Minutes
0
01
02
03
04
5
06
07
08
09
10

Impacts and Damages

- Private Property Damage (Destroyed – 33; Major Damage – 180; Minor Damage – 510) Losses = $15 million.
- Power outages (3 ¾ hrs)
- Cell phone blockages (30 min)
- Disruption of east coast air traffic (two hrs) and Metrorail (16 hrs).
- North Anna Nuclear Station Unit 1 and Unit 2 (off-line until September 17th – 25 days).
- Disaster declaration for Individual Assistance requested September 20th. [Hurricane Irene impacted Virginia on August 27th]

Challenges in planning for earthquakes

- Motivating people for a low probability but high consequence event. *[Show them scenarios of what could happen].*
- NO WARNING. *[Preplanning of the event].*
- Information Gap -- communication disruption and need for wide-area intelligence collection. *[Use modeling to predict impact].*
- Aftershocks -- disaster has not yet ended. *[Public education and information].*
- Access to impacted area. *[Use pre-event assessment].*

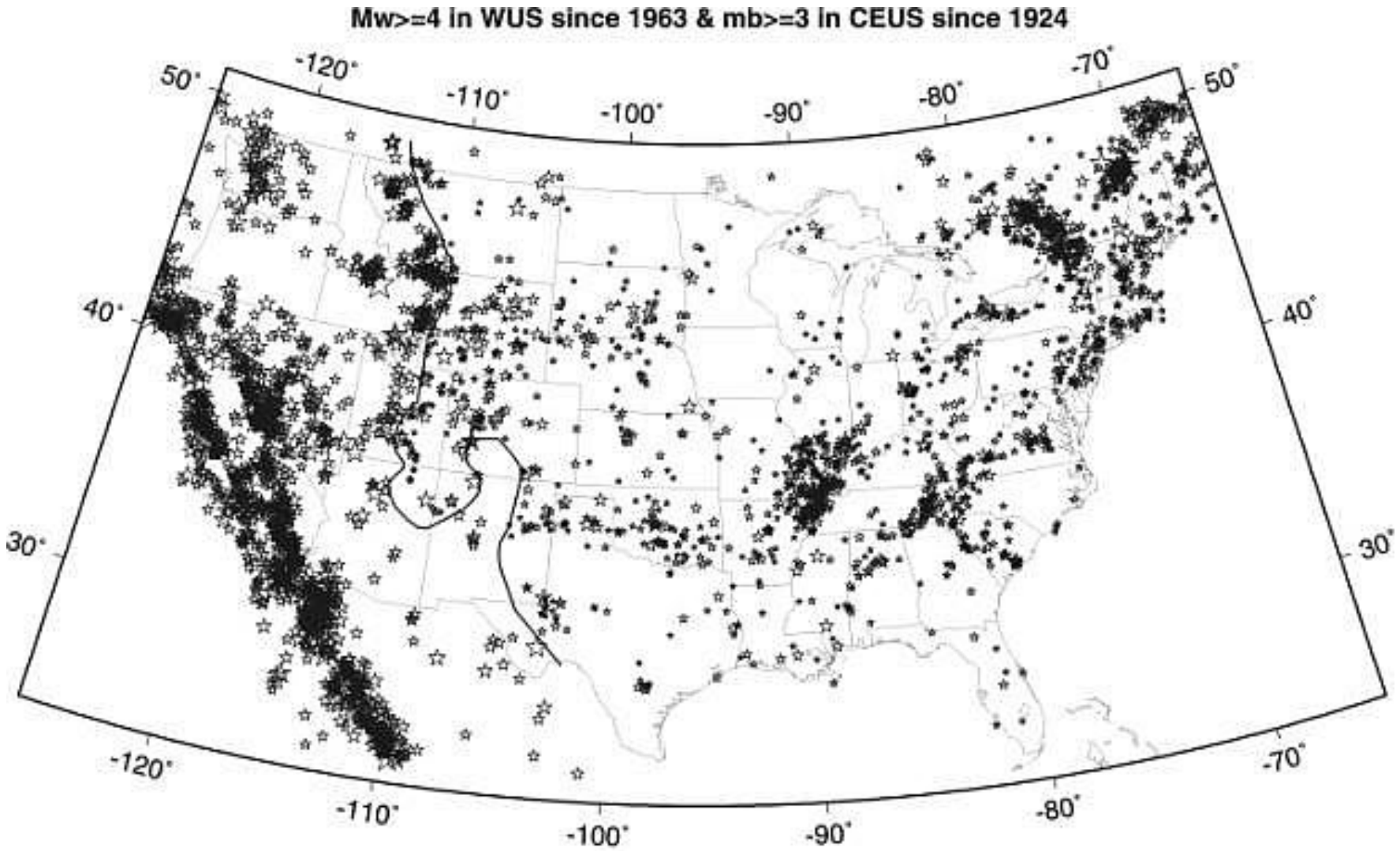
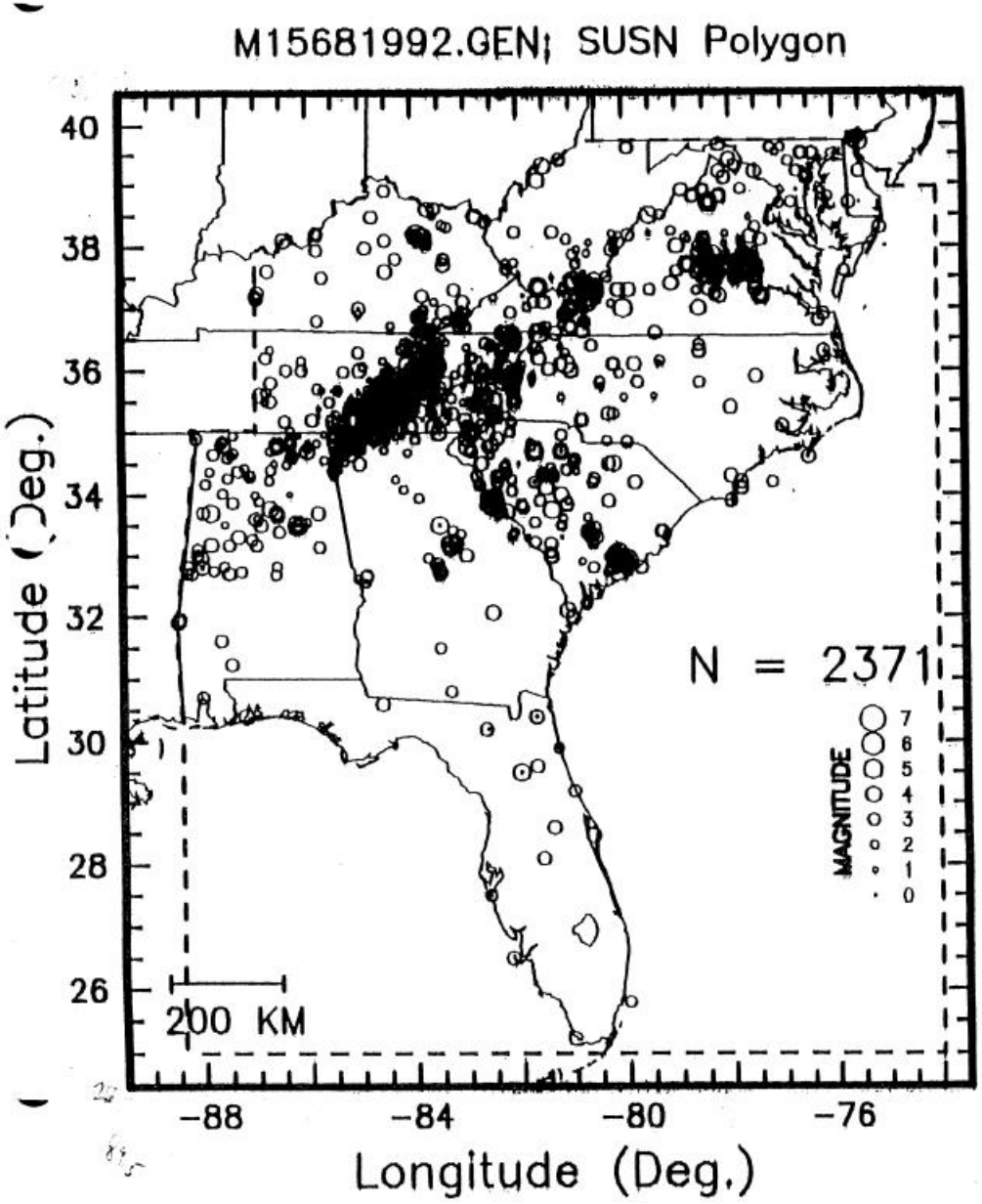


Figure 1. Seismicity map of the United States, showing mb 3 and above earthquakes since 1924 in the CEUS and M 4 and above earthquakes since 1963 in the WUS. Size of stars is scaled to magnitude. Boundary we chose to divide CEUS and WUS attenuation regions is shown as solid line starting in Montana and ending in western Texas.

Figure 1

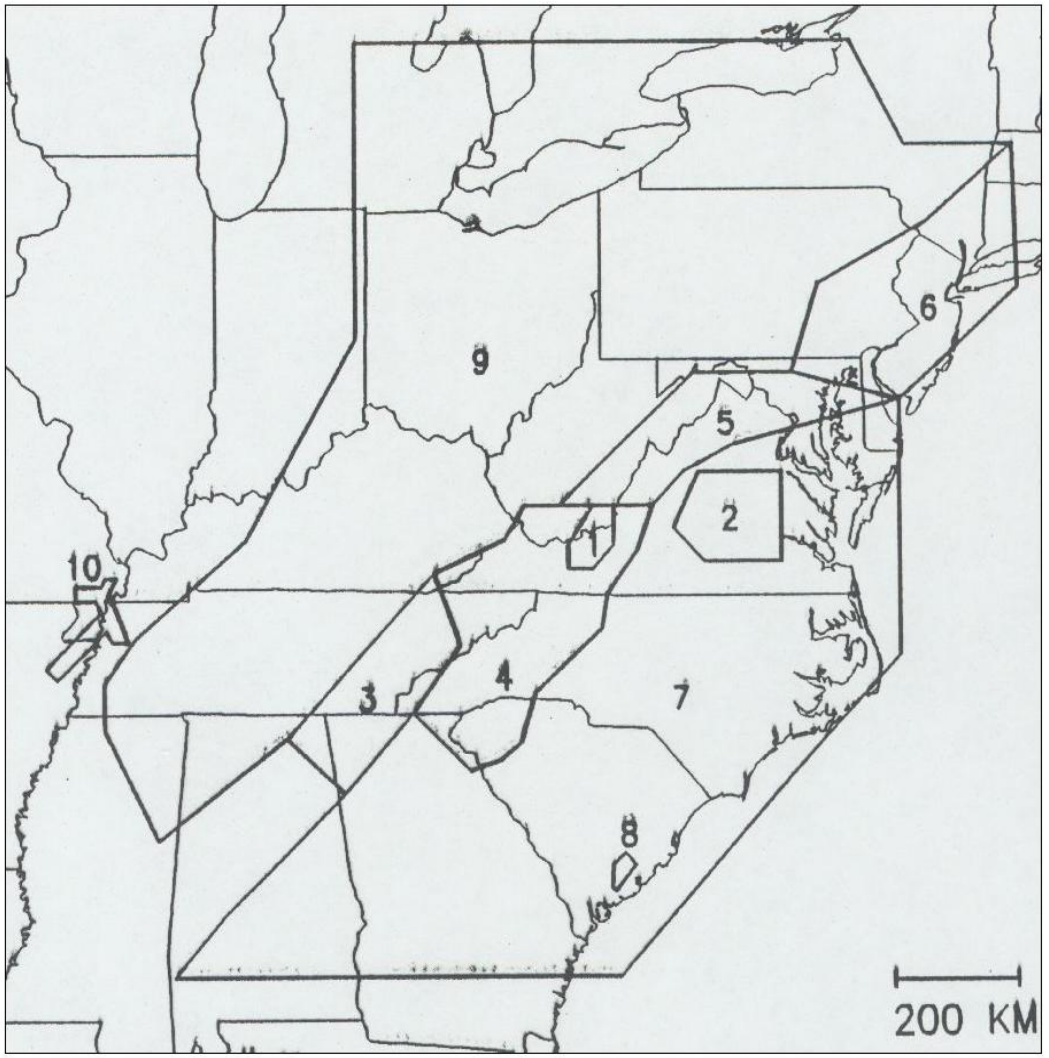


Map of earthquake epicenters from 1568 to 1992 for the Southeastern United States.

2371 earthquakes plotted. The size of the earthquakes are scaled by magnitude. (source: Virginia Tech earthquake catalog)

Map of the earthquake source zones in the south-central United States. The earthquake hazard within North Carolina, Virginia, Tennessee, and South Carolina is the accumulation of the hazard from the ten zones inside and adjacent to the states. (source: "Seismic Hazard Assessment for Virginia" by M.C. Chapman and F. Krimgold, Virginia Tech, 1994)

Earthquake source zones:
1 - Giles County, Virginia
2 - central Virginia
3 - eastern Tennessee
4 - southern Appalachians
5 - northern Virginia, Maryland
6 - central Appalachians
7 - Piedmont-Coastal Plain
8 - Charleston, South Carolina
9 - Appalachian foreland
10 - New Madrid



Earthquakes in North Carolina

- 22 times from 1735 to present earthquakes have caused damage in N.C.
- Greatest damage from the 1861 Wilkesboro, NC; 1886 Charleston, SC; 1916 Asheville, NC; and 1926 Mitchell Co., NC.
- Last damaging event – 1981 Henderson Co, NC.

Modified Mercalli Intensity Scale

I. Not felt except by a very few under especially favorable conditions.

II. Felt only by a few persons at rest, especially on upper floors of buildings.

III. Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck. Duration estimated.

IV. Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.

V. Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.

VI. Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.

VII. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.

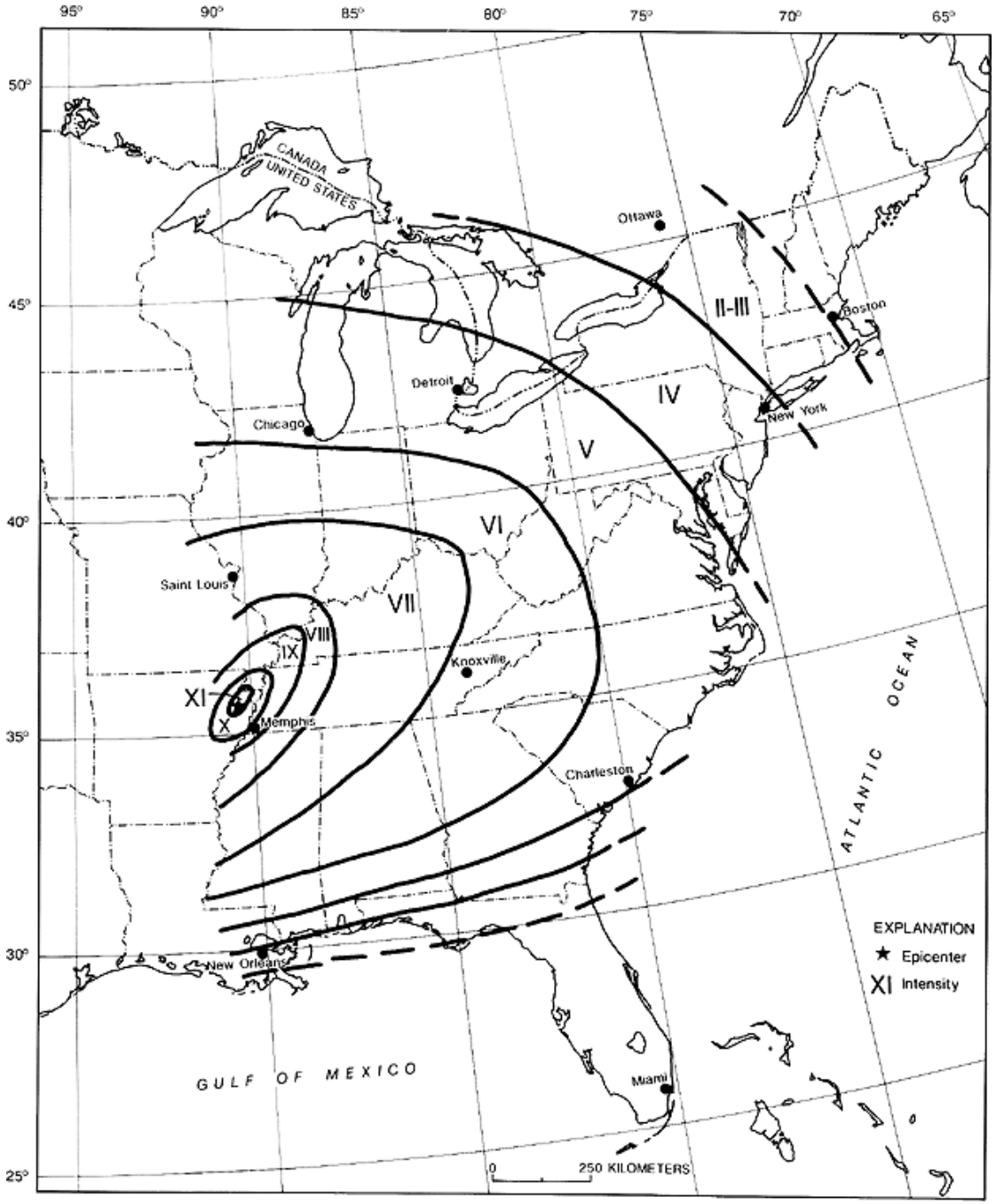
VIII. Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.

IX. Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.

X. Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent.

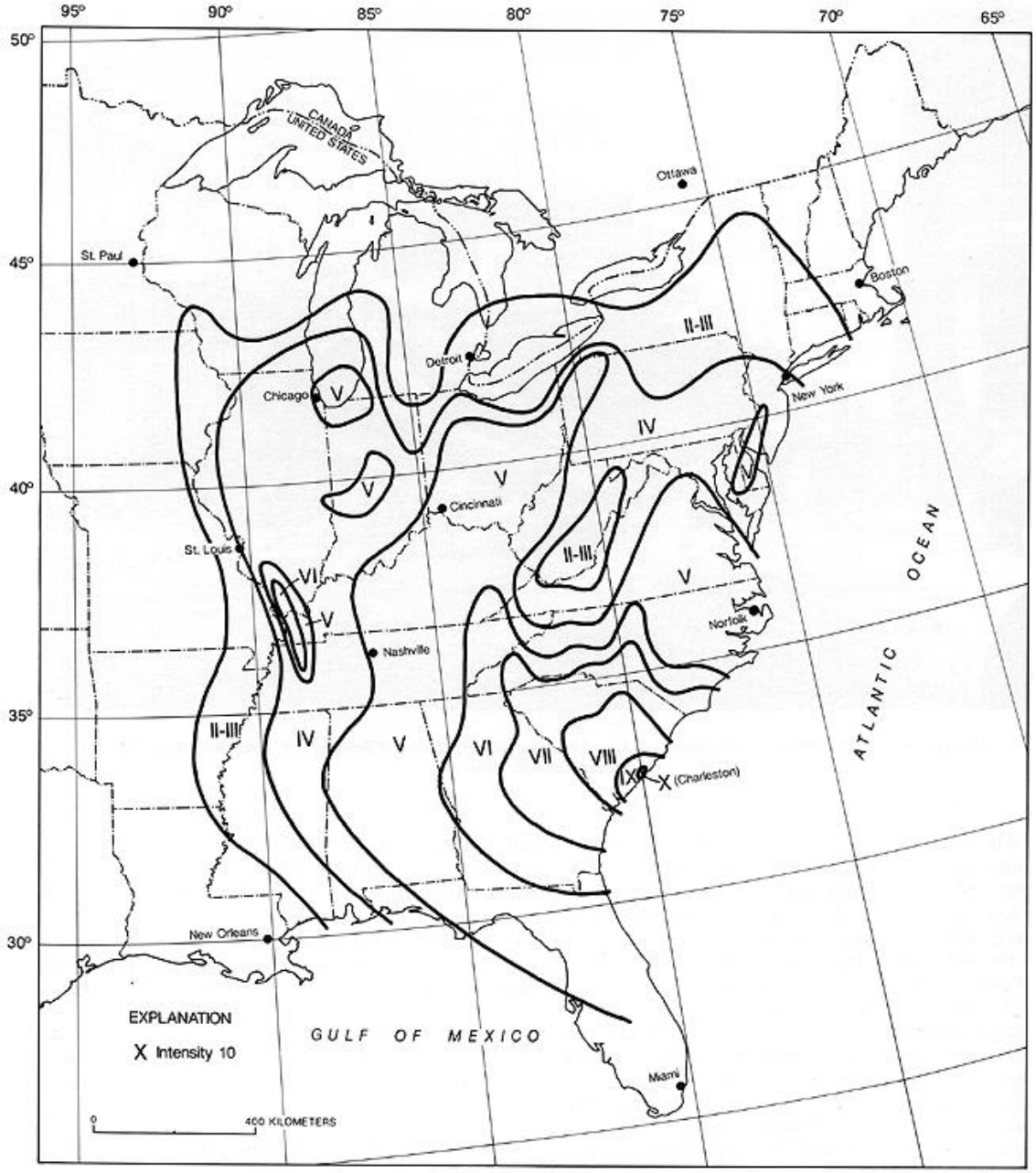
XI. Few, if any (masonry) structures remain standing. Bridges destroyed. Rails bent greatly.

XII. Damage total. Lines of sight and level are distorted. Objects thrown into the air.

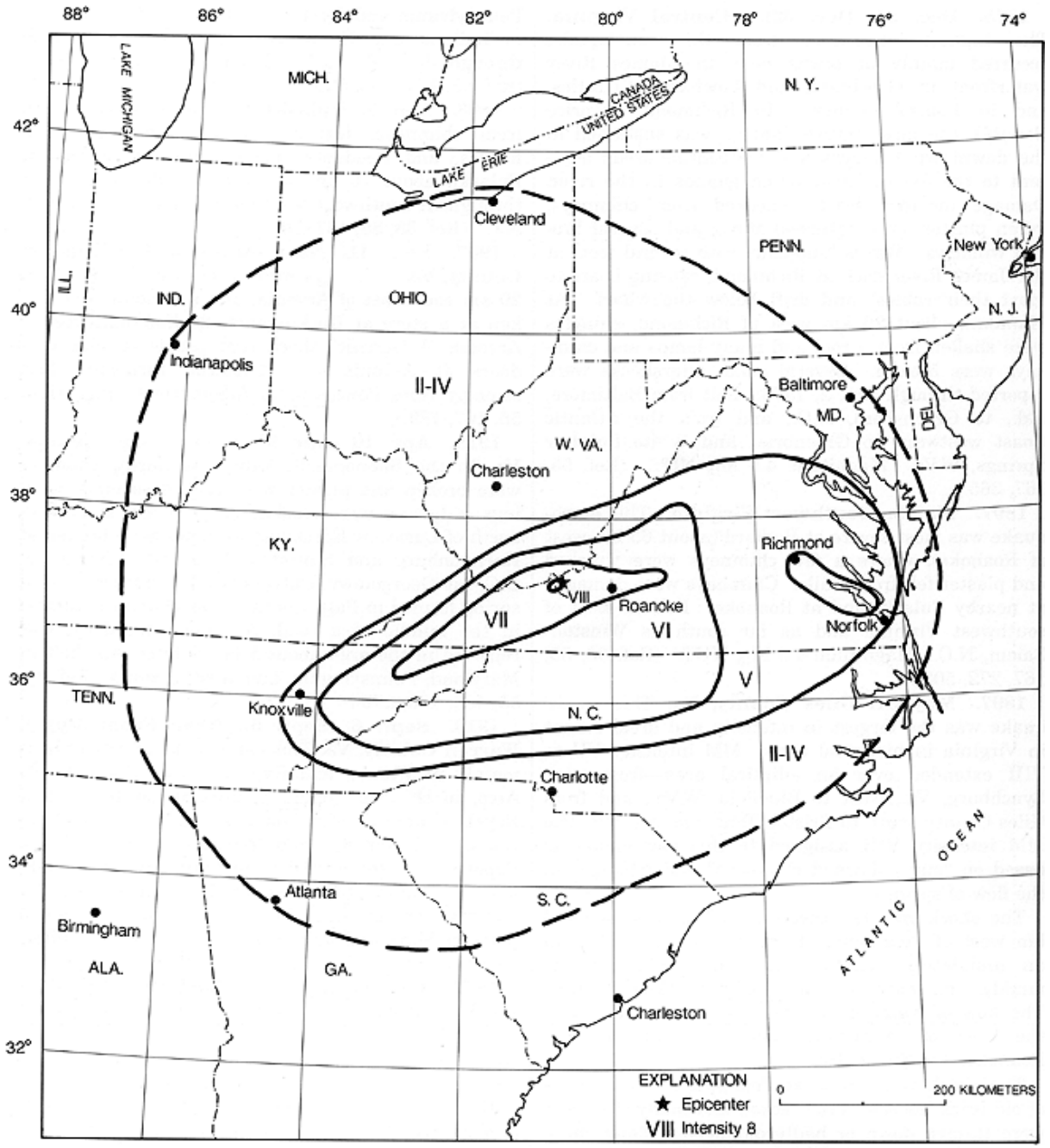


December 16, 1811

New Madrid Earthquake



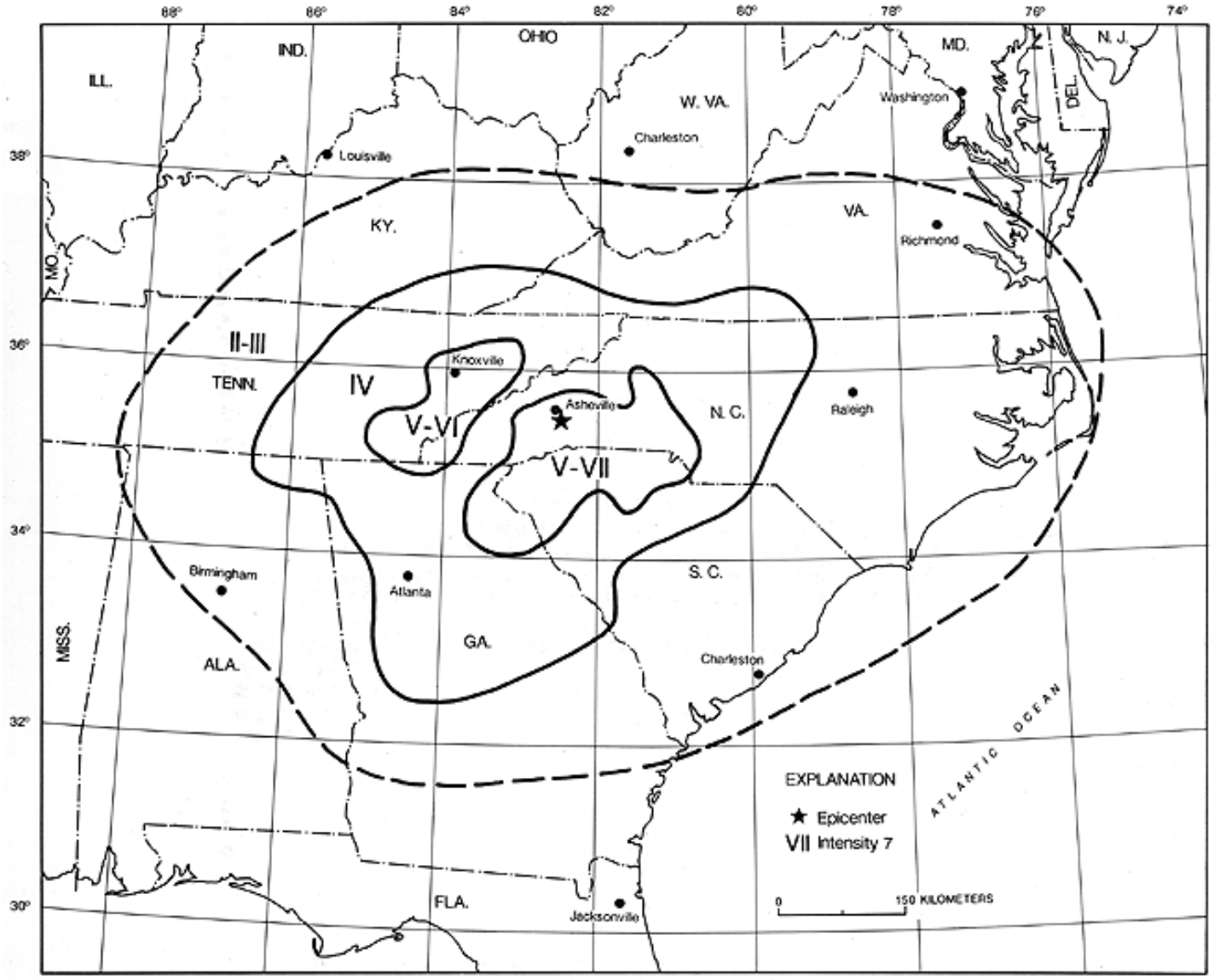
Charleston, South Carolina earthquake of August 31, 1886. Magnitude of 7.3 estimated from intensity and felt area.

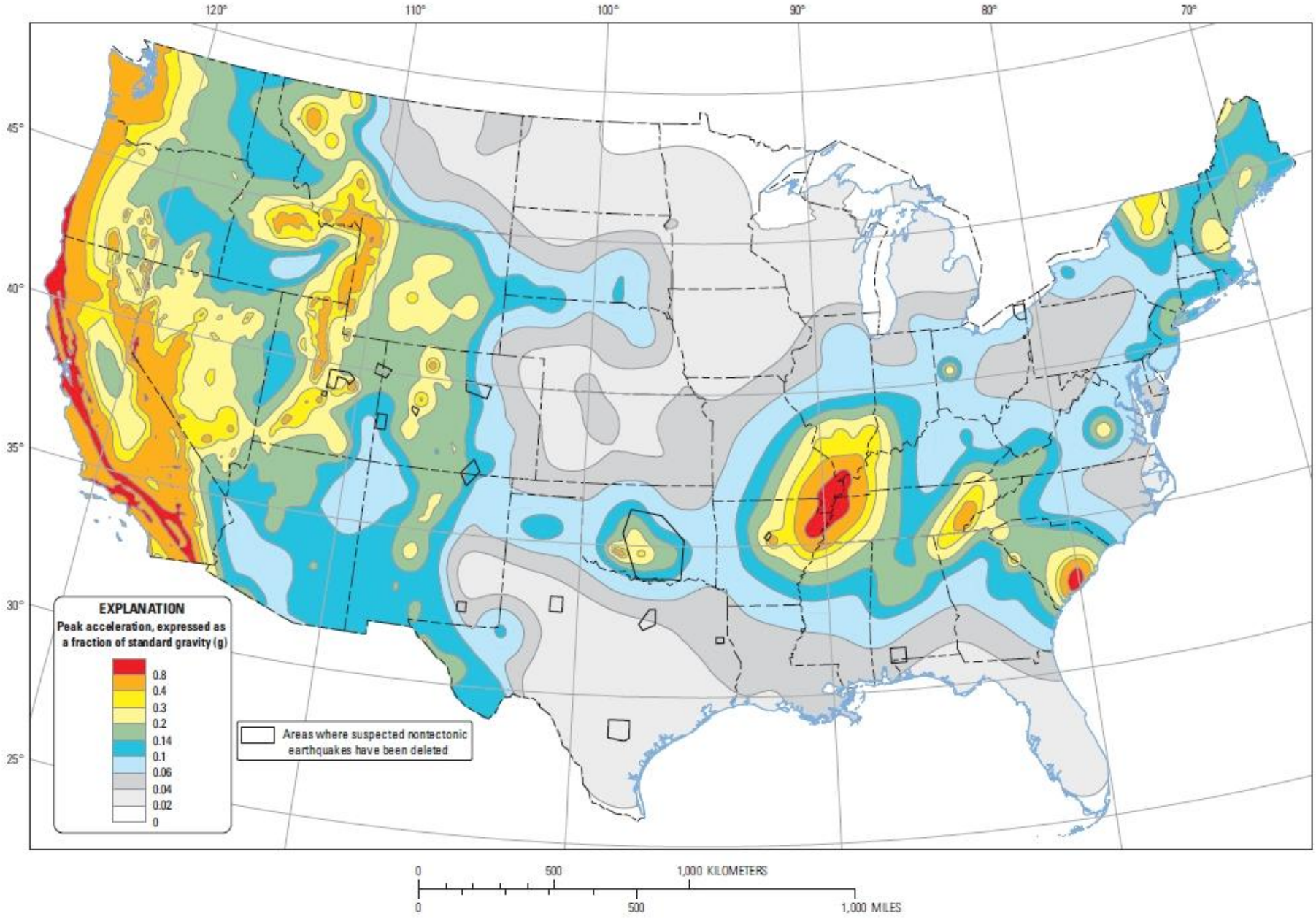


Isoseismal map for the Giles County, Virginia earthquake of May 31, 1897 -- the largest to occur in that State.

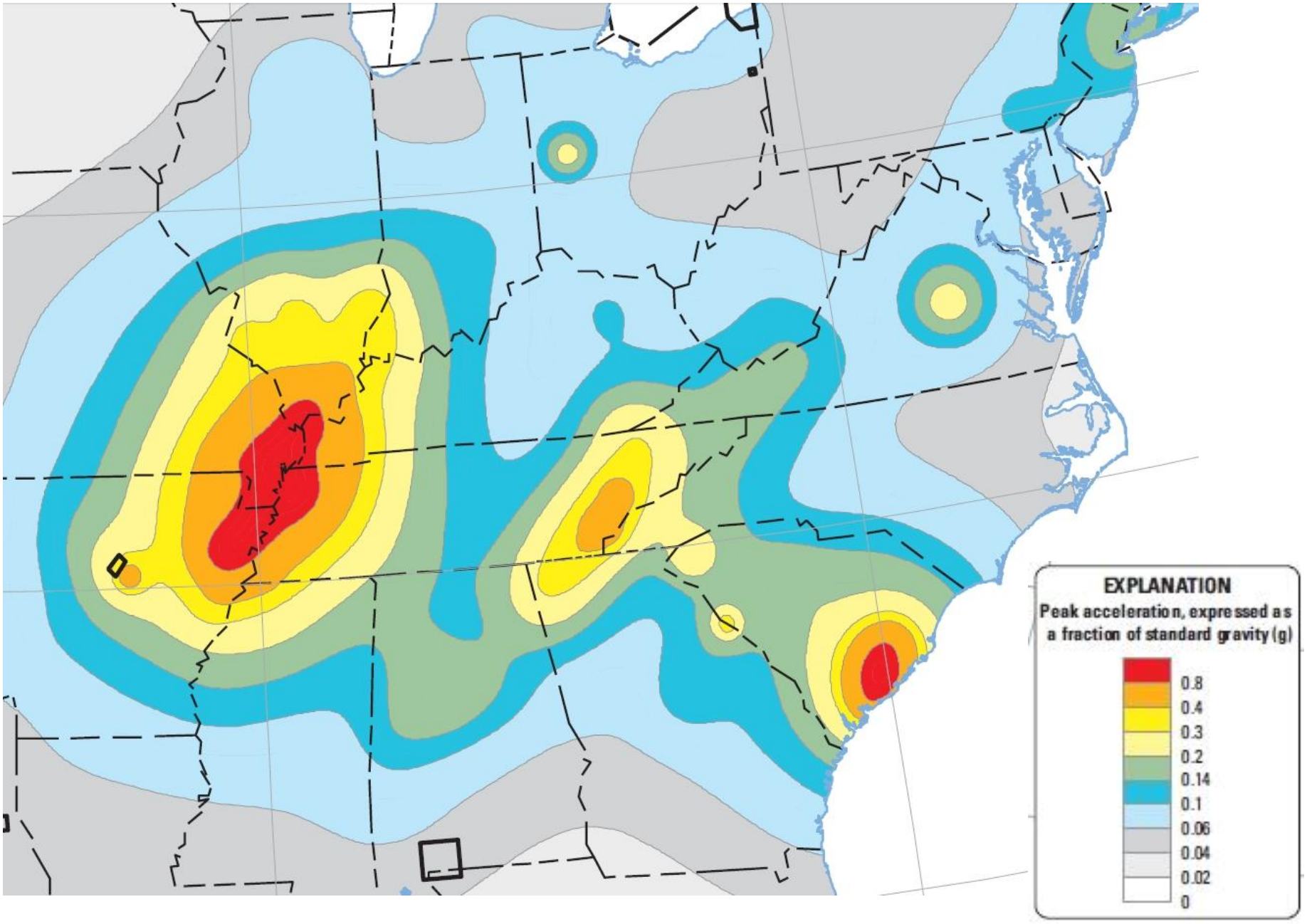
Earthquake magnitude of 5.8 estimated from intensity and felt area. This is the 3rd largest eastern US quake in the last 200 years and was felt in twelve states.

Waynesville, North Carolina – February 22, 1916





Two-percent probability of exceedance in 50 years map of peak ground acceleration



Two-percent probability of exceedance in 50 years map of peak ground acceleration

Earthquakes in North Carolina

The attached figures and tables give an overview of the earthquake hazard in North Carolina and the adjacent states.

Figure 1 -- **Map of earthquake epicenters from 1568 to 1992 for the Southeastern United States.** 2371 earthquakes plotted. The size of the earthquakes are scaled by magnitude. (source: Virginia Tech earthquake catalog)

Figure 2 -- **Map of the earthquake source zones in the south-central United States.** The earthquake hazard within North Carolina, Virginia, Tennessee, and South Carolina is the accumulation of the hazard from the ten zones inside and adjacent to the states. (source: *Seismic Hazard Assessment for Virginia* by M.C. Chapman and F. Krimgold, Virginia Tech, 1994)

Figure 3 -- **Map of the seismicity in and around North Carolina.** 878 earthquakes are plotted, scaled to magnitude, but only 157 of these are located inside North Carolina. Note the very active Eastern Tennessee Seismic Zone along the western edge of North Carolina. This is the second most active earthquake zone in the eastern United States. (source: Virginia Tech earthquake catalog).

Table 1 -- **List of earthquakes which have caused damage in North Carolina.** The list is complete to date and includes 21 earthquakes total, six located in North Carolina. The Modified Mercalli Intensity Scale (MM) is a measure of the effects of an earthquake on man and man's environment. The intensity decreases with distance from the earthquake epicenter but magnitude, a measure of the earthquake's energy output is constant everywhere. Magnitude is measured by seismographs. (source: Emergency Management and U.S. Geological Survey)

Figure 4 -- **Isoseismals of the February 21, 1916, Waynesville/Asheville earthquake.** Event which struck western North Carolina and is the largest centered inside the State. The earthquake had magnitude 5.5 on the Richter scale.

Data compiled by:

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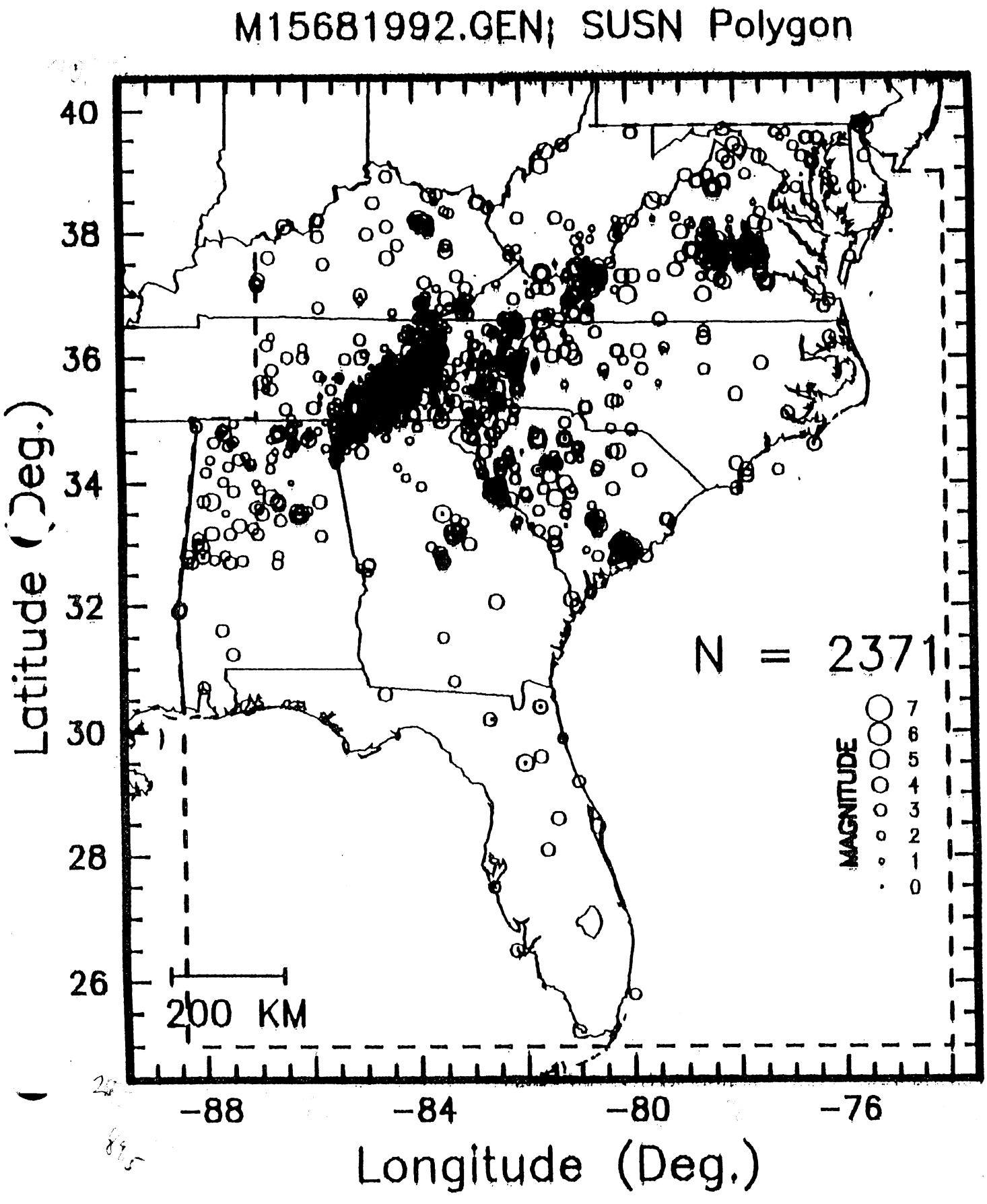
Figure 1


M15681992.GEN; SUSN Polygon
Latitude (Deg.)
40
38
36
34
32
30
28
26
N = 2371
MAGNITUDE
7
6
5
4
3
2
1
0
200 KM
-88
-84
-80
-76
Longitude (Deg.)

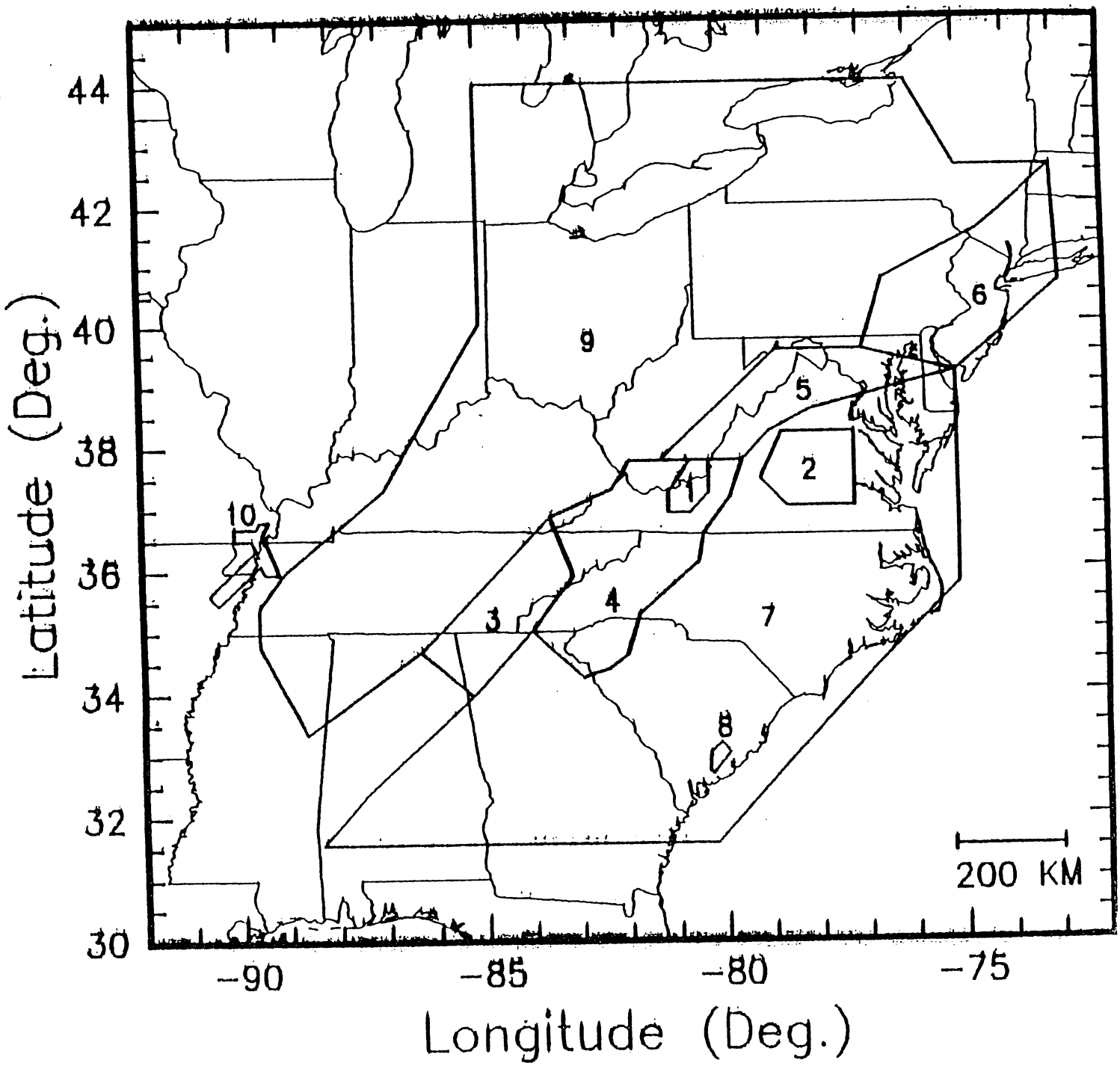


Figure 2 Earthquake source zones used in the hazard analysis. (1) Giles County, VA; (2) central VA; (3) eastern TN; (4) southern Appalachians; (5) northern VA, MD; (6) central Appalachians; (7) Piedmont-Coastal Plain; (8) Charleston, SC; (9) Appalachian foreland; (10) New Madrid.

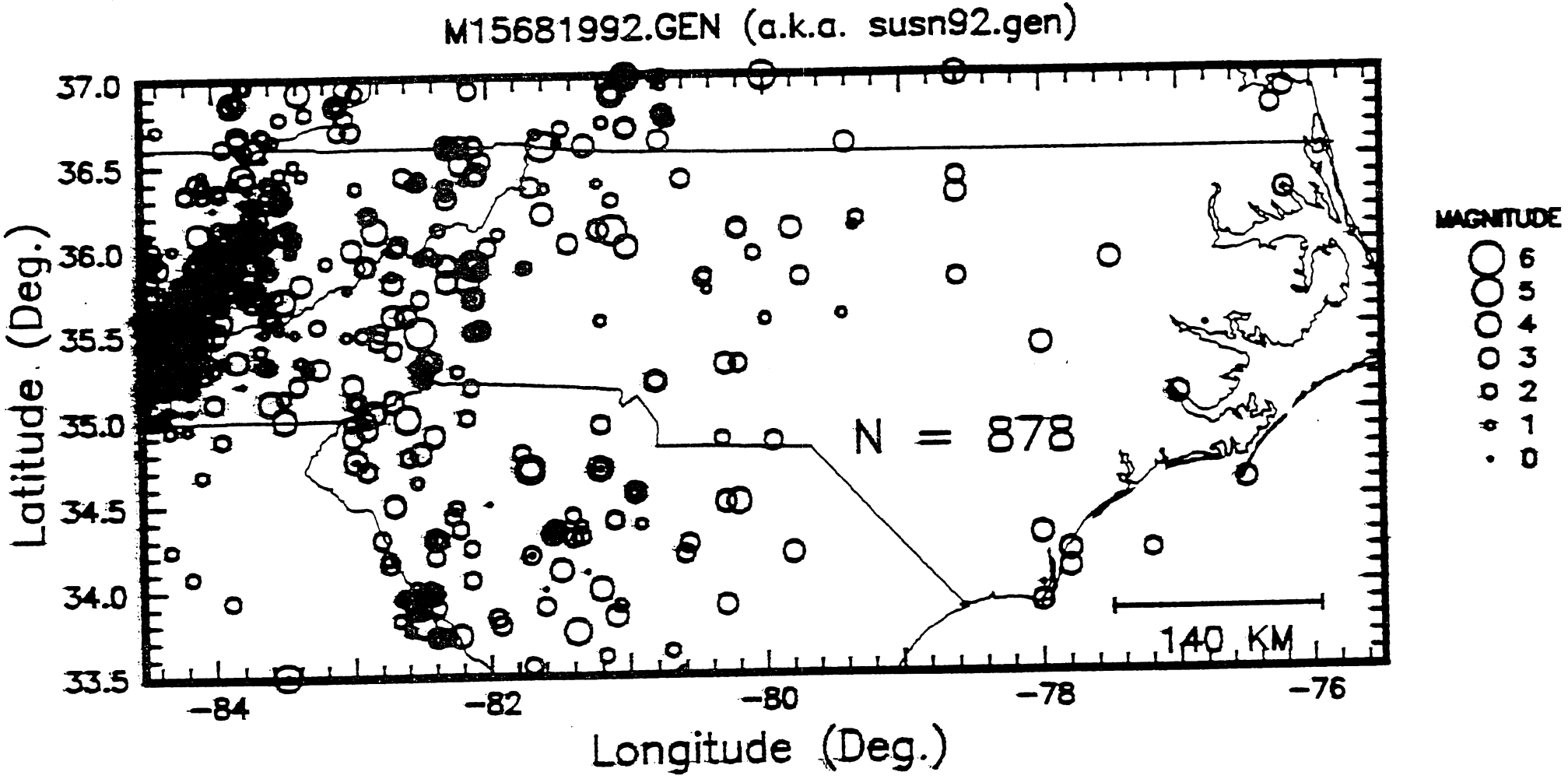

M15681992.GEN (a.k.a. susn92.gen)
37.0
36.5
36.0
35.5
35.0
34.5
34.0
33.5
Latitude (Deg.)
-84
-82
-80
-78
-76
Longitude (Deg.)
N = 878
140 KM
MAGNITUDE
6
5
4
3
2
1
0

Figure 3

Date	Location	Mag	MMI_o	MM in NC
1811 December 16 (a)	N.E. Arkansas	8.5	XI	VI
1811 December 16 (b)	N.E. Arkansas	8.0	X	VI
1811 December 16 (c)	N.E. Arkansas	8.0	X	VI
1812 January 23	New Madrid, Mo.	8.4	XI	VI
1812 February 7	New Madrid, Mo.	8.7	XII	VI
1852 April 29	Wytheville, Va.	5.0	VI	VI
1861 August 31	Wilkesboro, N.C.	5.1	VII	VII
1875 December 23	Central Virginia	5.0	VII	VI
1886 August 31	Charleston, S.C.	7.3	X	VII
1897 May 31	Giles County, Va.	5.8	VIII	VI
1913 January 1	Union County, S.C.	4.8	VII	VI
1916 February 21	Asheville, N.C.	5.5	VII	VII
1926 July 8	Mitchell Co., N.C.	5.2	VII	VII
1928 November 3	Newport, Tenn.	4.5	VI	VI
1957 May 13	McDowell Co., N.C.	4.1	VI	VI
1957 July 2	Buncombe Co., N.C.	3.7	VI	VI
1957 November 24	Jackson Co., N.C.	4.0	VI	VI
1959 October 27*	Chesterfield, S.C.	4.0	VI	VI
1971 July 13	Newry, S.C.	3.8	VI	VI
1973 November 30	Alcoa, Tenn.	4.6	VI	VI
1976 September 13	Southwest Virginia	4.1	VI	VI
1981 May 5	Henderson Co., N.C.	3.5	VI	VI

Mag = Earthquake Magnitude
MMI_o = Maximum Modified Mercalli Intensity at epicenter
MM in NC = highest intensity in N.C. from quake.

Table 1. Earthquakes which have caused damage in North Carolina

*Conflicting reports on this event, intensity in North Carolina at V not VI.

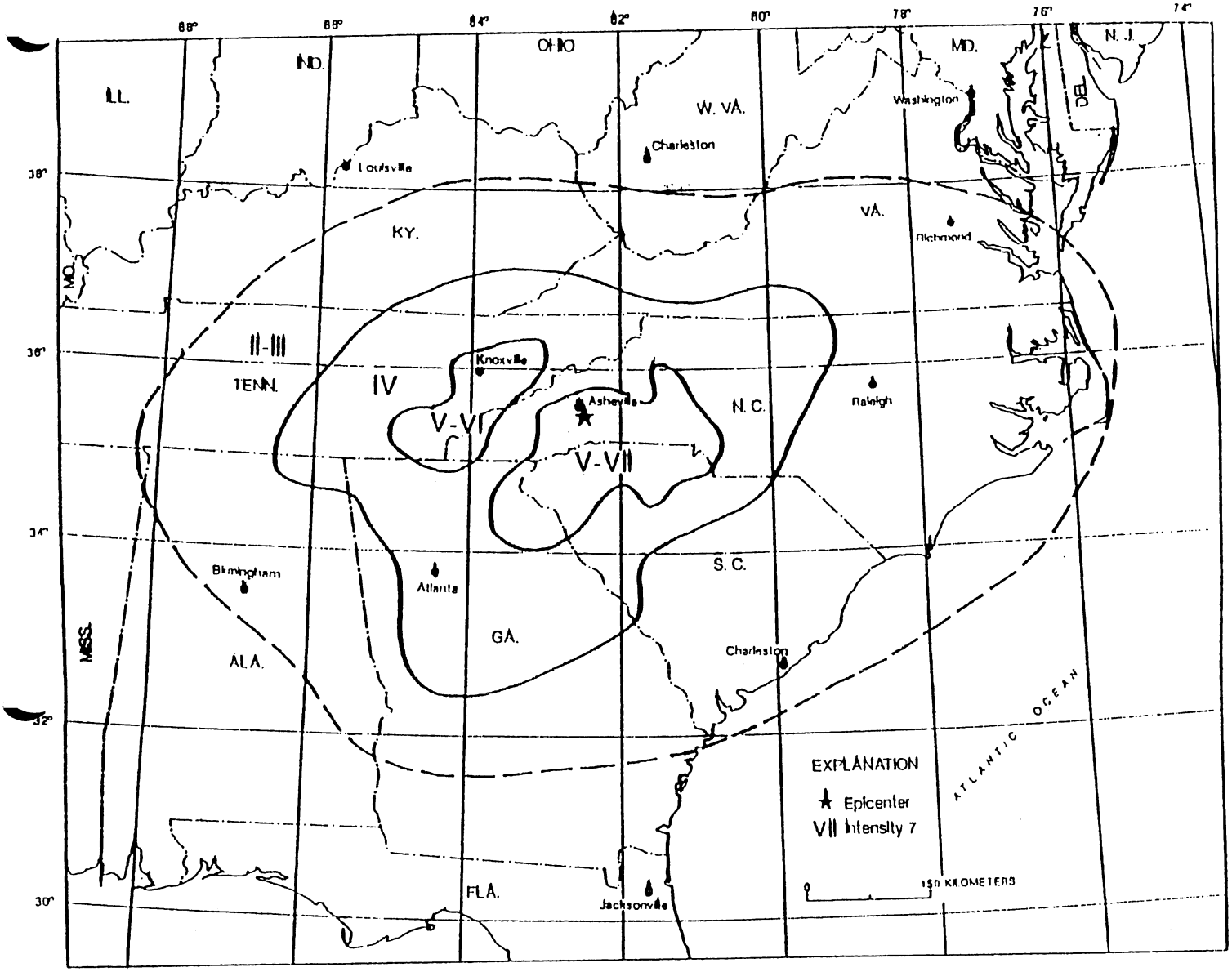


Figure 4 Isoseismal map for the Waynesville, North Carolina, earthquake of February 21, 1916. Isoseismals are based on intensity estimates from data listed in reference 272 of table 1.

MAG 5.2 M_{fa} ; 5.5 m_b

APPENDIX 10 TO ANNEX B
NORTH CAROLINA EMERGENCY OPERATIONS PLAN

EARTHQUAKE OPERATIONS PLAN

1. PURPOSE. This operations plan supports the NCEOP and outlines actions and coordination procedures the State Emergency Operations Center (EOC) and the State Emergency Response Team (SERT) take and follow when an earthquake has affected North Carolina.

2. SITUATION.

In the 274 years since 1735, 22 earthquakes have caused damage in North Carolina. Of these events, only seven were located within the state. In terms of the intensity of ground motion, four earthquakes have caused structural damage as measured on the Modified Mercalli Intensity at level VII [level 7]) -- August 31, 1861 Wilkesboro, N.C. (magnitude 5.1); August 31, 1886 Charleston, S.C. (magnitude 7.3); February 21, 1916 Asheville, NC (magnitude 5.5) and July 8, 1926 Mitchell County (magnitude 5.2). The last damaging earthquake struck Henderson County in 1981.

Seismologists have delineated four (4) earthquake source zones, which could generate ground motion of sufficient strength to cause structural damage in North Carolina. These are: Eastern Tennessee Seismic Zone; Southern Appalachian Seismic Zone; Charleston, S.C. Seismic Zone and the Giles County, Virginia Seismic Zone.

Map of the earthquake source zones in the south-central United States. The earthquake hazard within North Carolina, Virginia, Tennessee, and South Carolina is the accumulation of the hazard from the ten zones inside and adjacent to the states. (source: "Seismic Hazard Assessment for Virginia" by M.C. Chapman and F. Krimgold, Virginia Tech, 1994)

Earthquake source zones:
1 - Giles County, Virginia
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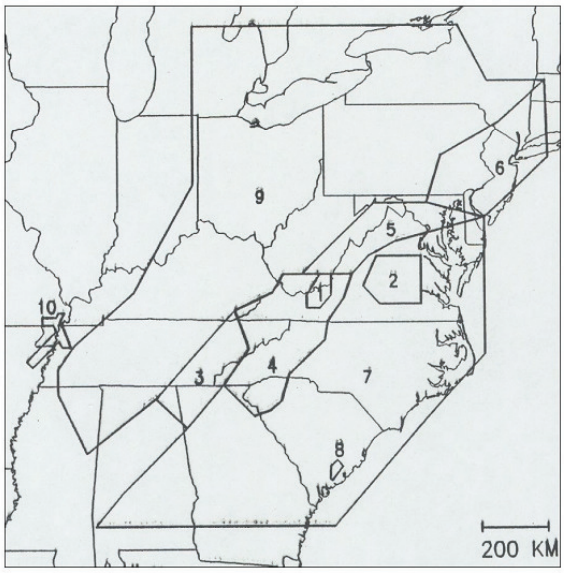

Figure 1

To determine the earthquake hazard nationwide, the U.S. Geological Survey has produced two principal earthquake hazard maps are “Peak Acceleration (%g) with 10% Probability of Exceedance in 50 Years” [Figure 2] and “Peak Acceleration (%g) with 2% Probability of Exceedance in 50 Years” [Figure 3]. These maps show the predicted level of acceleration in percent of g (the pull of gravity, “g” = 9.8 meters/sec/sec or 32 feet/sec/sec) with a 10% and 2% probability of exceedance during a 50-year interval. The 10% map represents the level of shaking for a 425-year return period. The 2% map represents the level over a 2,500-year return period.

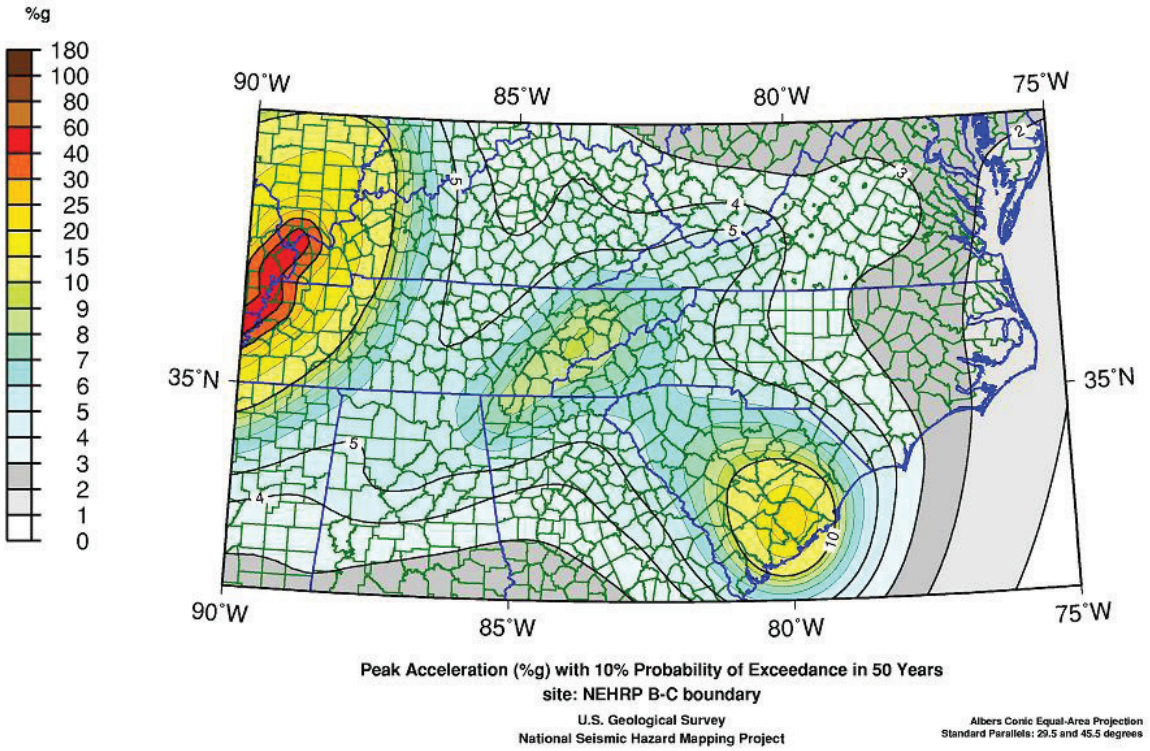

Figure 2

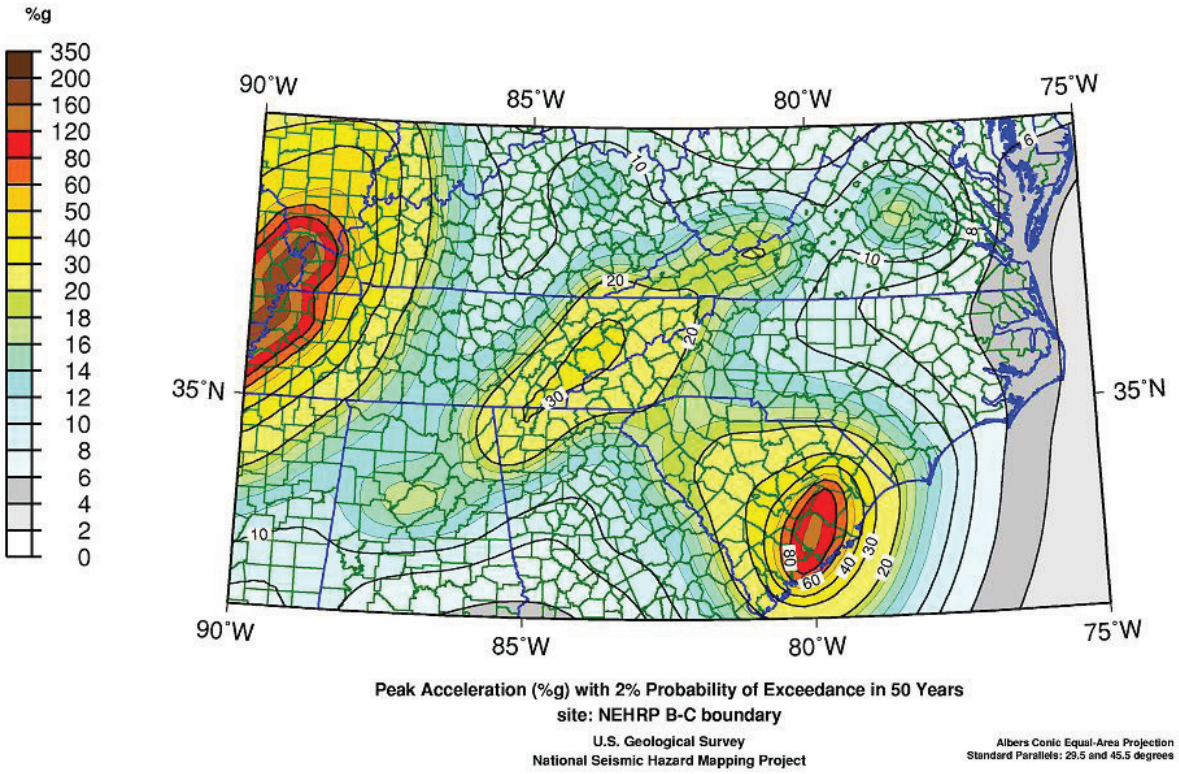

Figure 3

For a 10% exceedance (or 90% non-exceedance), the map [Figure 2] shows that peak accelerations in North Carolina range from three percent g (3%g) in the Coastal Plain to eight percent g (8%g) along the Blue Ridge Mountains. The table below shows that there is a 90% chance that ground shaking over the next 50 years would be between the threshold of architectural damage with cracks in walls and chimneys to the threshold of architectural failure with chimneys falling. The relationship between levels of acceleration the levels of damage are:

3% to 6% g – threshold of architectural damage (walls and chimneys crack).
6% to 12% g – threshold of architectural failure (chimneys, unsecured items fall).
12% to 24% g – threshold of structural damage (load bearing walls crack).
24% to 48% g – threshold of structural failure (buildings fall).

For the 2% exceedance (or 98% non-exceedance), the map [Figure 3] shows at least 3% g (threshold of architectural damage) everywhere in North Carolina and architectural damage in all counties west of the Inner Coastal Plain. The upper

bound of ground shaking is 30% g in Swain and Graham counties with structural failure in all or parts of Cherokee, Graham, Swain, Polk, Macon, Jackson, Haywood and Madison counties. Also note that structural damage could occur along the border with South Carolina from a large Charleston, S.C. event. Structural damage would also be expected in all counties east of Buncombe and west of Iredell.

To fully understand the expected level of shaking, there is a 90% chance that ground shaking in North Carolina would not exceed architectural damage over most of western North Carolina. There is a 98% chance shaking up to a level to cause structural damage i.e. Modified Mercalli Intensity VII could occur anywhere in North Carolina west of Iredell County or in counties along the border with South Carolina.

Essential Elements of Information (EEI). This information is necessary to determine required response actions and resources (Agencies must be tasked to answer these EEI).

a. Define the disaster area. What area, (counties, cities, and infrastructure) is affected and what is the damage?

    (1) Number of casualties and displaced personnel?
    (2) Extent of damage to buildings and structures?
    (3) Extent of damage to roads and bridges:

        (a) Which highways are closed and where are they closed?
        (b) What routes are open into the effected area for use by operational and logistics response units?

    (4) What areas are without power?
    (5) What is the damage to water/sewer systems in the disaster area?
    (6) What is the damage to medical infrastructure?
    (7) Aerial and ground reconnaissance information.

Before this information can be collected, the State EOC must fully use the DHS/FEMA loss estimation software – HAZUS. This GIS application can provide modeling results which have been show to rapidly estimate the extent of expected damage and the level of that damage.

Aftershocks -- There is not just one event, but there may be a series of aftershocks. If for example, the main shock has a magnitude of say 6.0 on the Richter Scale, aftershocks of up to ½ Richter unit smaller can occur afterwards. The number of aftershocks per unit of time will decrease in a power law relationship.

For example, if three (3) aftershocks occur between the main shock and one hour, then one could expect 3 aftershocks between one hour and 10 hours (~ ½ day), 3 between 10 hours and 100 hours (~5 days), 3 between 100 hours and 1000 hours (~ 50 days). For a larger number of aftershocks, the same rule applies. If 20 aftershocks occur within the first hour following the main shock, then one should expect 20 between one and ten hours, 20 between 10 hours and 100 hours, and 20 between 100 hours and 1000 hours.

U.S. Geological Survey – National Earthquake Information Center (USGS-NEIC) **Earthquake Notification System (ENS)**
Automatic detection and location of seismic events by computer monitoring seismic networks across the U.S. as well as worldwide can locate and determine the magnitude of earthquakes in 5 to 15 minutes. The time delay is not due to the computer processing, rather it is due to the speed earthquake waves travel. Even at 6 km/sec, primary waves from the other side of the world take 30 to 45 minutes to register in the United States. For small events, ones with magnitude less than 3.0, seismologists must identify the time segment and tag the signals for location and determination.

In 1977 when the National Earthquake Hazard Reduction Program (NEHRP) was enacted, the U.S. Geological Survey (USGS) was tasked with generating a series of nationwide ground motion estimations. These maps have been revised every six years since the 1980s and can be found on the USGS Earthquake Hazards Program website: http://earthquake.usgs.gov/research/hazmaps/. The two principal maps hazard maps are "Peak Acceleration (%g) with 10% Probability of Exceedance in 50 Years" and "Peak Acceleration (%g) with 2% Probability of Exceedance in 50 Years." The maps show the predicted level of acceleration in percent of g (the pull of gravity, "g" = 9.8 meters/sec/sec or 32 feet/sec/sec) with a 10% and 2% probability of exceedance during a 50-year interval. The 10% map represents the level of shaking for a 425-year return period. The 2% map represents the level over a 2,500-year return period.

The maps, which are referenced in building code design manuals, show that peak accelerations in North Carolina range from three percent g (3%g) to eight percent g (8%g) with a 90% chance of non-exceedance and six percent g (6%g) to thirty percent g (30%g) with a 98% chance of non-exceedance in 50 years. The relationship between levels of acceleration the levels of damage are:

3% to 6% g – threshold of architectural damage (cracks in walls and chimneys).
6% to 12% g – threshold of architectural failure (fall of chimneys and unsecured items).
12% to 24% g – threshold of structural damage (load bearing walls with cracks).
24% to 48% g – threshold of structural failure (buildings falling or are too weaken).

To summarize, the earthquake risk in North Carolina is moderate, not high or very-high like in California, but also not low like North Dakota.