# Earthquakes
# in
# North Carolina

N.C. Geological Survey Educator Training
Sept. 13-27, 2014

# Agenda for 2014 Earthquakes in North Carolina Workshop

**8:30- 9:00 am**
- Participants sign in, make name tag and get notebook

**9:00- 9:10 am - Block 1a:** **Introduction**
- Quick Introduction
- Facilities, snacks, timing, title of workshop, presenters

**9:10 – 9:30 am - Block 1b:** **EQ History in North Carolina**

**9:30 - 10:30 am - Block 2:** **Earthquakes and Tectonics**
- Review of Plate Tectonics
- Elastic Rock demonstration
- Plate Puzzle activity
- Plate Boundary examination using IRIS IEB earthquake viewer
- Evidence of Past Movement - folding and faulting
- Fault Blocks – paper models

**10:30 - 10:40 am - Morning Break** **Coffee and Snack Break**

**10:40 am–12:00 pm - Block 3:** **Waves/Measurement**
- Basics of Waves (slinky)
- Human Chain Wave
- What's Inside of the Earth? Black Box activity
- Journey to the Center of the Earth
- Measuring an Earthquake
- Pasta Quake 1 – 30 – 900

**12:00–12:45 pm - Lunch** **Lunch**

**12:45 – 1:45 pm - Block 4:** **Waves/Measurement** continued
- Human Seismometer
  - Explore Smart Phones
- Quake Catcher Network - QCN sensors
- Virtual Earthquake
- Examine Real Time Seismograms – (jAmaSeis)

**1:45 – 1:55 pm - Afternoon Break** **Break**

**1:55 – 3:30 pm - Block 5:** **Risk / Hazards / Preparedness**
- Asperities Aftershock demonstration
- Building Resonance demonstration
- IRIS Building activity
- Preparedness and the Great Shake Out

**3:30 – 4:00 pm - Block 6:** **Wrap up**
- Gather kit material
- Return deposit checks
- Evaluations

|  | *N.C. Essential Standards* | *Earthquakes* | *And Seismology* |
|---|---|---|---|
|  |  |  |  |
| ***4.E.2.3*** *(Grade/ Subject/ Essential Standard/Clarifying Objective* | *K-8 Earth Science (E)*<br>*9-12 Earth/Environmental Science (EEn)*<br>*K-8 Life Science (L)*<br>*9-12 Physics (Phy)* |  | *K-8 Physical Science (P)*<br>*9-12 Physical Science (PSc)* |
| *Topic* | *Essential Standard* | *Clarifying Obj.* |  |
| **SCIENCE** |  |  |  |
| **Earth History** |  |  |  |
| **4.E.2** | Understand the use of fossils and **changes in the surface of the earth as evidence of the history of Earth** and its changing life forms. | 4.E.2.3 | **Give examples of how the surface of the earth changes** due to slow processes such as erosion and weathering, and **rapid processes such as** landslides, volcanic eruptions, and **earthquakes.** |
| **Forces and Motion** | *Essential Standard* | *Clarifying Obj.* |  |
| **6.p.1** | **Understand the properties of waves and the wavelike property of energy in earthquakes**, light and sound waves. | 6.P.1.1 | **Compare the properties of waves to the wavelike property of energy in earthquakes**, light and sound. |
| **Earth Systems, Structures and Processes** | *Essential Standard* | *Clarifying Obj.* |  |
| **6.E.2** | **Understand the structure of the earth and how interactions of constructive and destructive forces have resulted in changes in the surface of the Earth over time and the effects of the lithosphere on humans** | 6.E.2.1<br>6.E.2.2 | 1.Summarize the structure of the earth, including the layers, the mantle and core based on the relative position, composition and density.<br>2.Explain how crustal plates and ocean basins are formed, move and interact using earthquakes, heat flow and volcanoes to reflect forces within the earth.<br>4.Conclude that the good health of humans requires: monitoring the lithosphere, maintaining soil quality and stewardship. |
| **Energy: Conservation and Transfer** | *Essential Standard* | *Clarifying Obj.* |  |

| | | | |
|---|---|---|---|
| **7.P.2** | Understand forms of energy, energy transfer and transformation and conservation in mechanical systems. | 7.P.2.1<br>7.P.2.2 | 1. Explain how kinetic and potential energy contribute to the mechanical energy of an object.<br>2. Explain how energy can be transformed from one form to another (specifically potential energy and kinetic energy) using a model or diagram of a moving object (roller coaster, pendulum, or cars on ramps as examples). |
| **Earth History** | *Essential Standard* | *Clarifying Obj.* | |
| **8.E.2** | **Understand the history of Earth** and its life forms based on **evidence of change** recorded in fossil records and **landforms**. | 8.E.2.2 | Explain the use of fossils, ice cores, composition of sedimentary rocks, **faults,** and igneous rock formations found in rock layers as evidence of the history of the Earth and its changing life forms. |
| **Earth Systems, Structures and Processes** | *Essential Standard* | *Clarifying Obj.* | |
| **EEn.2.1** | **Explain how processes and forces affect the lithosphere.** | EEn.2.1.1<br>EEn.2.1.2<br>EEn.2.1.4 | 1.**Explain how the** rock cycle, **plate tectonics,** volcanoes, and **earthquakes impact the lithosphere.**<br>2.**Predict the locations of** volcanoes, **earthquakes, and faults based on information contained in a variety of maps.**<br>4.**Explain the probability of and preparation for geohazards such as** landslides, avalanches, **earthquakes** and volcanoes **in a particular area based on available data.** |
| **Energy: Conservation and Transfer** | *Essential Standard* | *Clarifying Obj.* | |
| **PSc.3.2** | **Understand the nature of waves.** | PSc.3.2.1<br>PSc.3.2.2<br>PSc.3.2.3<br>PSc.3.2.4 | 1.Explain the relationships among wave frequency, wave period, wave velocity and wavelength through calculation and investigation.<br>2.Compare waves (mechanical, electromagnetic, and surface) using their characteristics.<br>3.Classify waves as transverse or |

|  |  |  |  |
|---|---|---|---|
|  |  |  | compressional (longitudinal).<br>4.Illustratethe wave interactions of reflection, refraction, diffraction, and interference. |
| **Energy: Conservation and Transfer** | *Essential Standard* | *Clarifying Obj.* |  |
| **Phy.2.2** | **Analyze the behavior of waves.** | Phy.2.2.1<br>Phy.2.2.2 | 1.Analyze how energy is transmitted through waves, using the fundamental characteristics of waves: wavelength, period, frequency, amplitude, and wave velocity.<br>2.Analyze wave behaviors in terms of transmission, reflection, refraction and interference. |
| **SOCIAL STUDIES** |  |  |  |
| **Geography and Environmental Literacy** | *Essential Standard* | *Clarifying Obj.* |  |
| **1.G.2** | Understand how humans and the environment interact within the local community | 1.G.2.3 | Explain how the environment impacts where people live (urban, rural, weather, transportation, etc.). |
| **3.G.1** | Understand the earth's patterns by using the 5 themes of geography: (location, place, **human -environment interaction**, movement and regions) | 3.G.1.3 | **Exemplify how people adapt to, change** and protect the **environment to meet their needs**. |
| **5.G.1** | Understand how human activity has and continues to shape the United States. | 5.G.1.1 | **Explain the impact of the physical environment on early settlements in the New World.** |
| **7.G.1** | Understand how geography, demographic trends, and environmental conditions shape modern societies and regions. | 7.G.1.1<br>7.G.1.3 | 1.Explain how environmental conditions and human response to those conditions influence modern societies and regions(e.g. natural barriers, scarcity of resources and factors that influence settlement)<br>3.**Explain how natural disasters (e.g. flooding, earthquakes,** |

| | | | |
|---|---|---|---|
| | | | **monsoons and tsunamis)**, preservation efforts and **human modification of the environment** (e.g. recycling, planting trees, deforestation, pollution, irrigation systems and climate change) **affect modern societies and regions.** |
| **8.G.1** | Understand the geographic factors that influenced North Carolina and the United States. | 8.G.1.1 | Explain how location and place have presented opportunities and challenges for the movement of people, goods, and ideas in North Carolina and the United States. |

# INSERT TAB
# N.C.
# EARTHQUAKE
# HISTORY

## Earthquake Education Workshops

September 2014
Charlotte, Candler, and Winston-Salem, NC

# *“Earthquake History of North Carolina”*

presented by

**Dr. Kenneth B. Taylor**

State Geologist Of North Carolina
N.C. Geological Survey
Division of Land Resources

Kenneth.b.taylor@ncdenr.gov
(919) 707-9211

# 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.

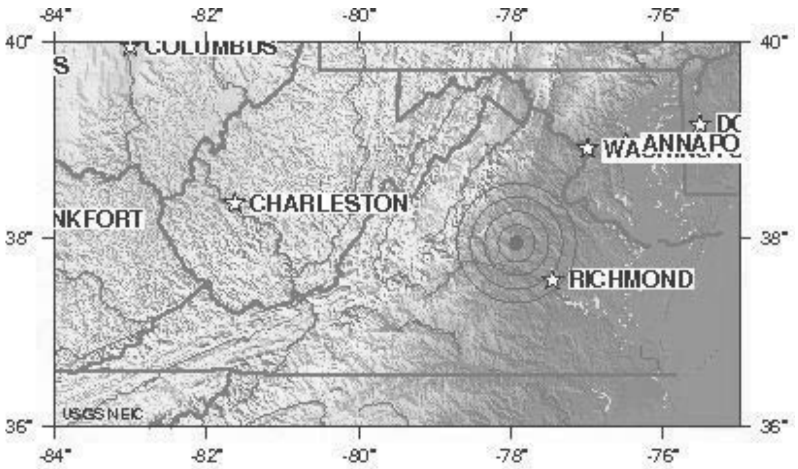


*Image courtesy of the US Geological Survey*

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*)

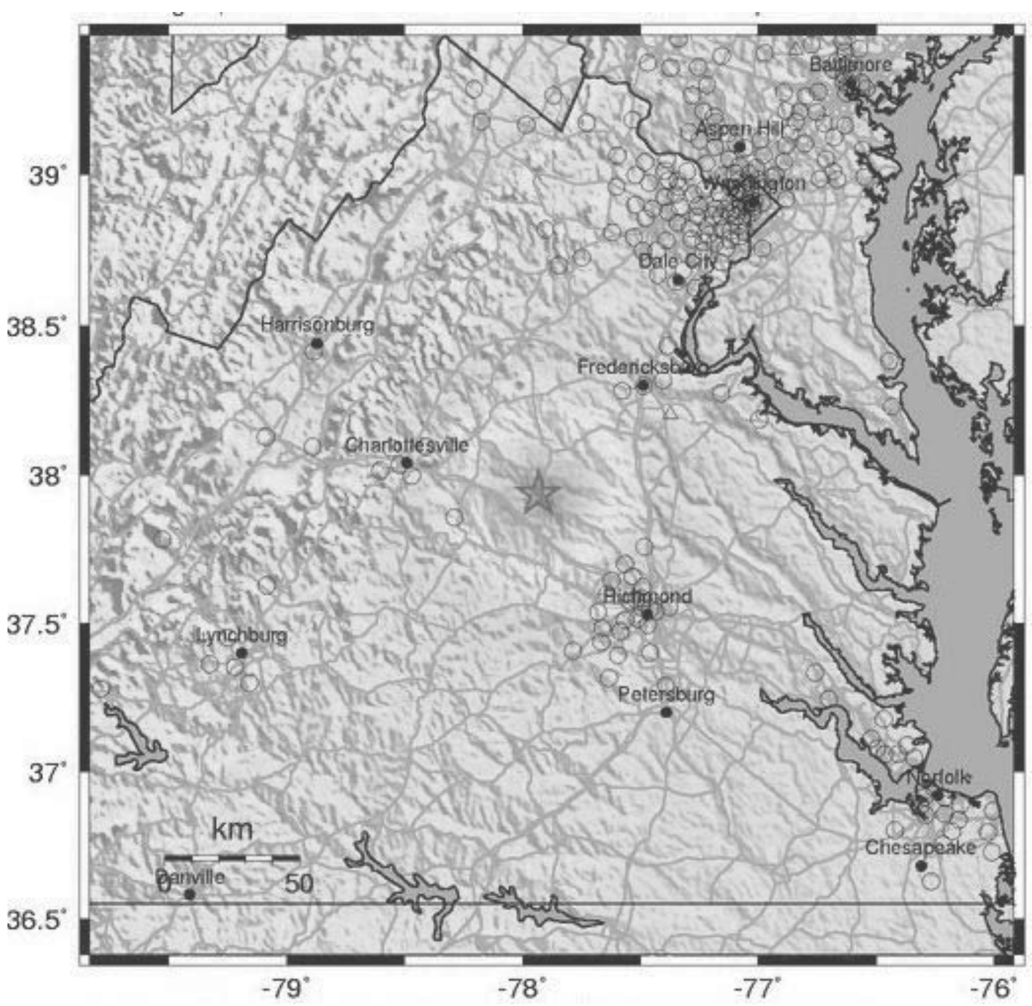
# Magnitude 5.8 VIRGINIA

## 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).

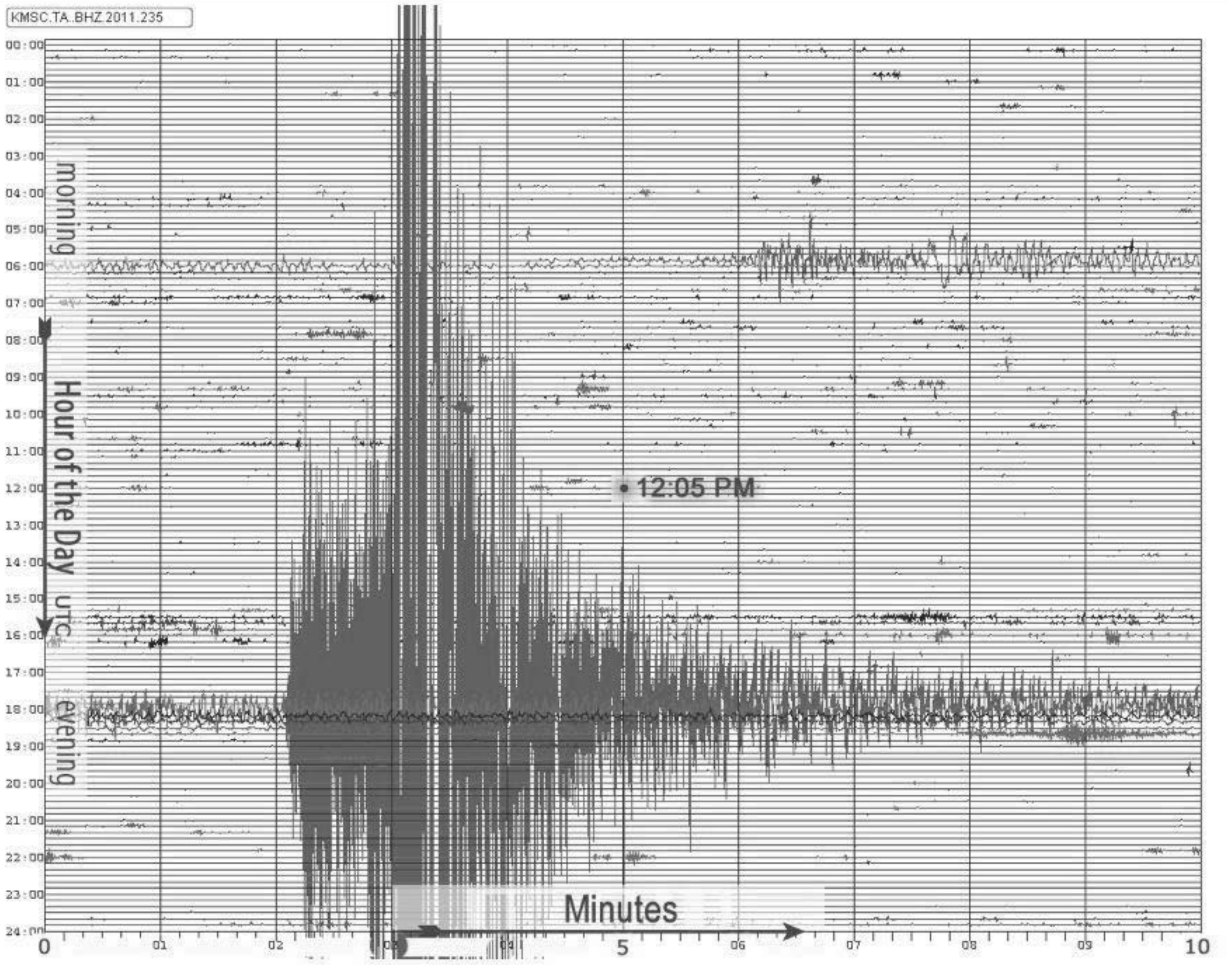
| Modified Mercalli Intensity | Perceived Shaking |
|---|---|
| X | Extreme |
| IX | Violent |
| VIII | Severe |
| VII | Very Strong |
| VI | Strong |
| V | Moderate |
| IV | Light |
| II-III | Weak |
| I | Not Felt |

Image courtesy of the US Geological Survey

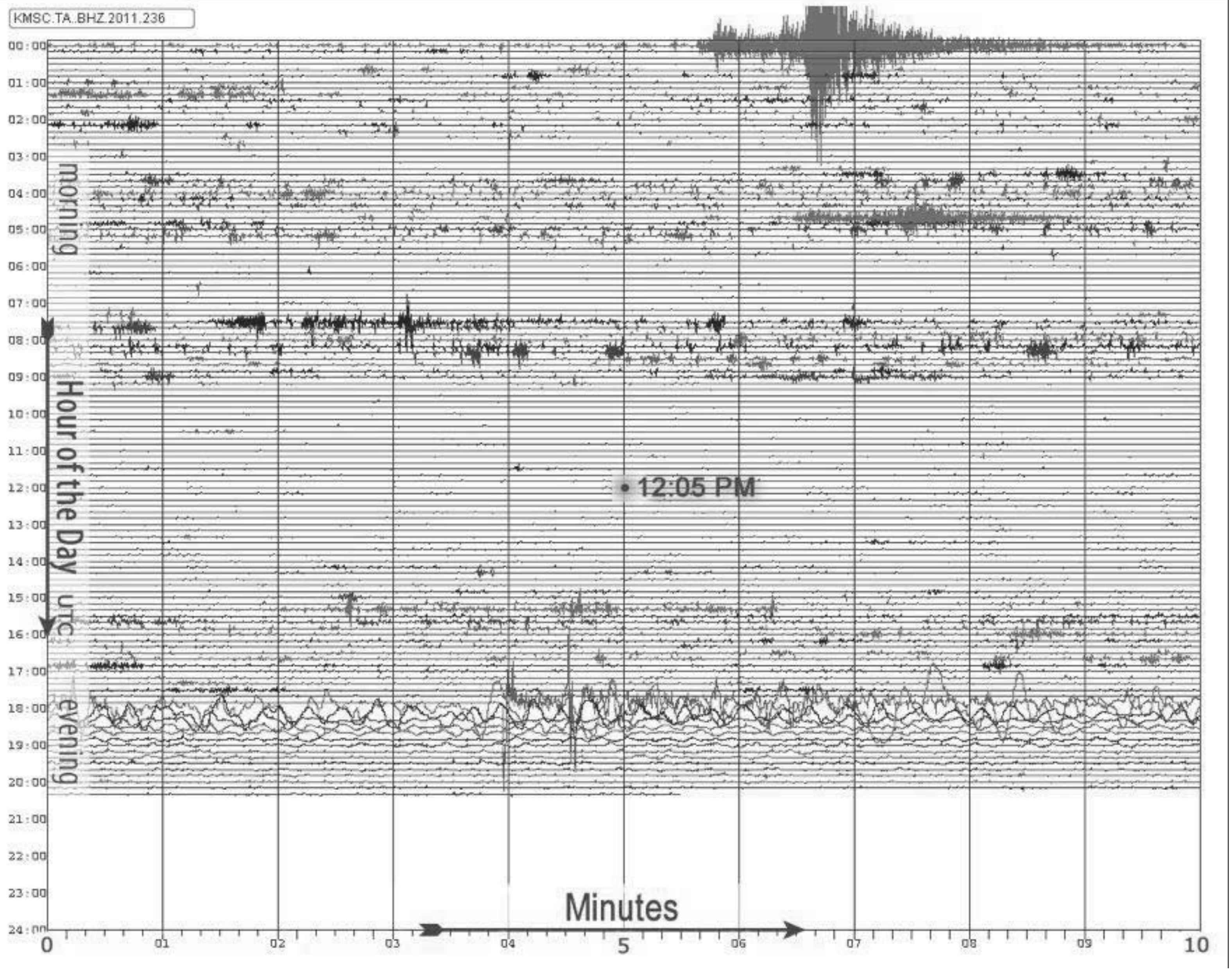


USGS Estimated shaking Intensity from M 5.8 Earthquake

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



# 08/24/2011 Seismic Activity at Station KMSC - Kings Mountain, Blacksburg, SC



# 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].*

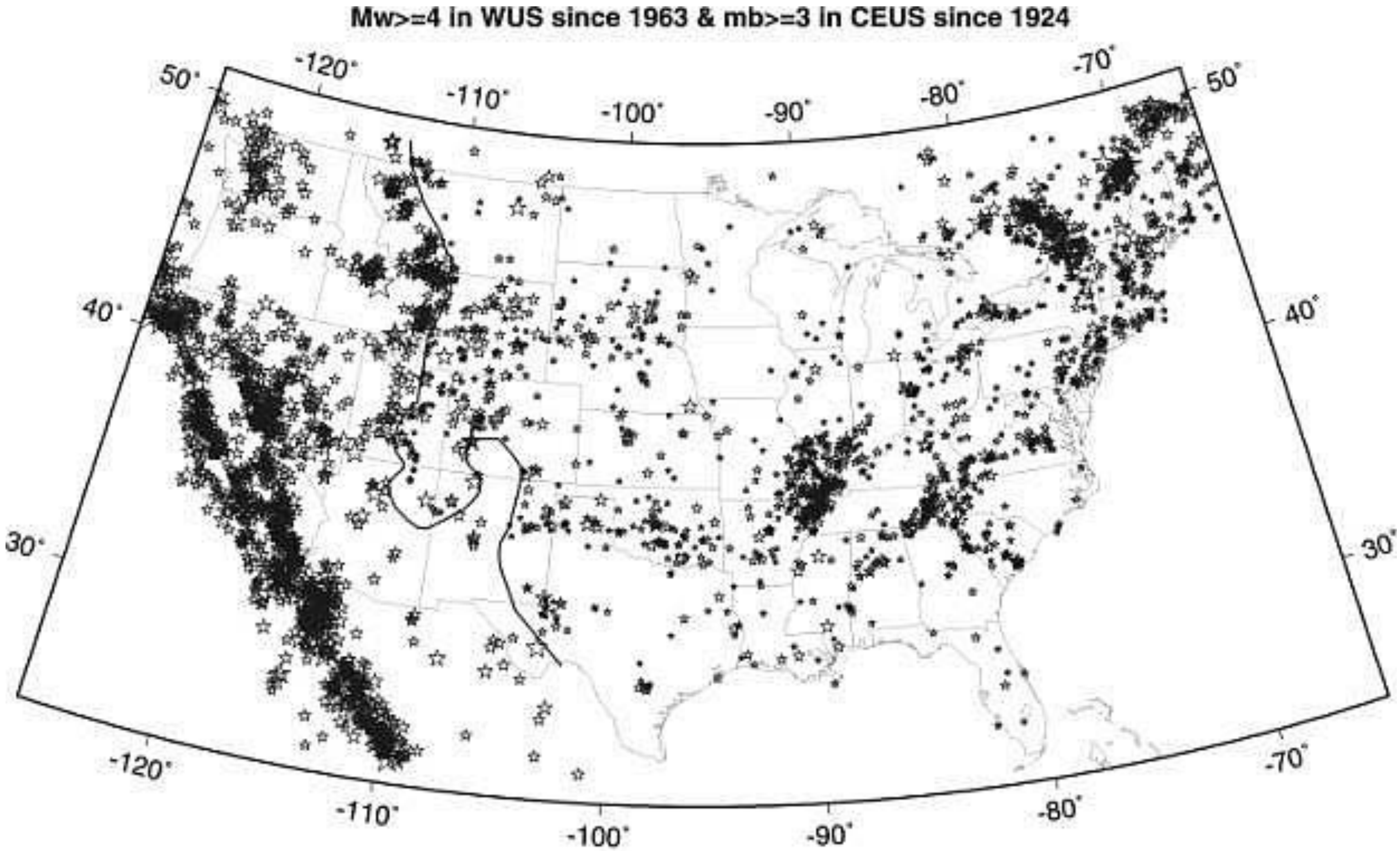
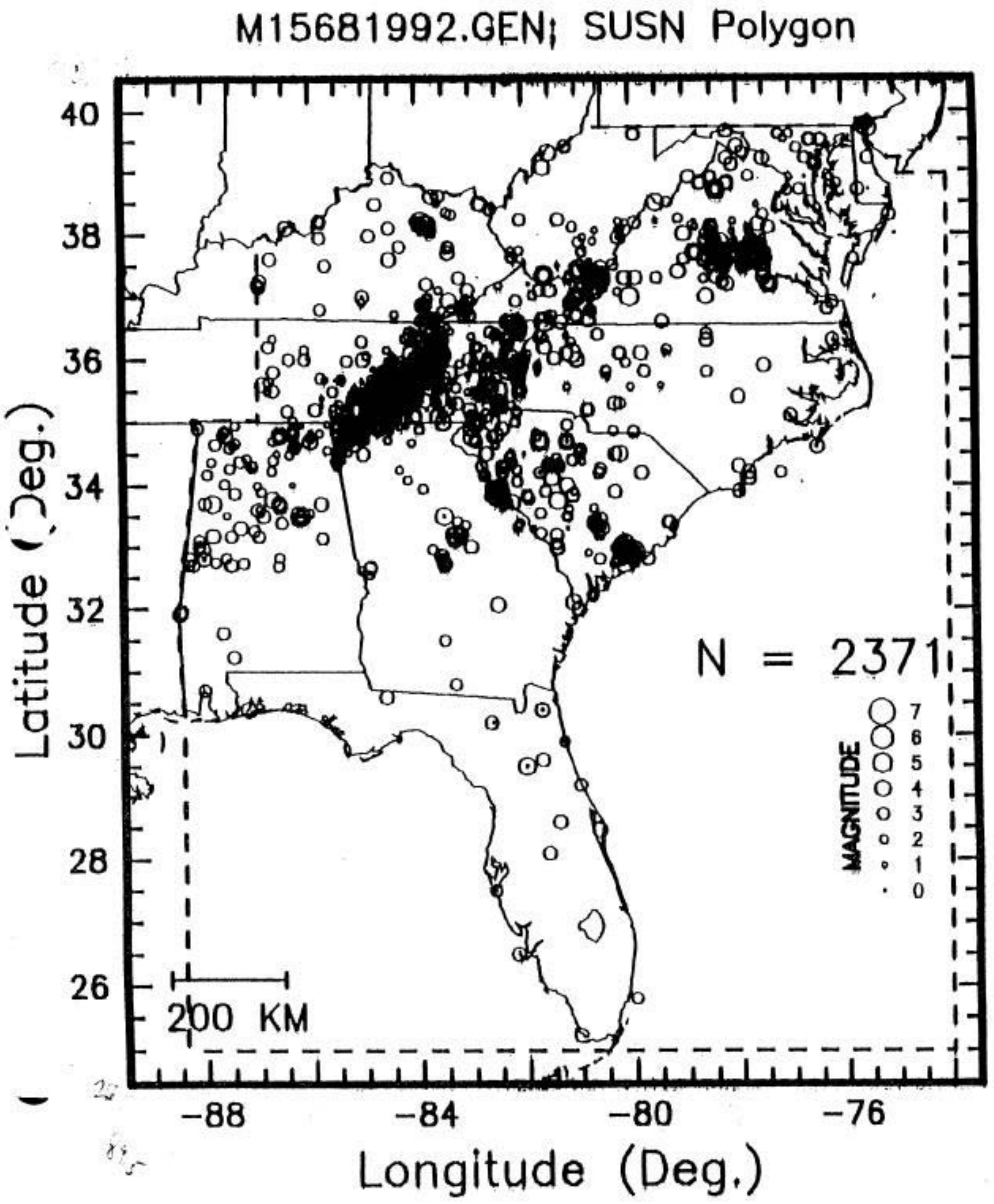


Figure 1. Seismicity map of the United States, showing mb 3 and above earthquakes since 1924 in the CEUS and M 4 and above earthquakes since 1963 in the WUS. Size of stars is scaled to magnitude. Boundary we chose to divide CEUS and WUS attenuation regions is shown as solid line starting in Montana and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

Figure 1

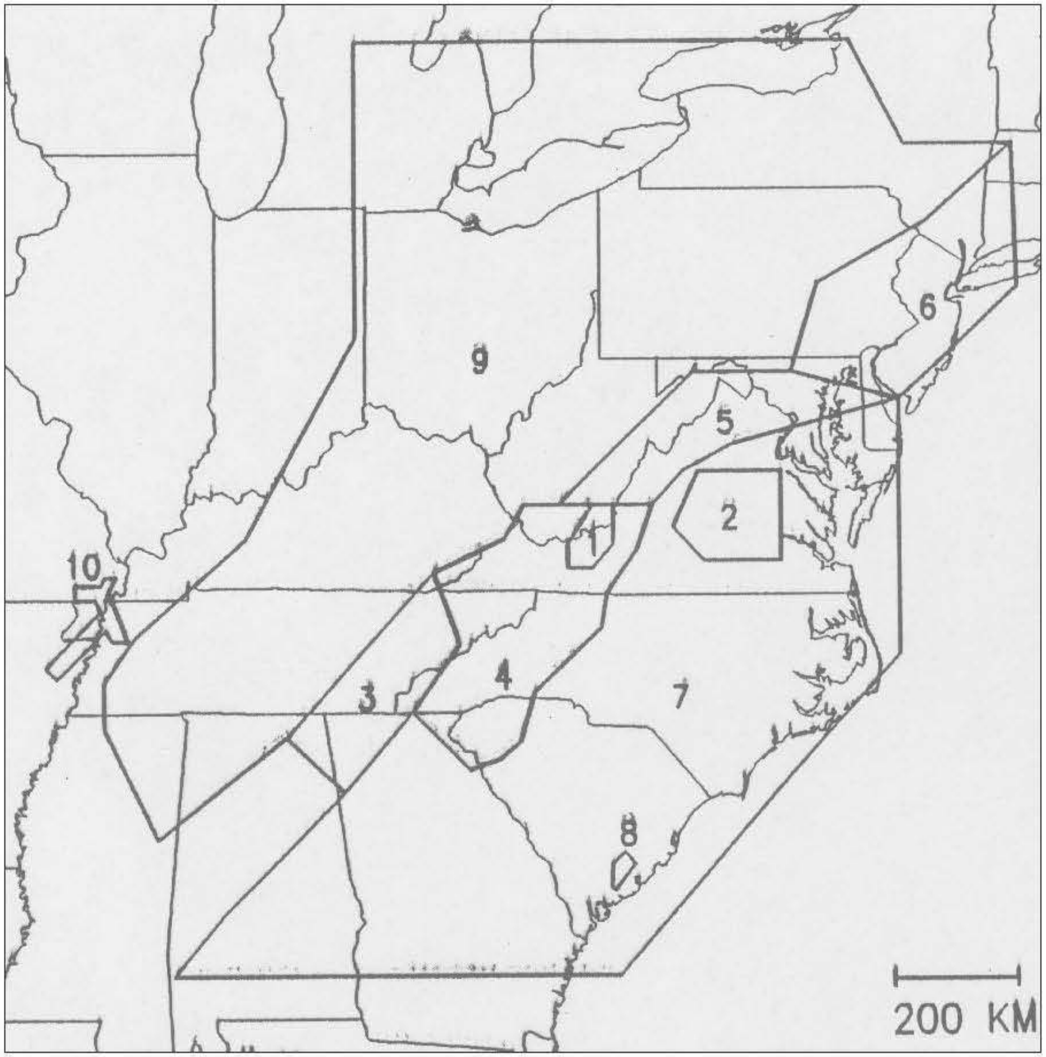


**Map of earthquake epicenters from 1568 to 1992 for the Southeastern United States.**

**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.

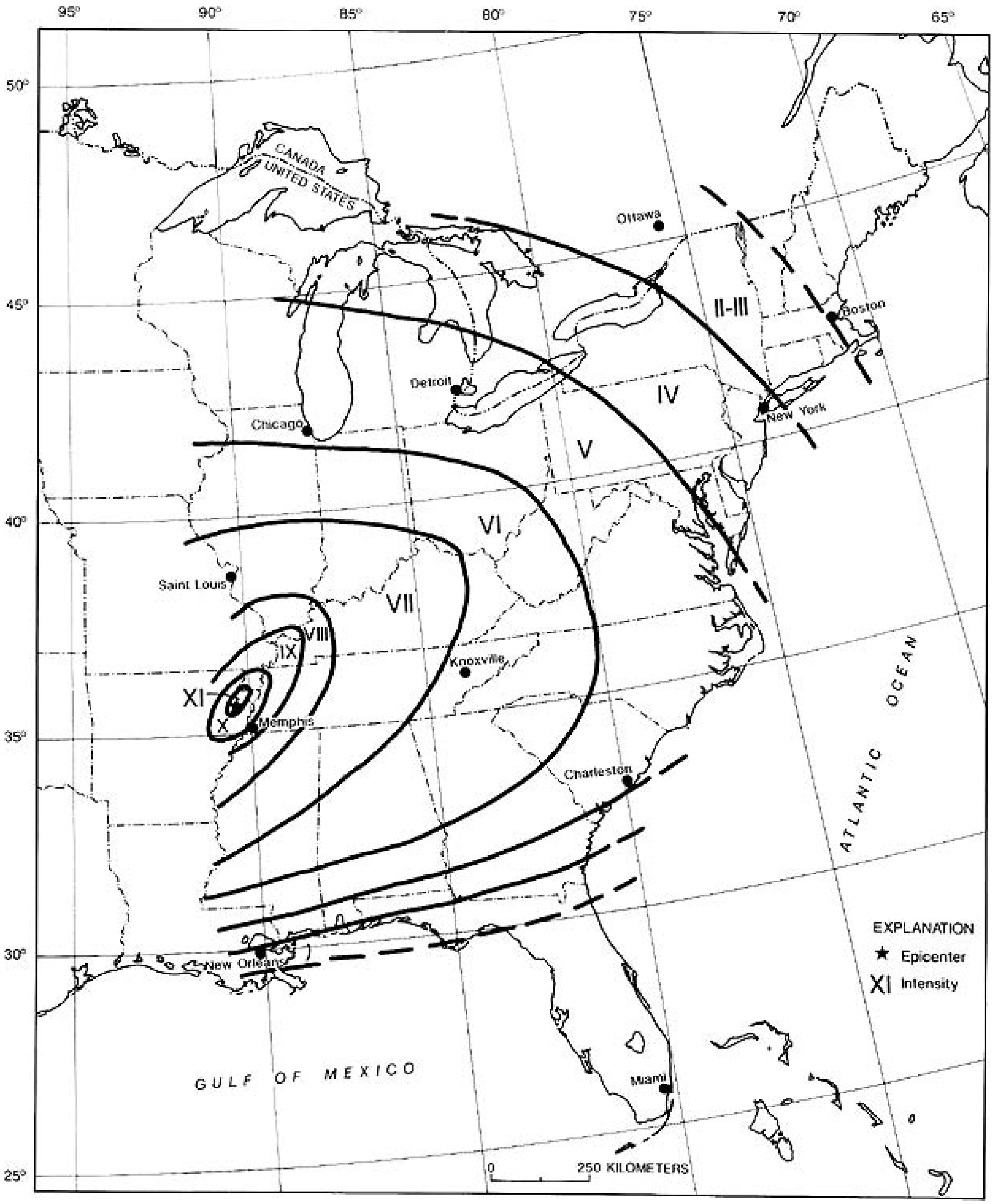
**VIII.** Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.

**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.

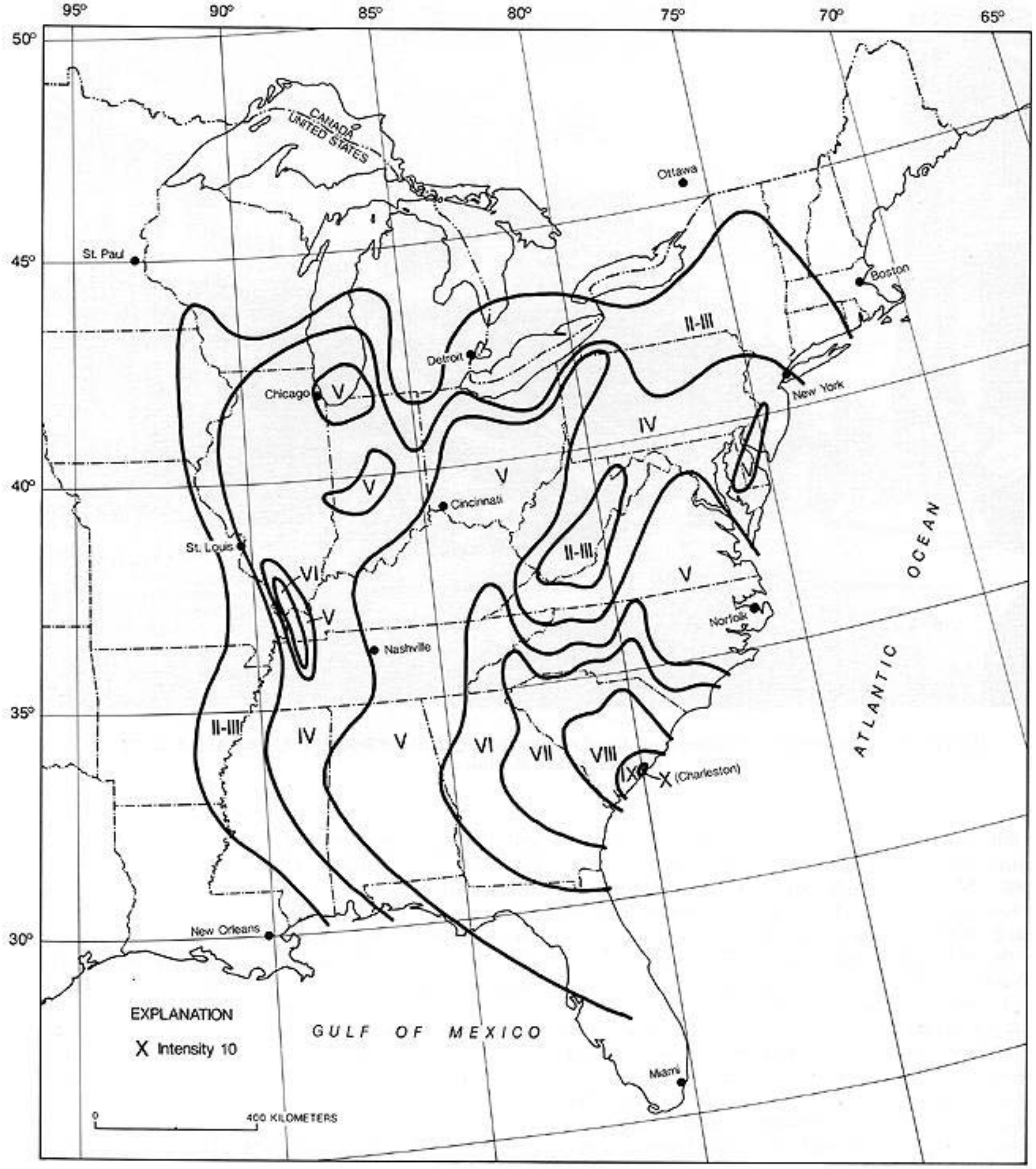
**XI.** Few, if any (masonry) structures remain standing. Bridges destroyed. Rails bent greatly.

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

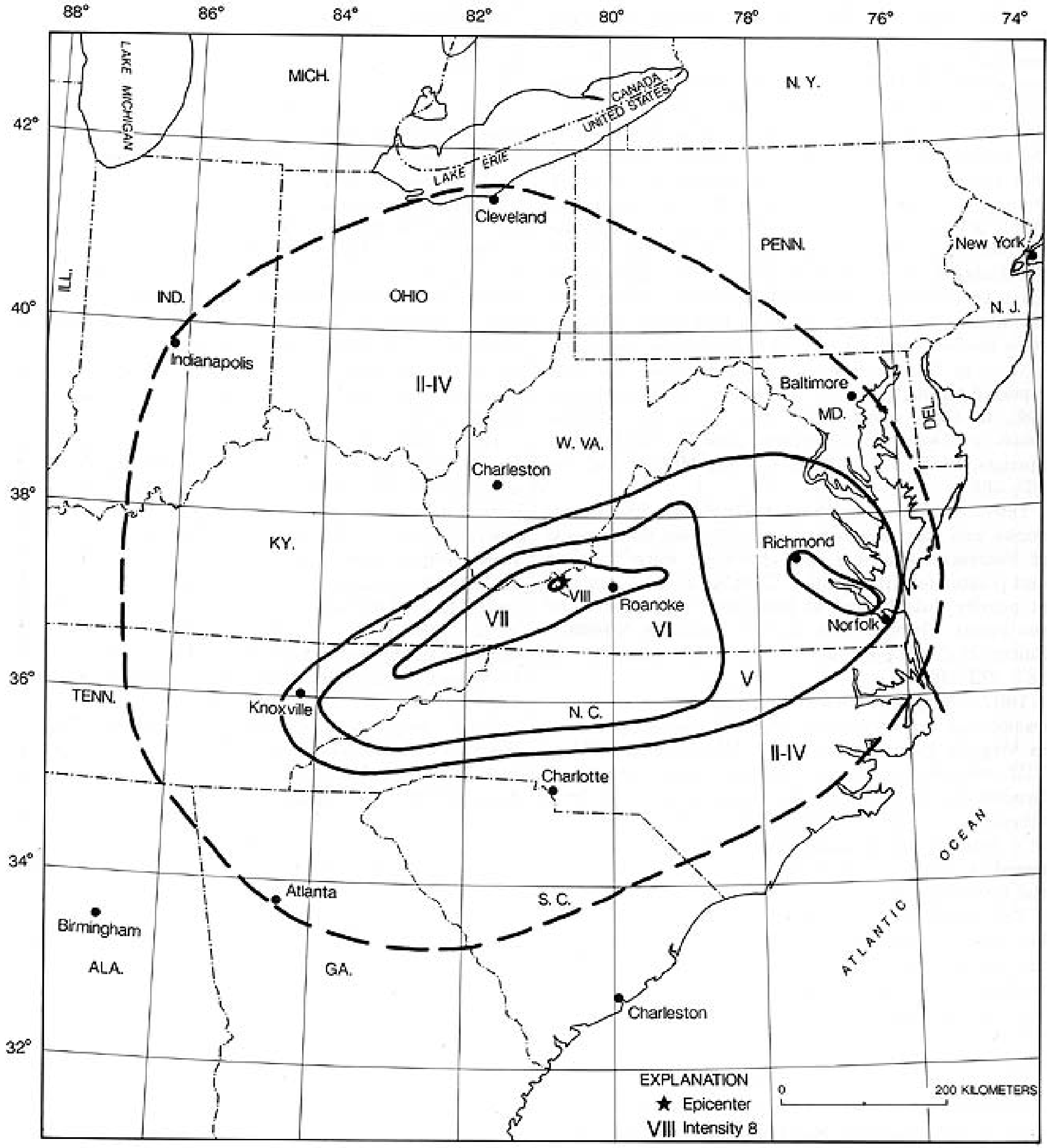


# December 16, 1811

# New Madrid Earthquake



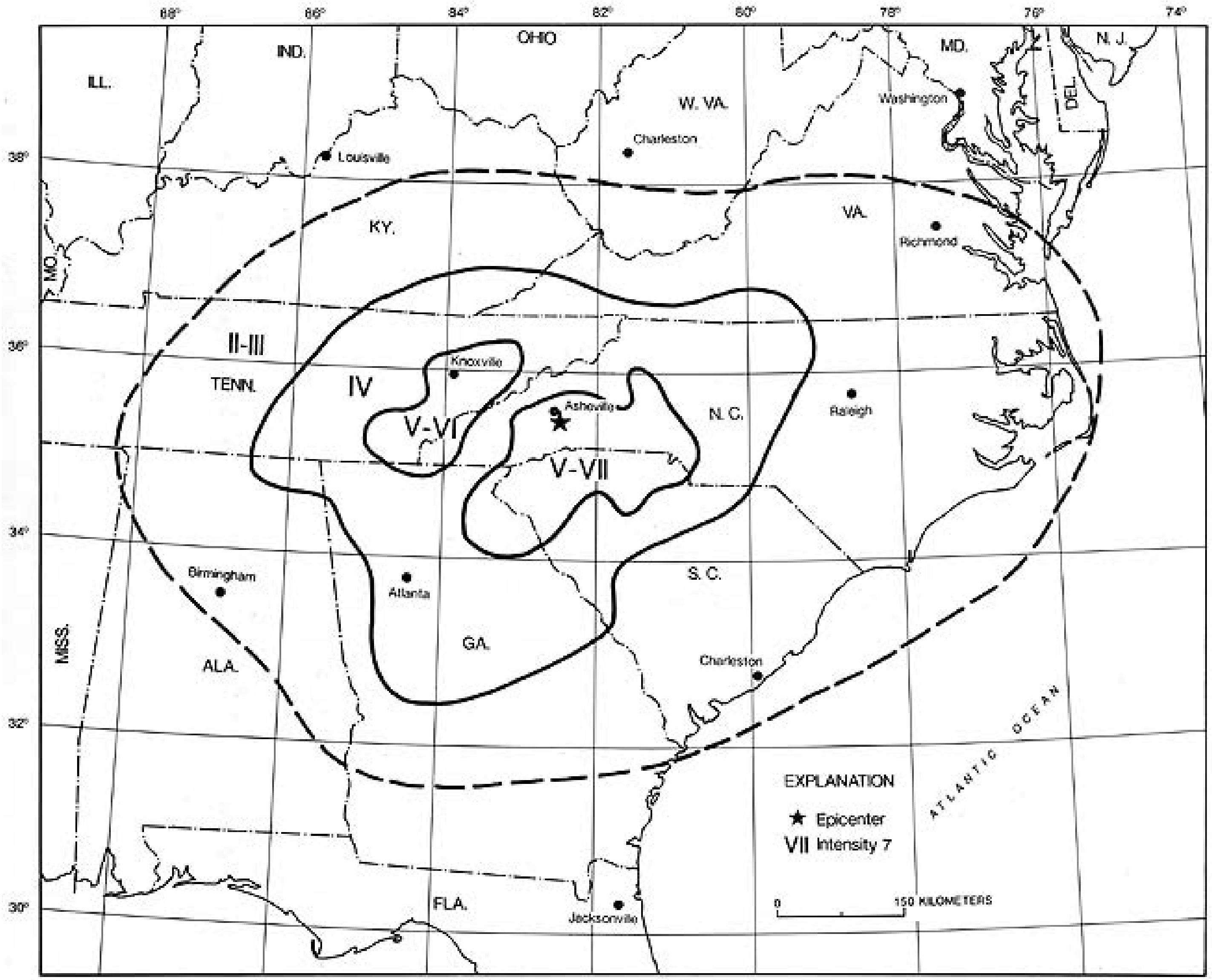
Charleston, South Carolina earthquake of August 31, 1886. Magnitude of 7.3 estimated from intensity and felt area.

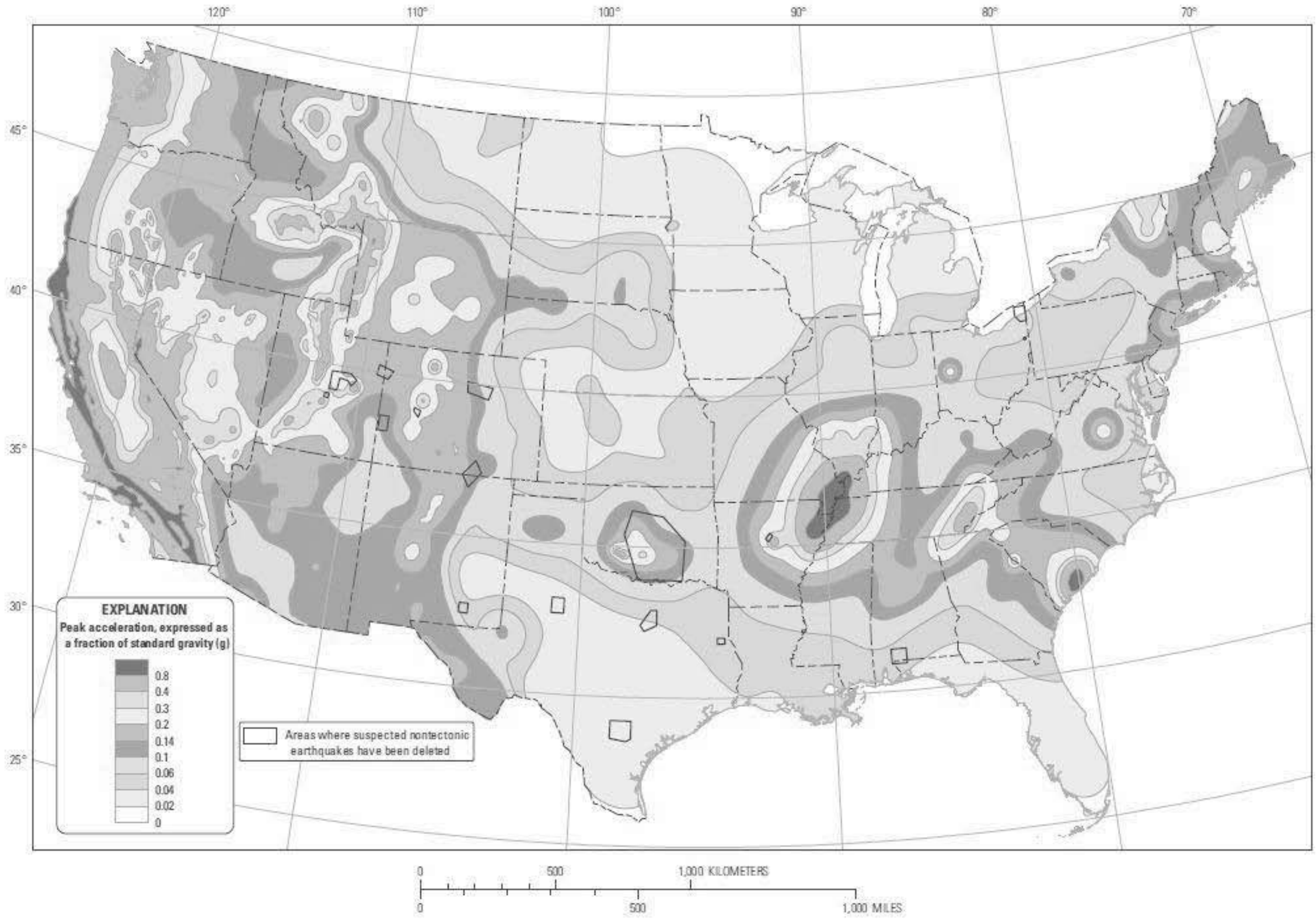


**Isoseismal map for the Giles County, Virginia earthquake of May 31, 1897 -- the largest to occur in that State.**

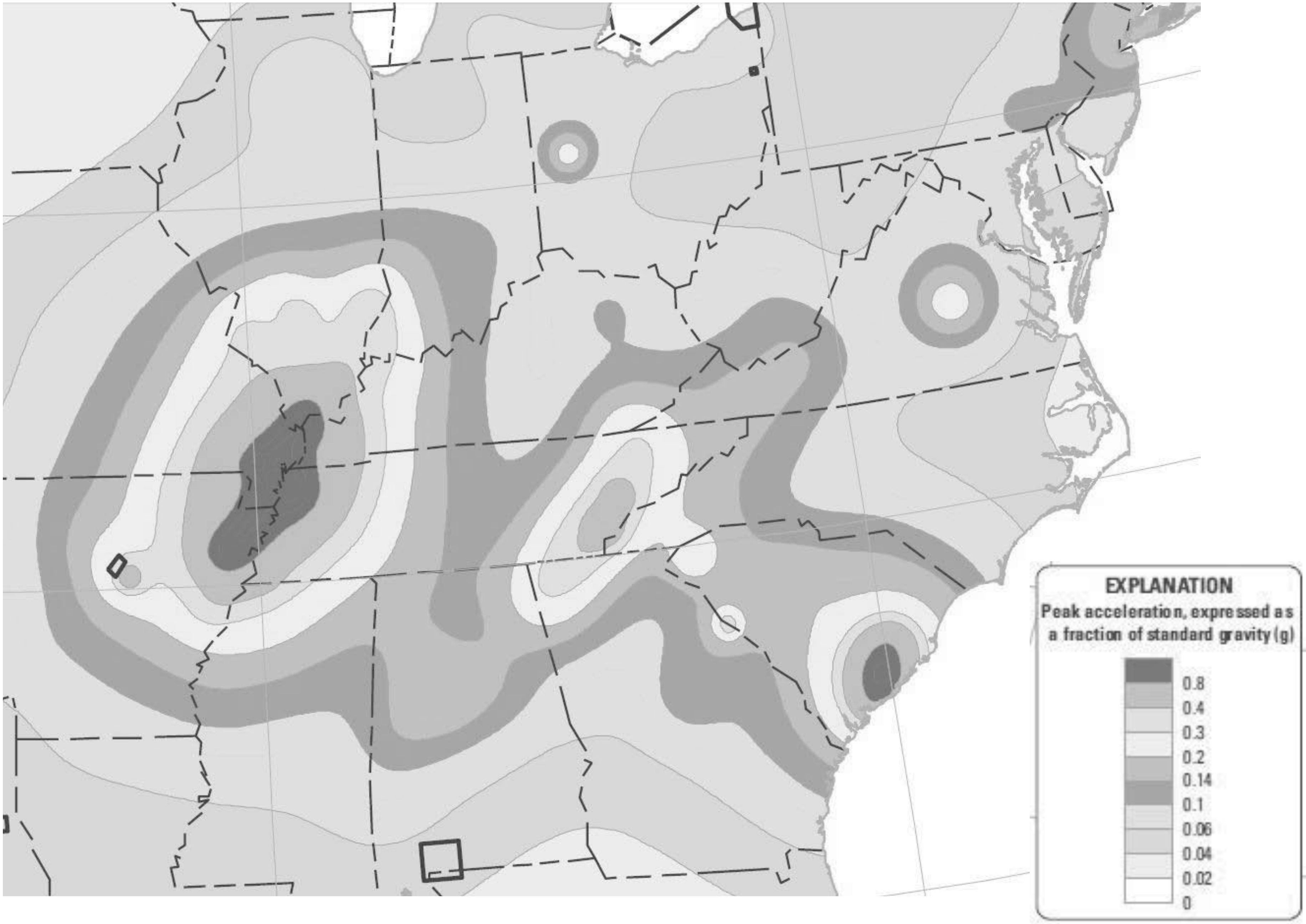
**Earthquake magnitude of 5.8 estimated from intensity and felt area. This is the 3$^{rd}$ largest eastern US quake in the last 200 years and was felt in twelve states.**

# 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).

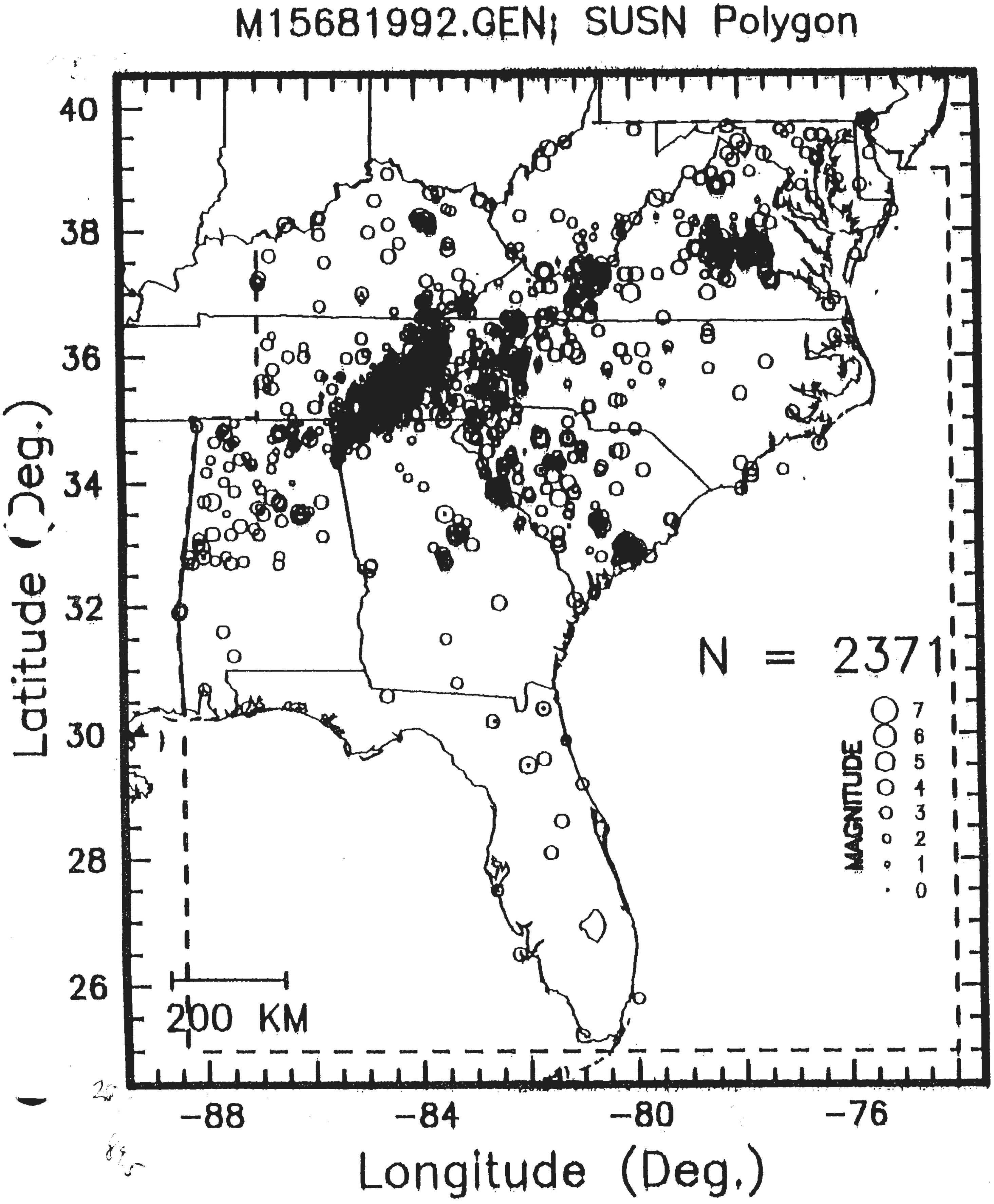
Table 1 -- **List of earthquakes which have caused damage in North Carolina.** The list is complete to date and includes 21 earthquakes total, six located in North Carolina. The Modified Mercalli Intensity Scale (MM) is a measure of the effects of an earthquake on man and man's environment. The intensity 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:

Dr. Kenneth B. Taylor
Earthquake Planner
N.C. Division of Emergency Management
75-B Zillicoa Street
Asheville, NC 28801
phone: (704) 251-6152; fax: (704) 251-6311

**Figure 1**


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

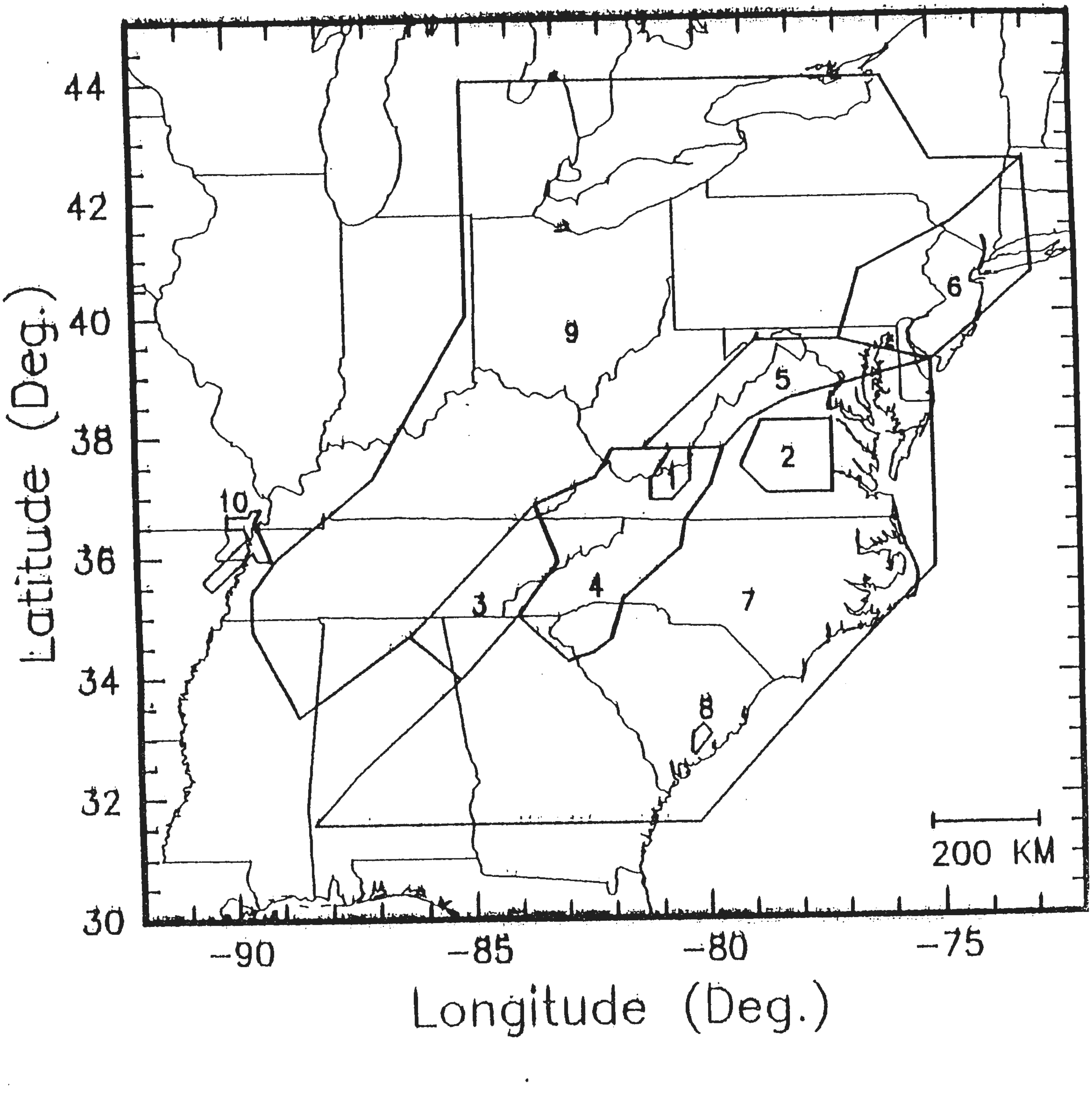


**Figure 2** Earthquake source zones used in the hazard analysis. (1) Giles County, VA; (2) central VA; (3) eastern TN; (4) southern Appalachians; (5) northern VA, MD; (6) central Appalachians; (7) Piedmont-Coastal Plain; (8) Charleston, SC; (9) Appalachian foreland; (10) New Madrid.

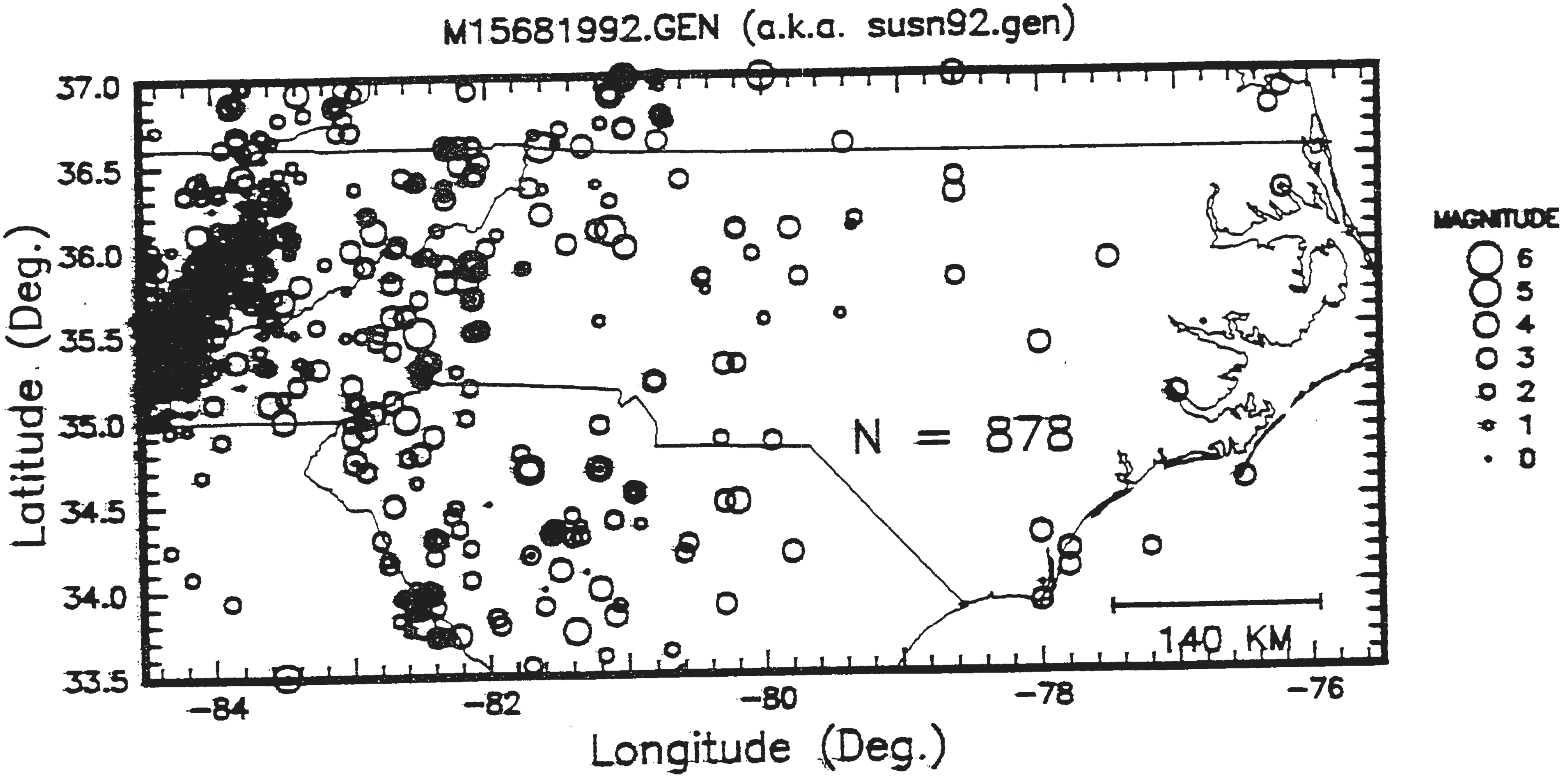

M15681992.GEN (a.k.a. susn92.gen)
Latitude (Deg.)
37.0
36.5
36.0
35.5
35.0
34.5
34.0
33.5
Longitude (Deg.)
-84
-82
-80
-78
-76
N = 878
140 KM
MAGNITUDE
6
5
4
3
2
1
0

Figure 3

| Date | Location | Mag | MMI$_0$ | 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$_0$ = 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.

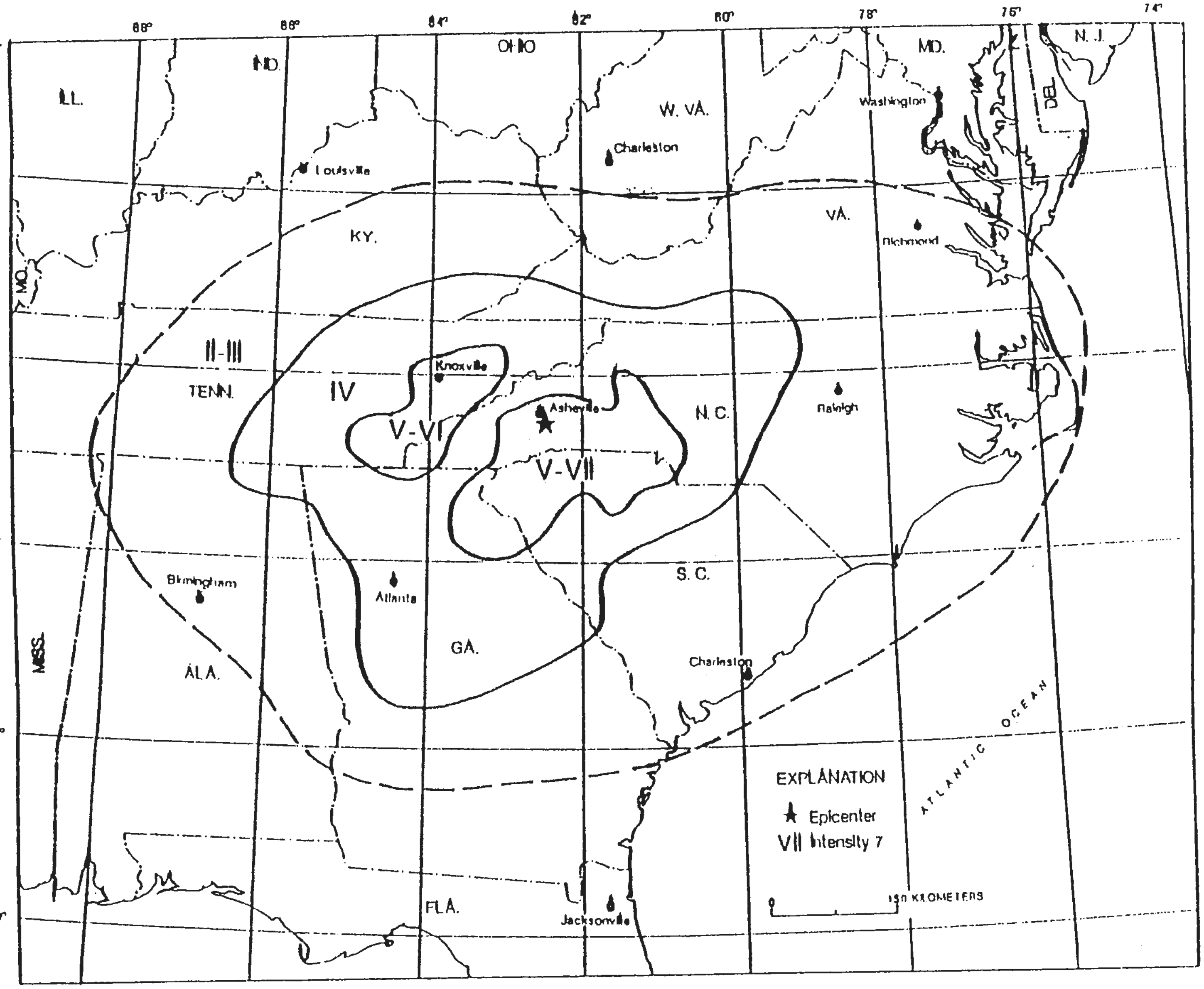


**Figure 4** Isoseismal map for the Waynesville, North Carolina, earthquake of February 21, 1916. Isoseismals are based on intensity estimates from data listed in reference 272 of table 1.

MAG 5.2 $M_{fa}$ ; 5.5 $m_b$

APPENDIX 10 TO ANNEX B
NORTH CAROLINA EMERGENCY OPERATIONS PLAN

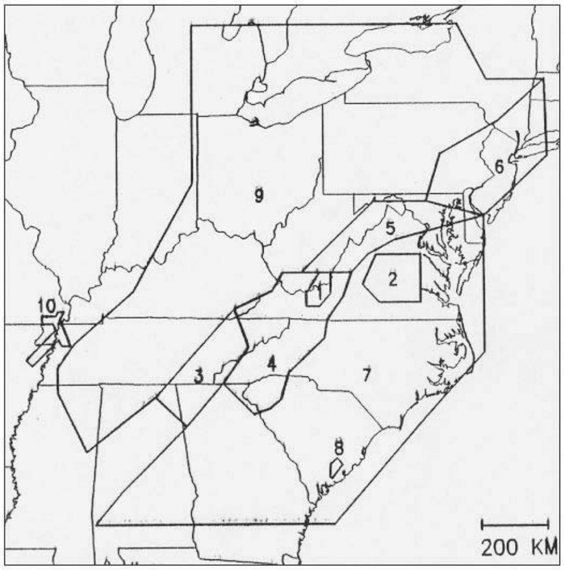
# EARTHQUAKE OPERATIONS PLAN

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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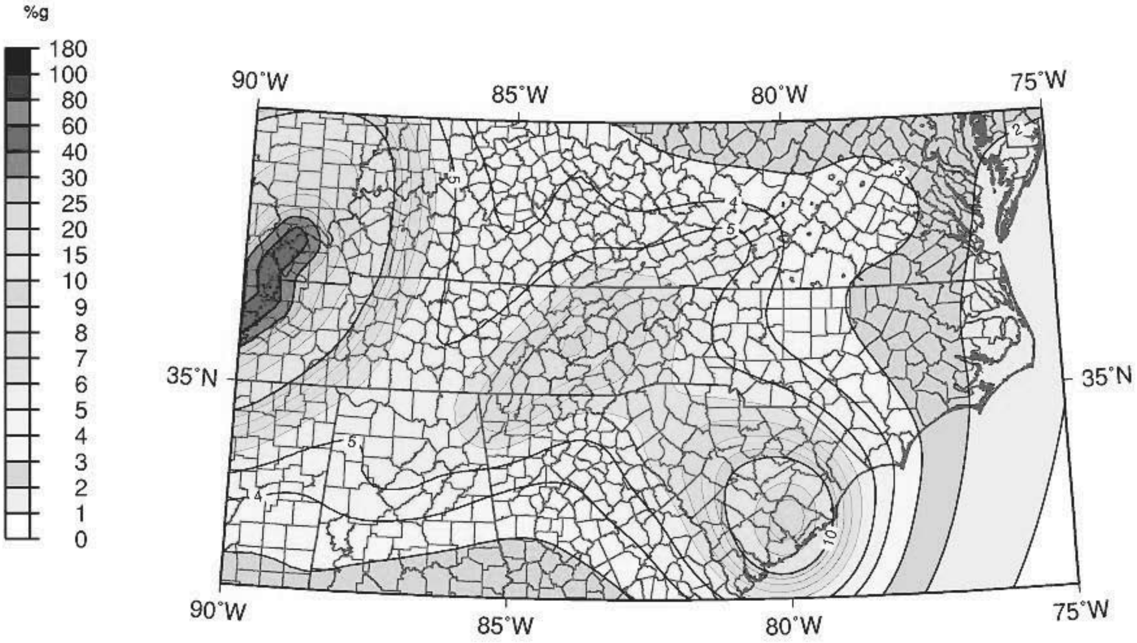
10 - New Madrid

Figure 1

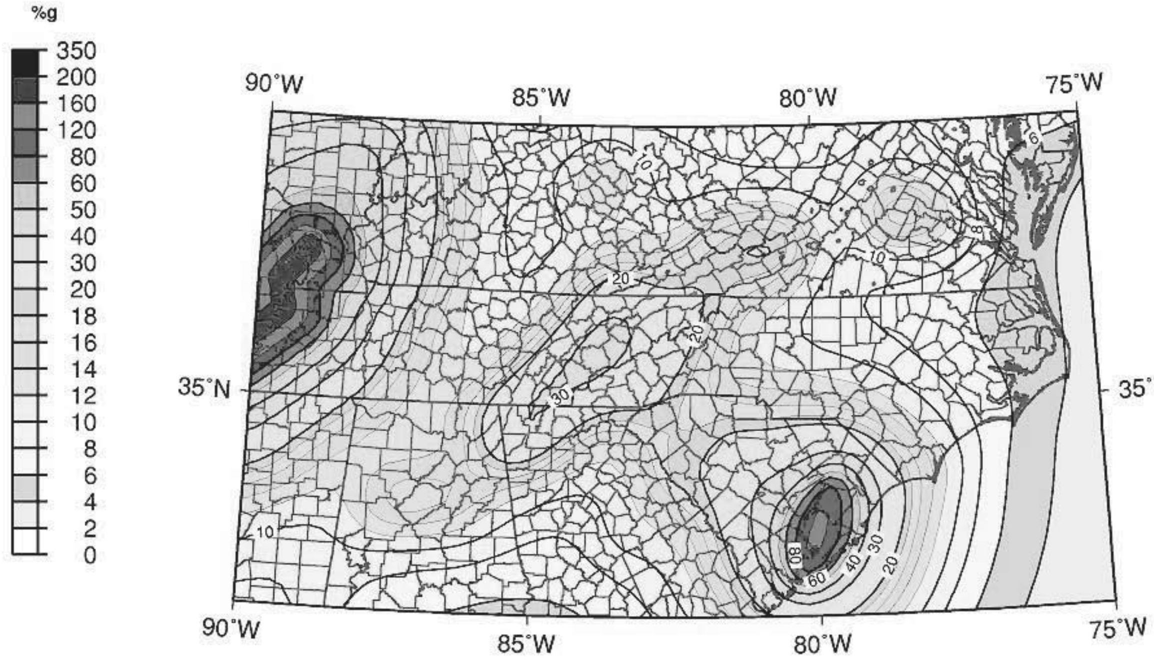
To determine the earthquake hazard nationwide, the U.S. Geological Survey has produced two principal earthquake hazard maps are “Peak Acceleration (%g) with 10% Probability of Exceedance in 50 Years” [Figure 2] and “Peak Acceleration (%g) with 2% Probability of Exceedance in 50 Years” [Figure 3]. These 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.



**Peak Acceleration (%g) with 10% Probability of Exceedance in 50 Years**
**site: NEHRP B-C boundary**
U.S. Geological Survey
National Seismic Hazard Mapping Project

Albers Conic Equal-Area Projection
Standard Parallels: 29.5 and 45.5 degrees

Figure 2



Peak Acceleration (%g) with 2% Probability of Exceedance in 50 Years
site: NEHRP B-C boundary
U.S. Geological Survey
National Seismic Hazard Mapping Project

Albers Conic Equal-Area Projection
Standard Parallels: 29.5 and 45.5 degrees

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.

# INSERT TAB
# EARTHQUAKES
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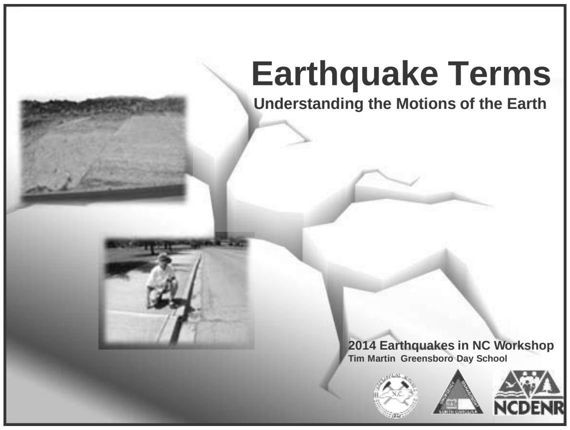
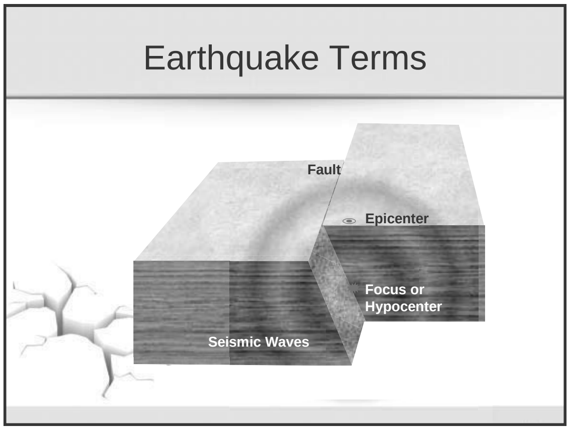
# TECTONICS



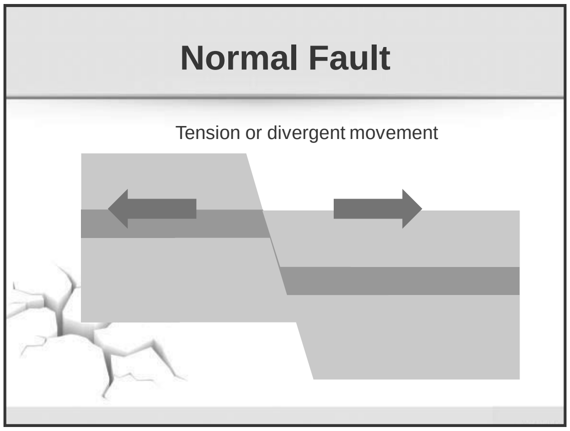
# Earthquake Terms

Understanding the Motions of the Earth

2014 Earthquakes in NC Workshop
Tim Martin Greensboro Day School

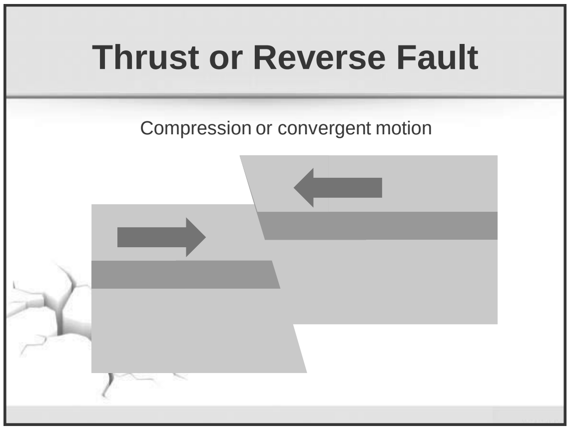


## Earthquake Terms



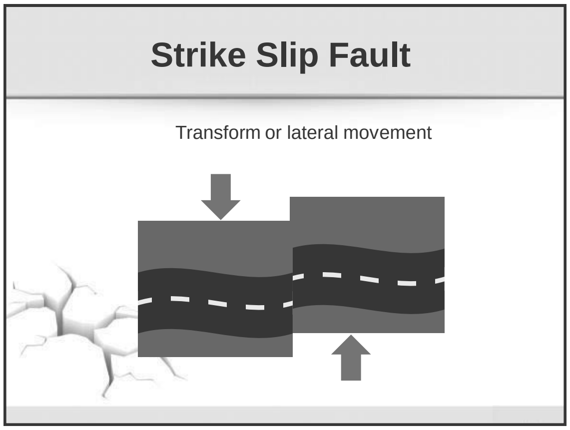
## Normal Fault

Tension or divergent movement



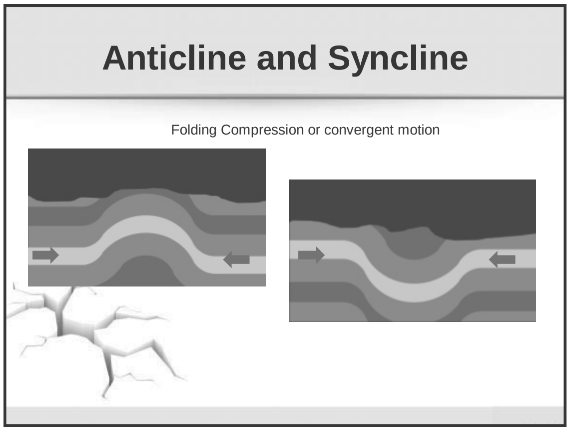
### Thrust or Reverse Fault

Compression or convergent motion



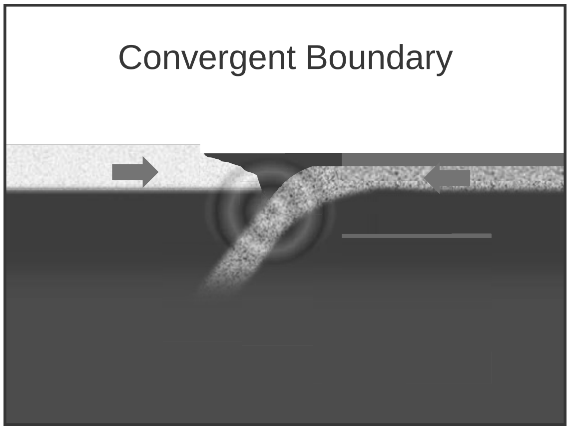
### Strike Slip Fault

Transform or lateral movement

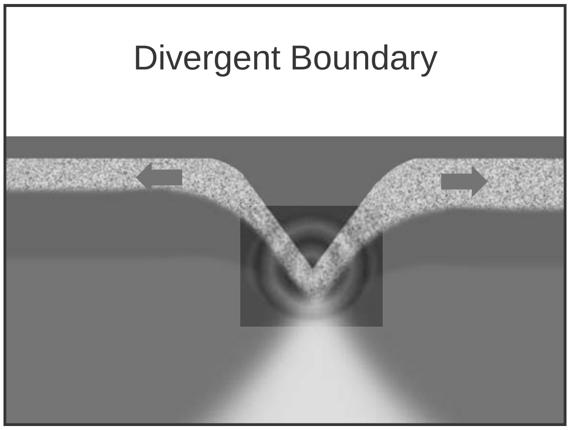


### Anticline and Syncline

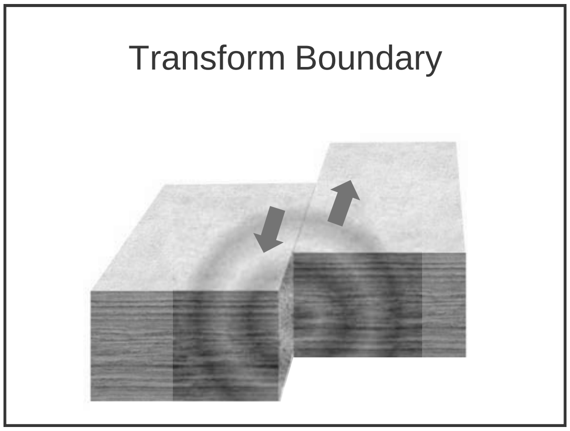
Folding Compression or convergent motion



## Convergent Boundary



## Divergent Boundary



## Transform Boundary

# Elastic Rocks

## Earthquakes in NC workshop

**Tim Martin** tmartin@greensboroday.org

**Background:**

Elastic Rebound Theory is a fundamental concept in understanding earthquakes.

While the Earth's tectonic plates are in constant motion, the rigid upper layers of the crust are frequently locked in position. As the lithospheric plates move (at an average rate of 5 cm or 2" per year) stress and strain will accumulate in the rigid surface rocks. The surface rocks will slowly bend and deform under the enormous pressure. This slow deformation will continue until an earthquake occurs and the locked rocks break. When the rupture occurs, the rocks will release the stored energy in the form of seismic waves. Along the earthquake fault, the deformed rocks will rebound (elastically) to a less stressed state.

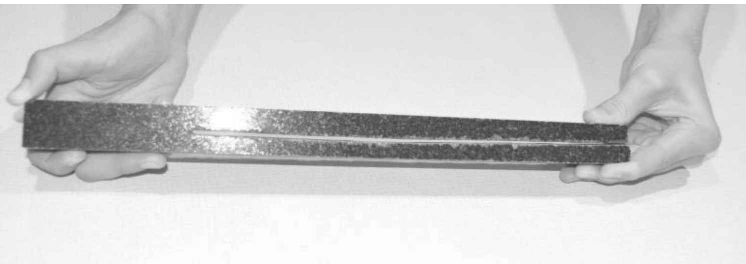
Note the difference between flexible and elastic. (Flexible means a substance is bendable whereas an elastic object may bend but it will return to its original position.)

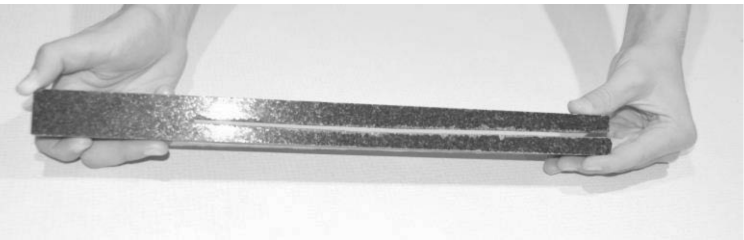
The term elastic is frequently associated with rubber (elastic) bands. While simplistic, it is an appropriate model for demonstrating the elastic rebound in an earthquake. The elastic band will stretch (deform) until it reaches a breaking point. At the time of the break, the elastic band will snap back to its original less stressed state.

**The Demonstration:**

While students may easily understand the elasticity of a rubber band, the elastic properties of solid rocks is counter intuitive to most. This demonstration shows that rocks are truly elastic.

Slit a long narrow rock sample (The example to the right was made from a cut-off piece from a kitchen counter top. (Igneous-gabbro) Others have successfully cut marble floor tile.) A masonry saw blade or tile saw can be used to cut a slit down the length of the rock. Under pressure (squeezed) rock will deform. When released, the rock will return to the normal un-stressed state.





This YouTube video from IRIS shows the demonstration. https://www.youtube.com/watch?v=HPRLrk7UFbQ

# Plate Puzzle [1]

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**April, 2000 (revised February, 2002; September, 2006)**

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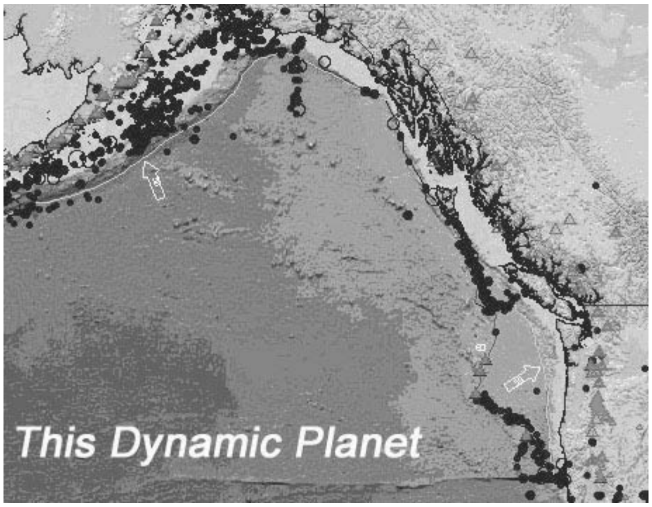


**Objectives:** Develop a better understanding of the Earth's plates and their distribution. Explore plate motions and the interactions of the plates along the plate boundaries. Before beginning this activity, students should have a basic knowledge of the Earth's plates, the lithosphere and asthenosphere, heat within the Earth, and the three types of plate boundaries – divergent, convergent and transform. Similar activities are contained in Tremor Troop (the FEMA/NSTA earthquake curriculum for grades K-6) on pages 43-44 and 56-60, and on Masters 13, 14a and 14b; and at: http://quake.wr.usgs.gov/research/deformation/modeling/teaching/puzzle/. Good activities to precede this lesson are the foam models of the lithosphere and the epicenter plotting activities. Good follow-up activities are: plate tectonics flip book, epicenter plotting using program Seismic Eruption, earthquake location, and thermal convection (http://web.ics.purdue.edu/~braile; these activities could also be performed before the Plate Puzzle* lesson; in this case, the Plate Puzzle activity is an excellent authentic assessment tool). Note: This is a revised description of this activity due to the release of a new version (2006) of the "This Dynamic Planet" map.

* MS Word and PDF versions of this document are located at:
http://web.ics.purdue.edu/~braile/edumod/platepuzz/platepuzz.doc, and
http://web.ics.purdue.edu/~braile/edumod/platepuzz/platepuzz.pdf.

[1] Explorations in Earth Science

Last modified October 15, 2006

The web page for this document is:
**http://web.ics.purdue.edu/~braile/edumod/platepuzz/platepuzz.htm**

Partial funding for this development provided by the National Science Foundation.

**Introduction:** The “This Dynamic Planet” map (Figure 1) is an excellent resource for learning about plate tectonics. The map is an attractive display of plate tectonic features such earthquake epicenters, the locations of volcanoes, topography and ocean bathymetry. The map also shows the inferred location of plate boundaries so that one can examine the relationship of the tectonic features to the plate boundaries. The map legend (below the main map) and the back side of the map (Figure 2) display several smaller maps, diagrams and text that help explain plate tectonics. The map is also available online in an interactive version (http://www.minerals.si.edu/tdpmap/) that allows one to select data to be displayed and zoom in to areas of interest for a close-up view (Figures 3, 4 and 5). One can also display close-ups of the diagrams in the legend and the back side of the map. The legend below the map includes a map of the plate boundaries (Figure 6) and related legend (Figure 7) and a schematic diagram illustrating plate tectonic features on the surface and at depth (Figure 8). Examples of explanatory material from the back of the map are shown in Figures 9, 10 and 11.

The plate puzzle activity requires cutting a copy of the map into pieces along the plate boundaries so that students can put it together like a jigsaw puzzle. The plate boundaries illustrated in the map in Figure 12 are suggested. An additional plate tectonic map that can be used to describe the plates is given in Figure 13. Detailed instructions and suggested questions to use with the plate puzzle activity are provided in the next sections.

## Preparation:

1. Obtain an extra copy of the map “This Dynamic Planet” (you should have one copy hanging on the wall during the teaching of your Earth science unit). The map (“This Dynamic Planet,” T. Simkin and others, 2006) is available from the U.S. Geological Survey, Information Services, Box 25286, Federal Center, Denver, CO 80225, or by phone at (888) ASK-USGS, $14 + $5 shipping, new product number 206335, and an interactive version of the map and additional downloadable information is available online at: http://www.minerals.si.edu/tdpmap/ (Figures 1 and 2). A companion document, “This Dynamic Earth: The Story of Plate Tectonics,” is also available from the USGS ($7 + $5 shipping) and on the Internet at: http://pubs.usgs.gov/gip/dynamic/dynamic.html.

2. With scissors, trim the white edges and the legend below the map from the map area. Save the legend. **Cut strips off the left and right sides of the map at 100°E longitude (some areas of the world are duplicated on both sides of the map).**

3. Cut the map into pieces along the plate boundaries (Figure 12). Don’t worry about the details of the boundaries, such as the many small transform faults along the mid-ocean ridges; just make a smooth cut approximately on the plate boundary. When you are finished, you should have the following plates (18 separate pieces of the puzzle):

   African Plate (The African plate is defined as two smaller plates, the Nubian and the Somalia plates, Figure 6, on the 2006 “This Dynamic Planet” map; because the plate boundaries between these smaller plates are not very distinct, we suggest cutting along the African plate boundaries as shown in Figure 12)
   Antarctic Plate (cut into two pieces, for convenience, along the Antarctic peninsula just south of the southern tip of South America, see Figure 12)
   Arabian Plate (includes Saudi Arabia)

Australian Plate (in two pieces because of the map edge at 100°E longitude)
Caribbean Plate
Cocos Plate (southwest of Middle America)
Eurasian Plate (in two pieces because of the map edge at 100°E longitude)
Indian Plate
Juan de Fuca Plate (west of Washington State)
Nazca Plate
North American Plate
Pacific Plate
Philippine Plate (west of Japan)
Scotia Plate (east of the southern tip of South America)
South American Plate

4. Find the arrows on most of the plates and the white numbers on many of the mid-ocean ridges that indicate the directions and velocities of plate motion. Write the velocity of the plate motion next to the arrows using a black felt pen so that the numbers are more visible. The velocities are given in mm/yr. If you are more familiar with plate motions given in cm/yr, you can write the velocities in cm/yr by "moving the decimal point." For example, for the Arabian Plate, the velocity is 26 mm/yr or 2.6 cm/yr.

5. Laminate the 18 plate pieces and cut off excess laminating material. Also, laminate the legend – the strip cut off the bottom of the map – and save for reference.

6. For the discussion of the completed map in the procedure described below, it is convenient to have the students stand around the map and to use a laser pointer (or a meter stick or other pointer) to point out specific plates, plate boundaries, velocity vectors, or other features.

## Procedure:

1. Give one piece of the puzzle (a plate or piece of a plate) to each student or pair of students. Tell them that they will be responsible for their plate – placing it in the right position to form the world map and determining the plate's motion with respect to surrounding plates. Have the students assemble the map (like putting together a jigsaw puzzle) on the floor or on a large table. An alternative procedure that works well and stimulates thinking and discovery is the following. Give a piece of the puzzle to each student (or team of students). Tell them that these are pieces of a puzzle and that it comes from a world map. Their instructions are to put the puzzle together without talking. They can point to communicate, but the puzzle is to be put together in silence. After the puzzle is completed, the students can be asked about what they think the pieces are and why. Examples of pieces of the puzzle are shown in Figure 14.

2. Note the arrows and velocities (in mm/yr) that indicate the motion of the plates. Some plates do not include arrows. Find the highest and lowest plate velocities. Comment on the speed of the plates; for example, 35 mm/yr or 3.5 cm/yr is equivalent to 35 km/million years. So, the plates are not moving very fast – about the speed that a person's fingernails grow. What areas of the Earth are associated with the largest plate velocities?

3. Have each student (or pair of students) determine how their plate moves with respect to the surrounding plates. Students should discuss with each other and agree with each other or note

their differing interpretations. After a brief time for discussion, ask a few students to explain what their plate’s motion is and how it is interacting with adjacent plates.

4. Find locations on the map that are associated with (Descriptions and illustrations of these plate boundaries are included on the back side of the 2006 “This Dynamic Planet” map and on the plate tectonic schematic diagram in the map legend, Figure 8. Plate boundaries can be illustrated using foam models; http://web.ics.purdue.edu/~braile/edumod/foammod/foammod.htm):

    a. *convergence*; for example: the South American plate and the Nazca plate, the western Pacific, India and Asia. Note that convergence occurs when two plates are moving in almost opposite directions (for example, South America and Nazca), or when two plates are moving in nearly the same direction but the plate that is “following” is moving faster (for example, the Pacific plate and the Philippine plate). These two types of motions that result in convergence could be modeled with two parallel lines of students representing the edges of two plates. In the first type of convergence, the students face each other and walk slowly forward until collision. In the second type of convergence, the students face the same direction and walk slowly forward, with the second line of students walking faster until colliding with the first line.

    b. *divergence*; for example: the Mid Atlantic Ridge (note Iceland on two sides of the ridge) or the East Pacific Rise.

    c. *transform* [this one is more difficult]; for example: the San Andreas fault in California, New Zealand (the Alpine fault), and the transform faults along the southern boundary of the Nazca plate.

Sometimes the plate motions and interactions are more complicated. For example, for the North American and Pacific plates, the Pacific plate is moving approximately northwest while the North American plate is moving approximately southwest. The combination of these motions and the irregularly shaped plate boundaries results in convergence along the Aleutian Islands, divergence at the Juan de Fuca ridge and predominately transform motions along the San Andreas fault and within the Gulf of California. Moving these two plates a small amount in the direction of the arrows (note that the Pacific plate moves faster) will illustrate the different interactions along these boundaries (collision in the Aleutians, “opening” of the ridge area at the Juan de Fuca plate, and transform or strike-slip faulting along the San Andreas fault system).

For each of these examples, move the appropriate plates a small amount in the direction of the arrows to see what the plate interactions will be. Question about or comment on the features that are associated with the plate boundaries – earthquakes, mountain ranges, deep sea trenches, volcanoes. For this and other parts of the activity, it is convenient for the class to stand around the map and to use a laser pointer or a meter stick to point our individual plates or plate boundaries.

To better view the correlation of earthquake and volcanic activity along plate boundaries and to display the plate names and distribution, Figures 15 and 16 can be made into color or black and white transparencies. The transparency from Figure 16 can be overlain on the transparency from Figure 15 to show that the pattern of earthquake epicenters delineates the plates.

Examples of the plate boundaries and further information and illustrations of plate tectonics and continental drift can be found in the USGS publication "This Dynamic Earth" and in the video by T.A. Atwater (1988). These materials provide excellent color illustrations to supplement the Plate Puzzle activity.

5. Questions to generate discussion:

   a. Explain why the Australian continent has few earthquakes. However, note that there are very active earthquake zones near Australia.

   b. What is the cause of the Himalayan Mountains? Why is this zone of convergence unique on the Earth today (there are several examples of past continent-continent collisions)? You can explore the collision of the Indian plate with Asia using the plate tectonic flip book.

   c. Compare the earthquake activity, volcanic activity and topography of the west and east coasts of South America. Why are these continental margins so different?

   d. What happens when the plates move apart at the mid-ocean ridges? Note Iceland, an area of active volcanism, that is located along the Mid-Atlantic ridge. To further explore the mid-ocean ridges and other marine areas, you may wish to view a color map of ocean floor bathymetry at: http://www.ngdc.noaa.gov/mgg/announcements/images_predict.HTML, or a color map of the ages of the ocean crust at: http://gdcinfo.agg.emr.ca/app/app3_e.html.

   e. What do you think is happening in east Africa, an area of volcanic and earthquake activity and distinctive topography?

   f. Can you find areas representing different stages of continental separation (continental rifting, initial ocean crust formation, full ocean basins separating two continental areas)?

   g. What direction do you think that the Scotia plate is moving? How do you know?

   h. What direction do you think the Juan de Fuca plate is moving? How do you know?

   i. Note the Hawaiian Islands in the middle of the Pacific plate. Although the islands are not near a plate boundary, they are seismically and volcanically very active. The ages of the volcanic rocks in the Hawaiian Islands, the chain of seamounts to the west-northwest, and the Emperor seamounts located further west and north, all increase toward the west and north. These observations indicate that the Hawaiian Island chain is the track of a mantle hotspot, currently located beneath the southeastern part of the Island of Hawaii (the “Big Island”). You can illustrate the formation of the Hawaiian Islands by movement of the Pacific lithospheric plate over the mantle hotspot using a small flashlight (a pen light works well) or a laser pointer held directly to the bottom of the Pacific plate puzzle piece (the light will show through the paper). The volcanic islands and seamounts at the northern end of the Emperor seamounts, near the Aleutian trench, are over 65 million years old. At the “bend” in the seamount chains that connects the Emperor and Hawaiian chains, the volcanic rocks are about 42 million years old. At Kauai, the westernmost of the main Hawaiian Islands, the volcanic rocks are about 5 million years old. The Big Island (Hawaii) is less than 1 million years old and eruptions are occurring today. To model the hotspot, place the flashlight or laser pointer under the north end of the Emperor seamount chain and cause the plate to move northwest and then west-northwest (at the "bend") until the flashlight is at the current position of the hotspot under Hawaii. What direction has the plate been moving (with respect to the mantle hotspot)? Where will the future volcanic chain of islands and seamounts be? How fast is the plate moving at Hawaii? Does the velocity measurement (near the arrow) agree with the velocity estimated from the volcanic ages (divide the distance in km from Hawaii to the "bend" by 42 million years, then convert to mm/yr or cm/yr)?

j. The "This Dynamic Planet" map is a Mercator projection so the geographic features (plates, continents, etc.) are somewhat distorted, particularly in the high-latitude areas of the world. To examine this distortion and obtain a better visual image of what the plates look like, compare the outlines of the continents on the Mercator projection with the outlines on a globe.

**Connections to National Science Education Standards (National Research Council, 1996, http://www.nap.edu/readingroom/books/nses/html/):** *Teaching Standards:* inquiry-based (A,B); opportunity for assessment (C). *Professional Development Standards:* opportunity for learning new Earth science content (A,C); suggestions for effective teaching strategies (B). *Assessment Standards:* authentic assessment (C). *Content Standards: Science as Inquiry* – practice inquiry and fundamental science skills (grades 5-8 and 9-12, A); *Physical Science* – properties of matter (grades K-4, 5-8, B), structure and properties of matter (grades 9-12, B); *Earth and Space Science* – properties of Earth materials (grades K-4, D), structure of the Earth system (grades 5-8, D), geochemical cycles, origin and evolution of the Earth system (grades 9-12, D).

**Acknowledgements:** We are grateful to John Lahr who first suggested to us using the "This Dynamic Planet" map for the Plate Puzzle. That clever suggestion resulted in the development of this activity that has become a favorite of many educators interested in teaching about plate tectonics, plate motions and the relationship of plate tectonics to earthquakes and volcanic activity.

## References:

Atwater, Tanya, Continental Drift and Plate Tectonics Video, 20 minute videotape, 1988, (obtain from Rick Johnson, Instructional Consultation, UC-Santa Barbara, Santa Barbara, CA 93106, $15, make check payable to "Regents of the University of California.")

National Science Teachers Association, *Tremor Troop – Earthquakes: A teacher's package for K-6 grades*, NSTA Publications, Washington, DC, 169 pp., 1990. (This book contains a reasonably complete curriculum for teaching earthquakes and related Earth science topics; FEMA 159, for free copy, write on school letterhead to: FEMA, PO Box 70274, Wash., DC 20024; FEMA 159, Revised Edition, August, 2000, available from FEMA Publication Warehouse, 1-800-480-2520).

Simkin, Tom, Robert I. Tilling, Peter R. Vogt, Stephen H. Kirby, Paul Kimberly, and David B. Stewart, *This Dynamic Planet – World Map of Volcanoes, Earthquakes, Impact Craters, and Plate Tectonics*, Smithsonian Institution and U.S. Geological Survey, 2006.

U.S. Geological Survey, *This Dynamic Earth: The Story of Plate Tectonics*, available from: U.S. Geol. Survey, Map Distribution, Federal Center, PO Box 25286, Denver, CO 80225, $7 + $5 shipping, (1-888 ASK-USGS).

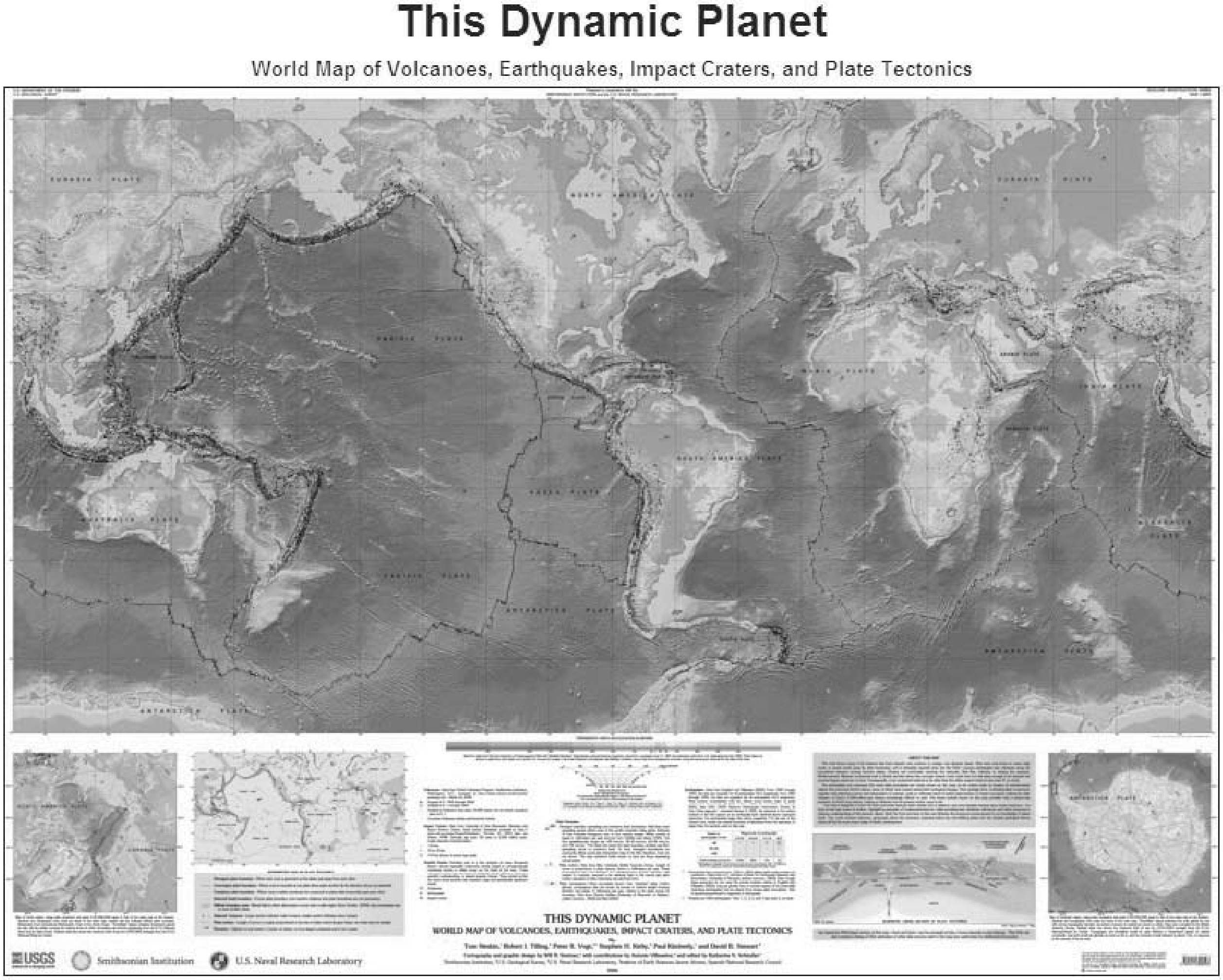


*Figure 1. Reduced size image of 2006 "This Dynamic Planet" map (map size is ~150 x 100 cm, including legend, 1:30,000,000 scale at the equator), compiled by Tom Simkin, Robert I. Tilling, Peter R. Vogt, Stephen H. Kirby, Paul Kimberly, and David B. Stewart. Cartography by Will R. Stettner. From the website: http://www.minerals.si.edu/tdpmap/.*

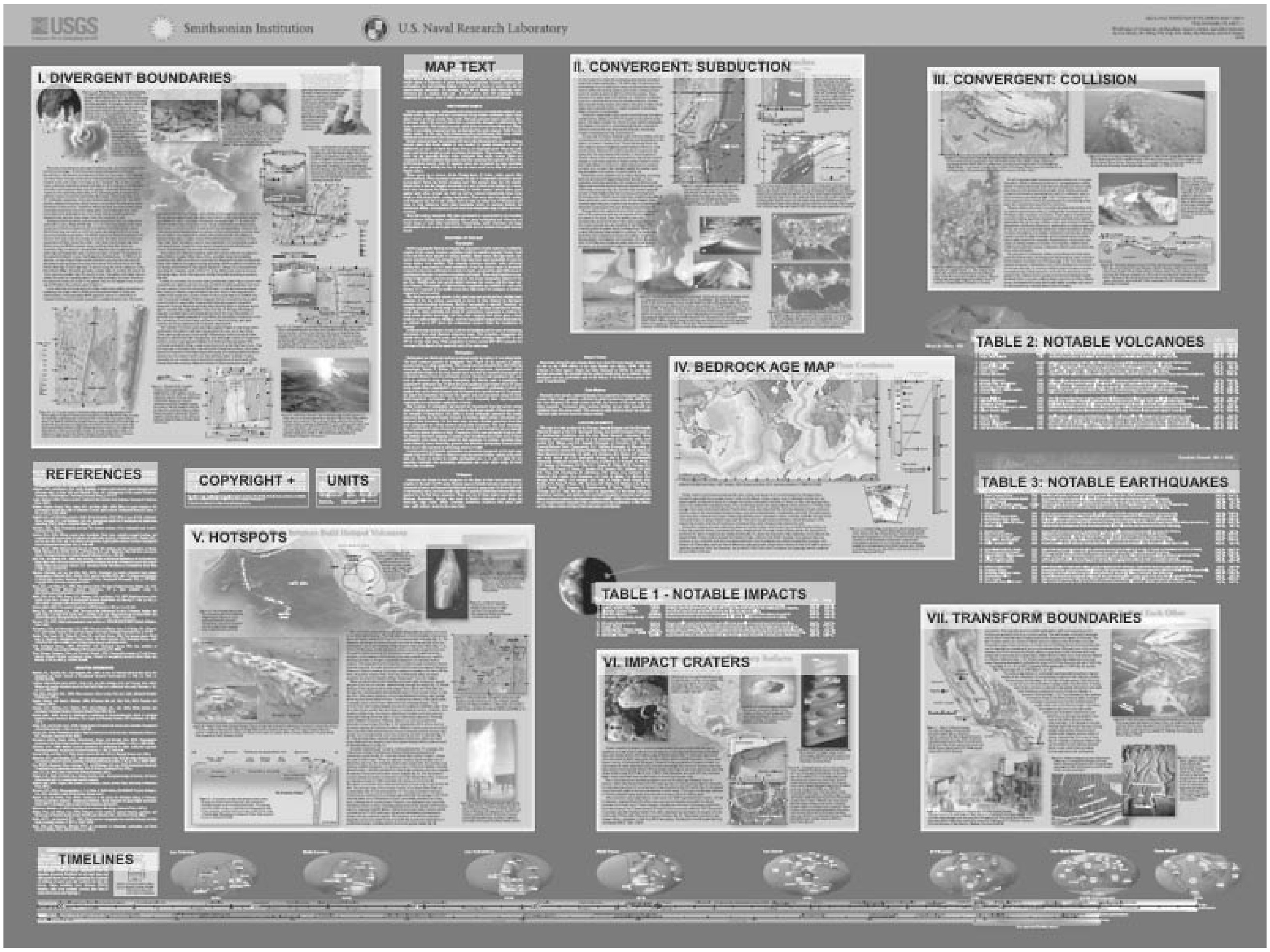
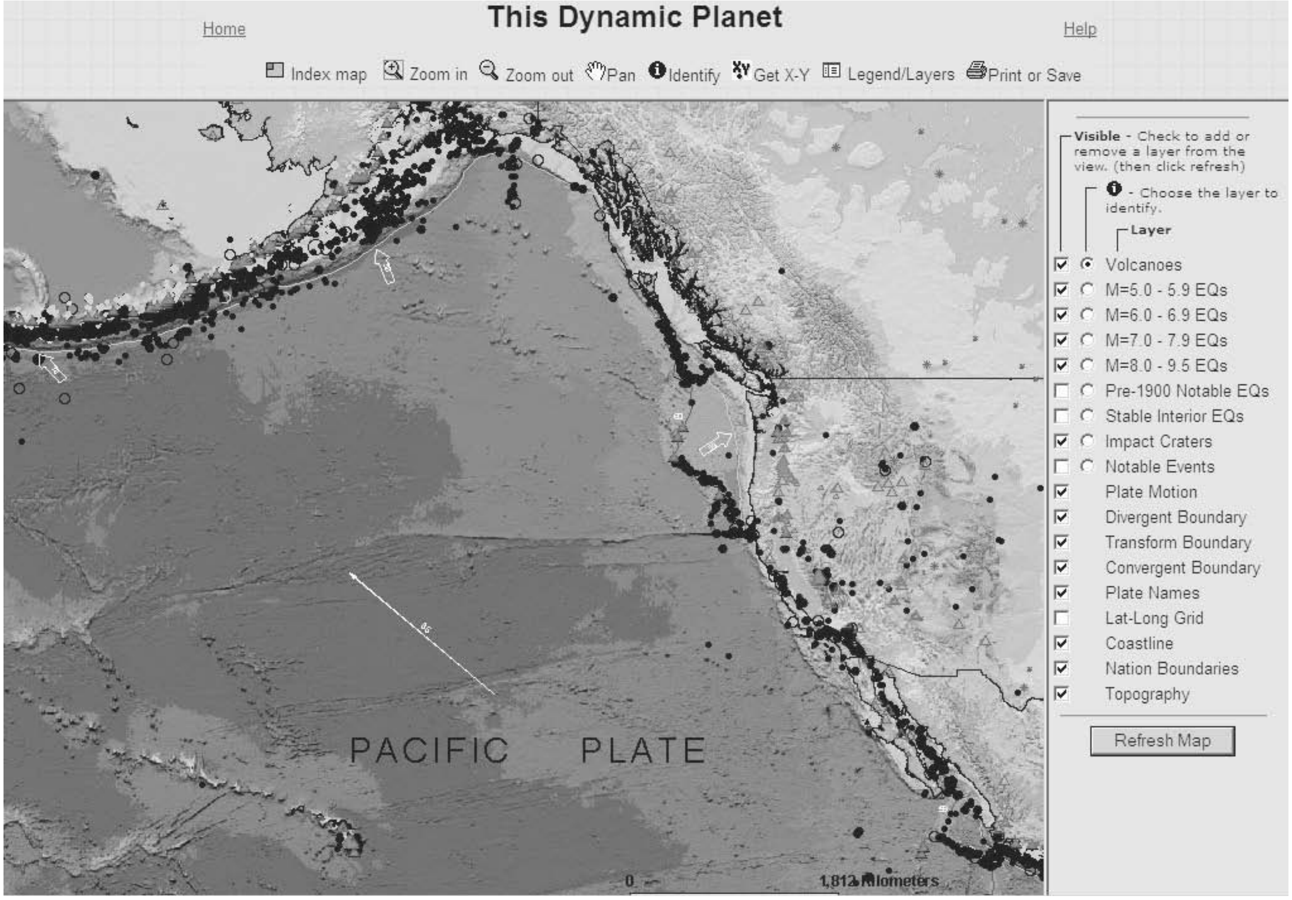


*Figure 2. Reduced size image of back side of the 2006 "This Dynamic Planet" map. Information on plate boundaries, hotspots, notable volcanoes, earthquakes and impacts, and references is provided. This information can be viewed interactively to zoom in on the features at the website (http://www.minerals.si.edu/tdpmap/).*



**Visible** - Check to add or remove a layer from the view. (then click refresh)

- Choose the layer to identify.

**Layer**

☑ ● Volcanoes
☑ ○ M=5.0 - 5.9 EQs
☑ ○ M=6.0 - 6.9 EQs
☑ ○ M=7.0 - 7.9 EQs
☑ ○ M=8.0 - 9.5 EQs
☐ ○ Pre-1900 Notable EQs
☐ ○ Stable Interior EQs
☑ ○ Impact Craters
☐ ○ Notable Events
☑ Plate Motion
☑ Divergent Boundary
☑ Transform Boundary
☑ Convergent Boundary
☑ Plate Names
☐ Lat-Long Grid
☑ Coastline
☑ Nation Boundaries
☑ Topography

*Figure 3. Close-up view of the northeast Pacific plate region and northwestern North America from the interactive "This Dynamic Planet" website (http://www.minerals.si.edu/tdpmap/). Zoom tool and other options are located above the map. Lists on the right allow selection of data and features to display.*

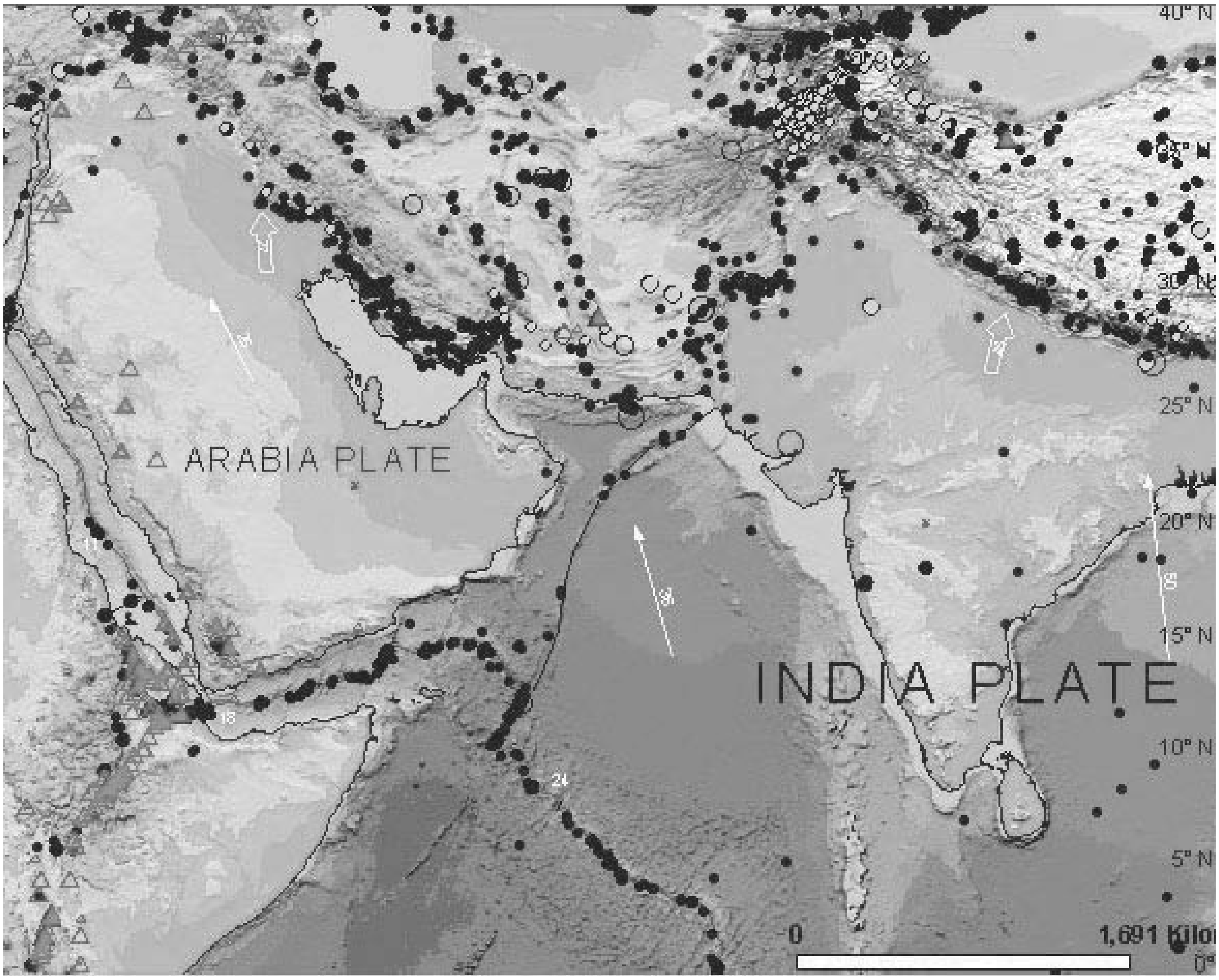


*Figure 4. Example (Indian Plate and surrounding area) of the earthquake, topography, volcano, plate motion and geographic data shown on the "This Dynamic Planet" map (from the interactive website with all earthquakes selected, http://www.minerals.si.edu/tdpmap/). Dots are earthquake epicenters. Red triangles are volcanoes. Arrows indicate direction of plate motion. Numbers next to the arrows show plate velocity in mm/yr.*

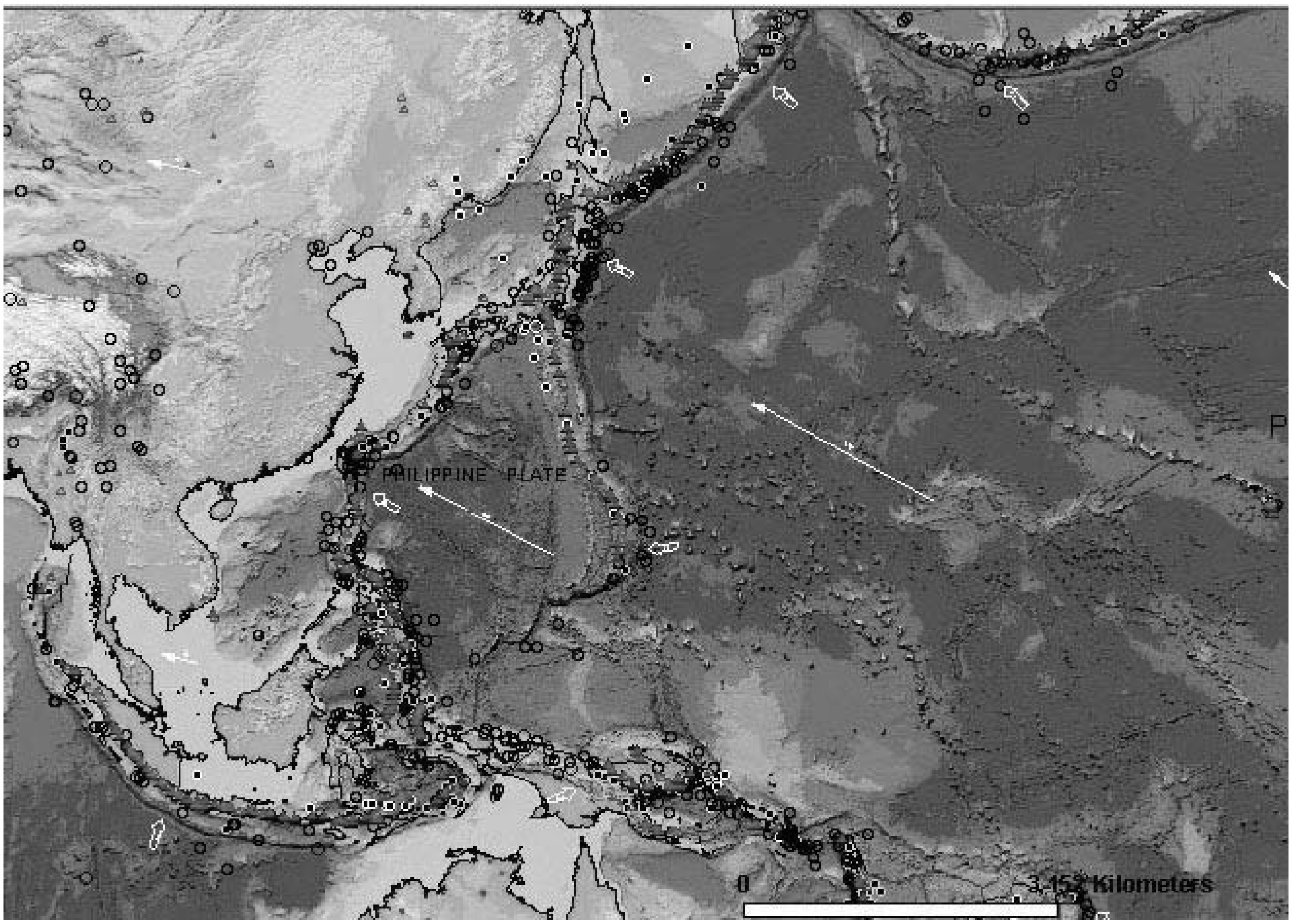


*Figure 5. Example (Western Pacific area) of the earthquake, topography, volcano, plate motion and geographic data shown on the "This Dynamic Planet" map (from the interactive website with all earthquakes selected, http://www.minerals.si.edu/tdpmap/). Dots are earthquake epicenters. Red triangles are volcanoes. Arrows indicate direction of plate motion. Numbers next to the arrows show plate velocity in mm/yr.*

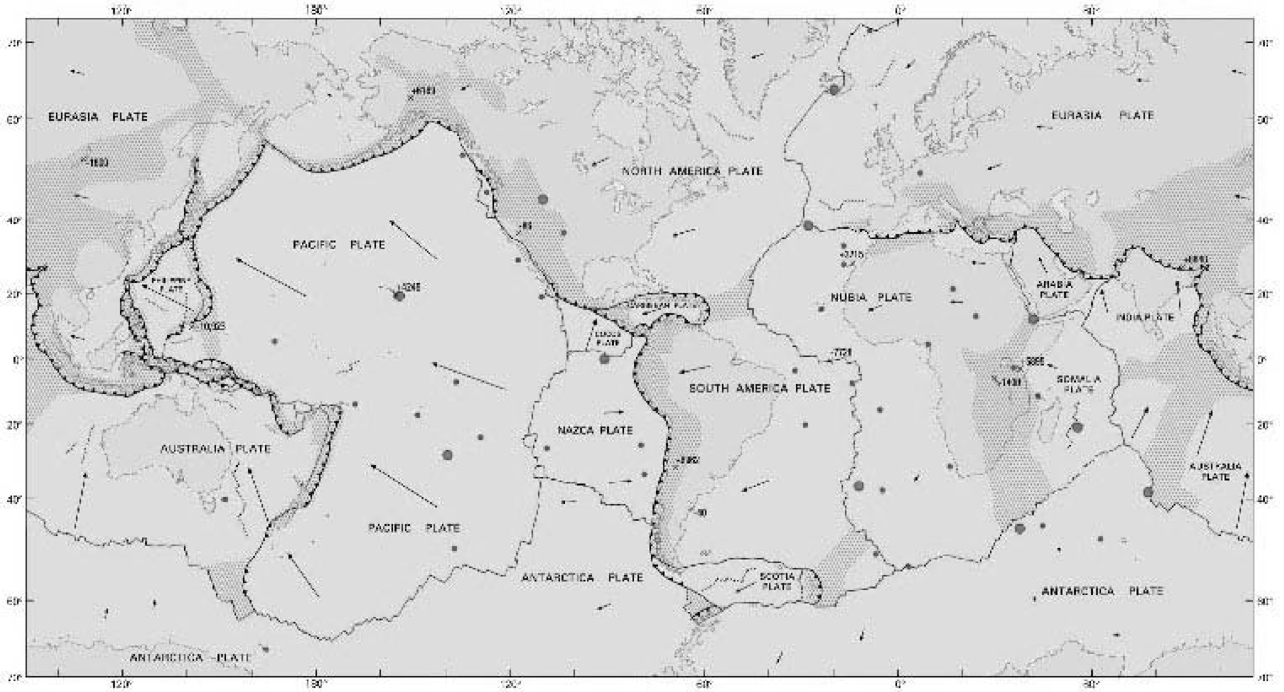
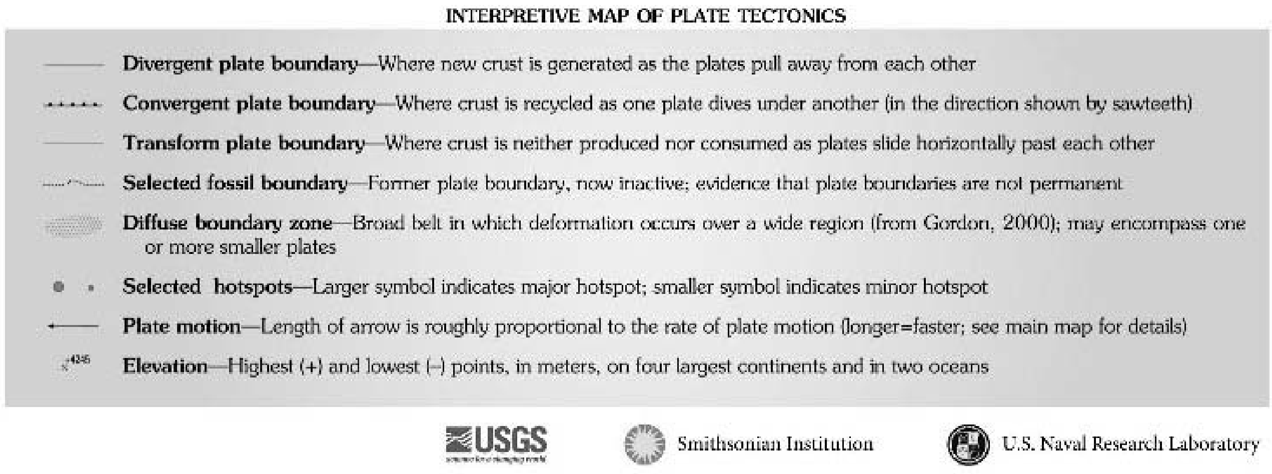


*Figure 6. Plate boundaries from the 2006 "This Dynamic Planet" map.*



INTERPRETIVE MAP OF PLATE TECTONICS

**Divergent plate boundary**—Where new crust is generated as the plates pull away from each other

**Convergent plate boundary**—Where crust is recycled as one plate dives under another (in the direction shown by sawteeth)

**Transform plate boundary**—Where crust is neither produced nor consumed as plates slide horizontally past each other

**Selected fossil boundary**—Former plate boundary, now inactive; evidence that plate boundaries are not permanent

▨ **Diffuse boundary zone**—Broad belt in which deformation occurs over a wide region (from Gordon, 2000); may encompass one or more smaller plates

● • **Selected hotspots**—Larger symbol indicates major hotspot; smaller symbol indicates minor hotspot

← **Plate motion**—Length of arrow is roughly proportional to the rate of plate motion (longer=faster; see main map for details)

×4245 **Elevation**—Highest (+) and lowest (–) points, in meters, on four largest continents and in two oceans

USGS Smithsonian Institution U.S. Naval Research Laboratory

*Figure 7. Legend for plate boundaries (Figure 6).*

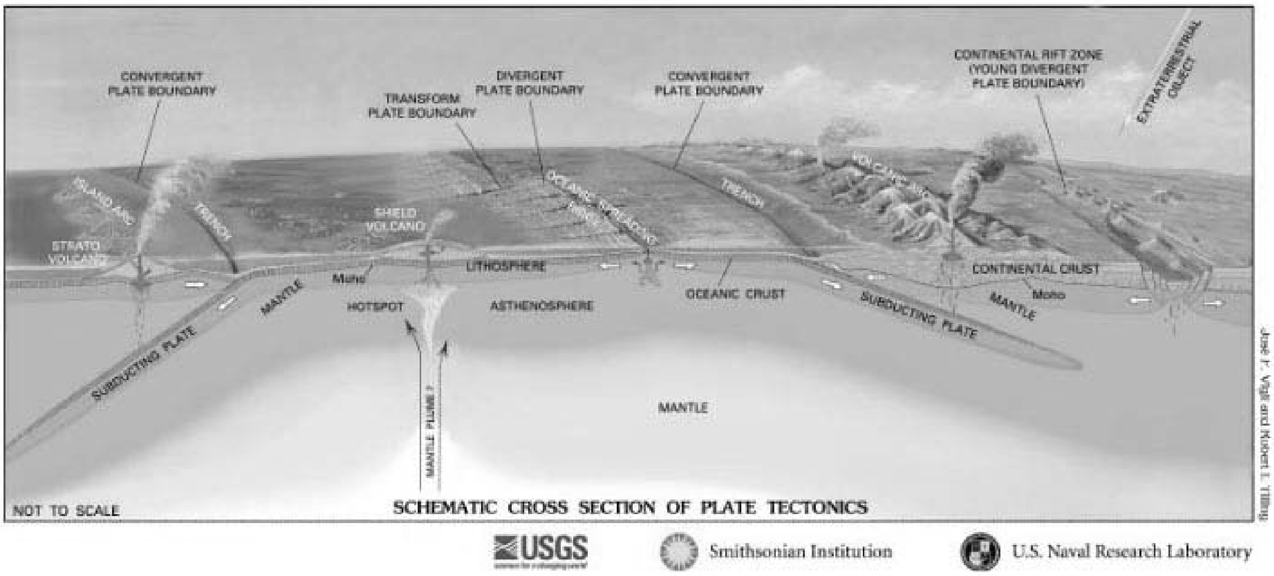


*Figure 8. Schematic diagram illustrating plate tectonics (from the 2006 "This Dynamic Planet" map).*

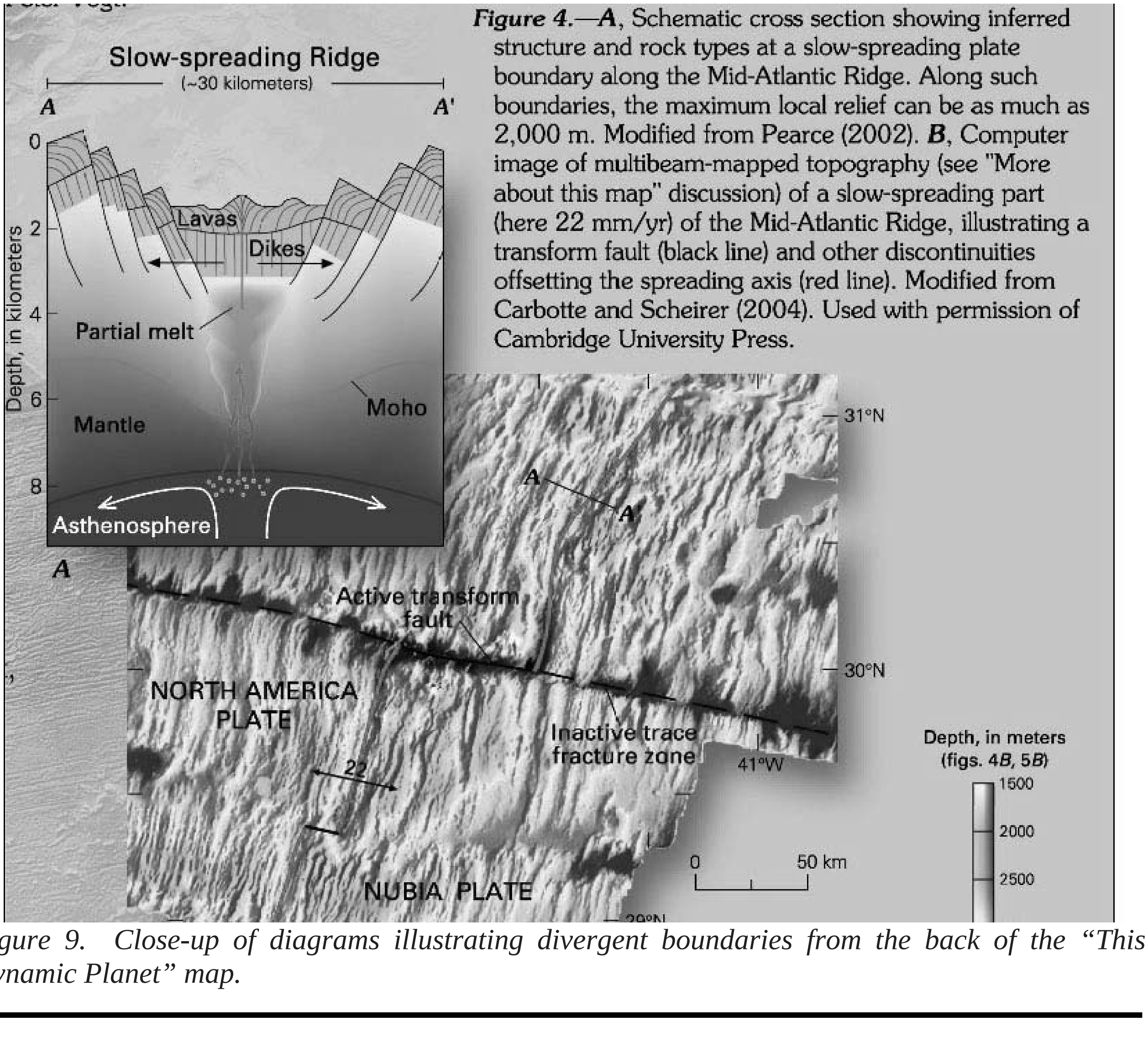


***Figure 4.*—*A***, Schematic cross section showing inferred structure and rock types at a slow-spreading plate boundary along the Mid-Atlantic Ridge. Along such boundaries, the maximum local relief can be as much as 2,000 m. Modified from Pearce (2002). ***B***, Computer image of multibeam-mapped topography (see "More about this map" discussion) of a slow-spreading part (here 22 mm/yr) of the Mid-Atlantic Ridge, illustrating a transform fault (black line) and other discontinuities offsetting the spreading axis (red line). Modified from Carbotte and Scheirer (2004). Used with permission of Cambridge University Press.

*Figure 9. Close-up of diagrams illustrating divergent boundaries from the back of the "This Dynamic Planet" map.*

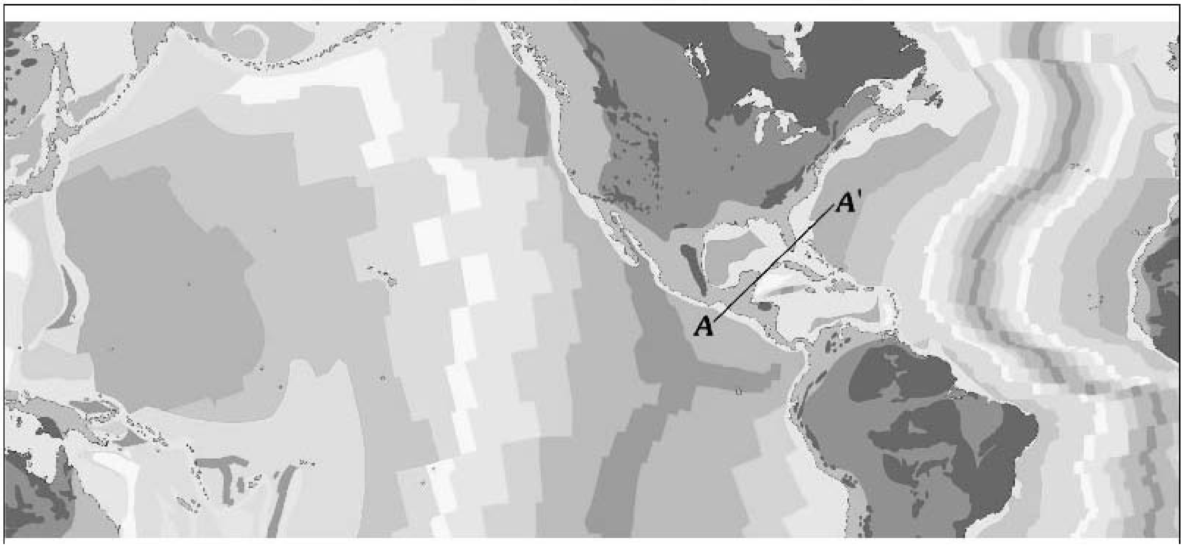
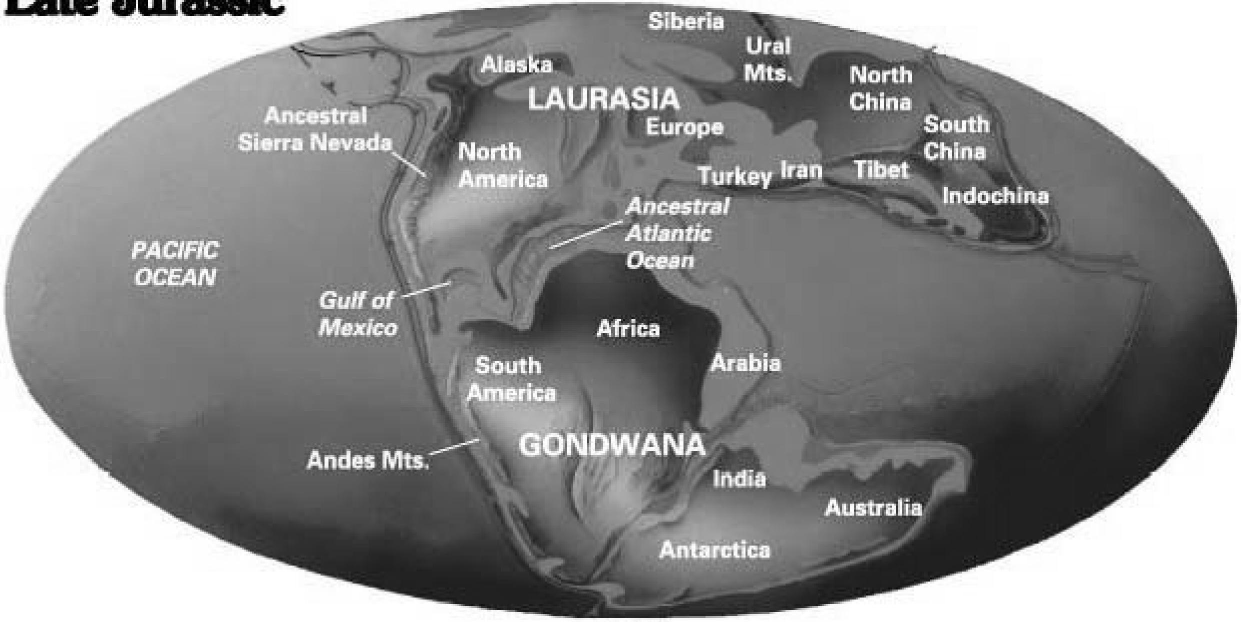


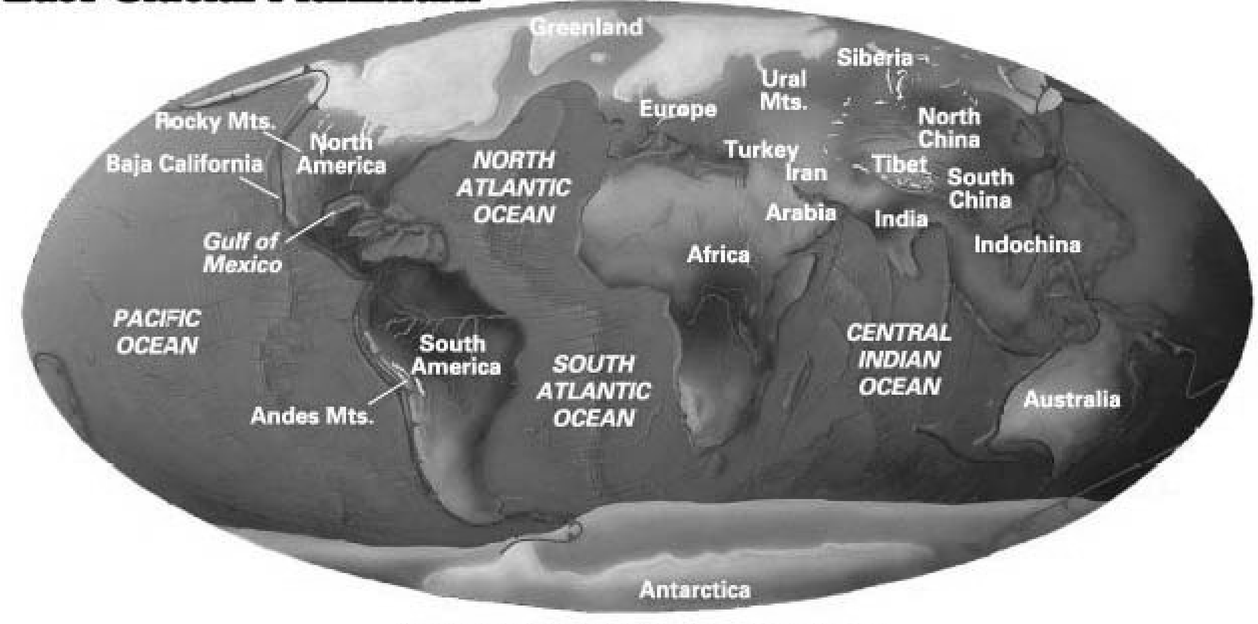
Figure 10. Crustal age map from the back of the "This Dynamic Planet" map.

**Late Jurassic**



**152 Ma**

**Last Glacial Maximum**



**0.018 Ma (18,000 years ago)**

*Figure 11. Plate reconstruction maps (152 Ma, upper and 0.018Ma, lower) from the back of the "This Dynamic Planet" map.*

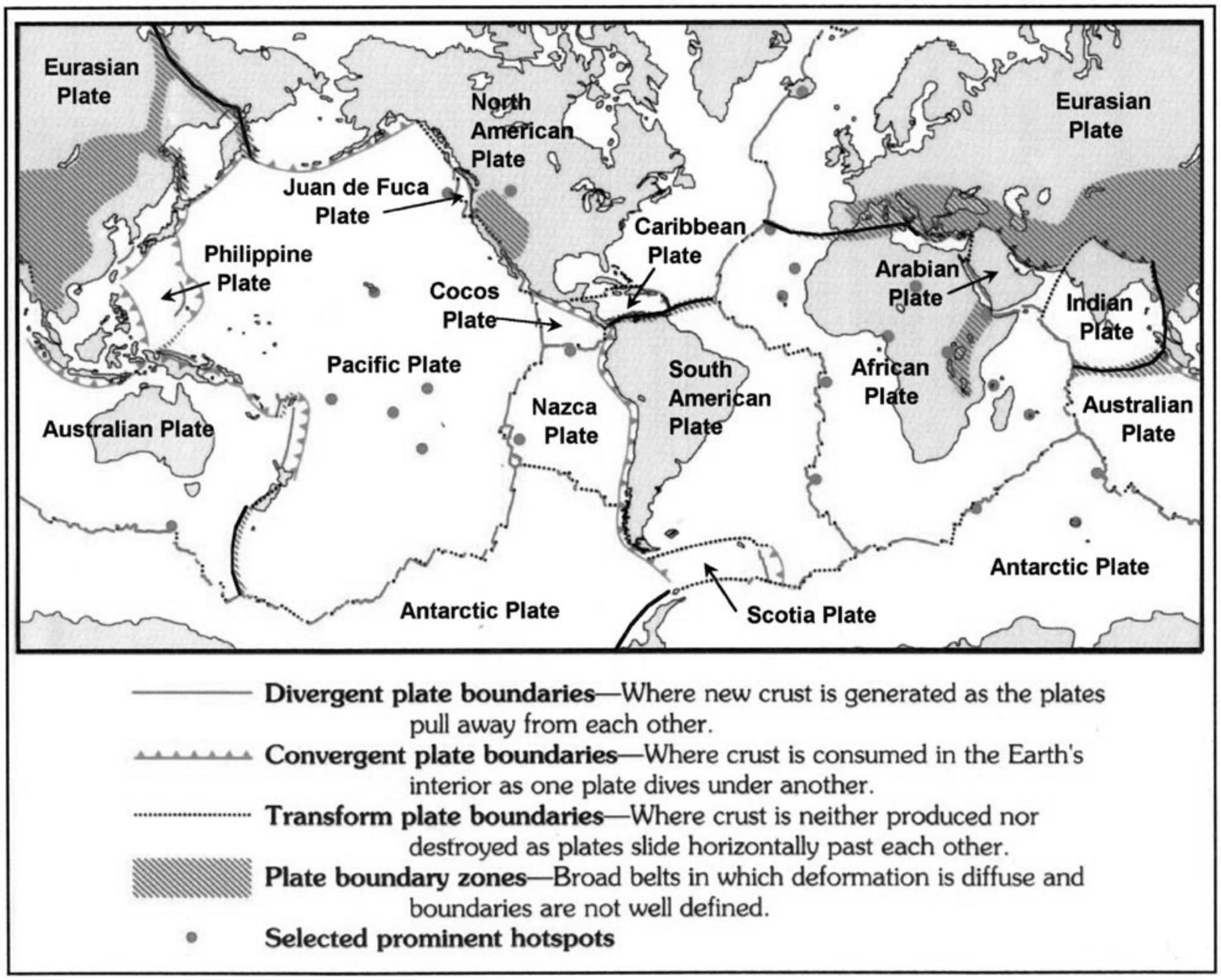


*Figure 12. Map of plate boundaries and plate names (modified from the 1996 legend of the "This Dynamic Planet" map). For the plate puzzle activity, cut along boundaries (divergent, convergent and transform boundaries) and along the "plate boundary zones" (diagonal shaded areas) that are marked with a bold line. Cut the Antarctic plate along the bold line to the southwest of the Scotia plate. The result will be 18 plates or pieces of plates. Because the map is a Mercator projection, the polar regions are not shown and the high-latitude regions are distorted.*

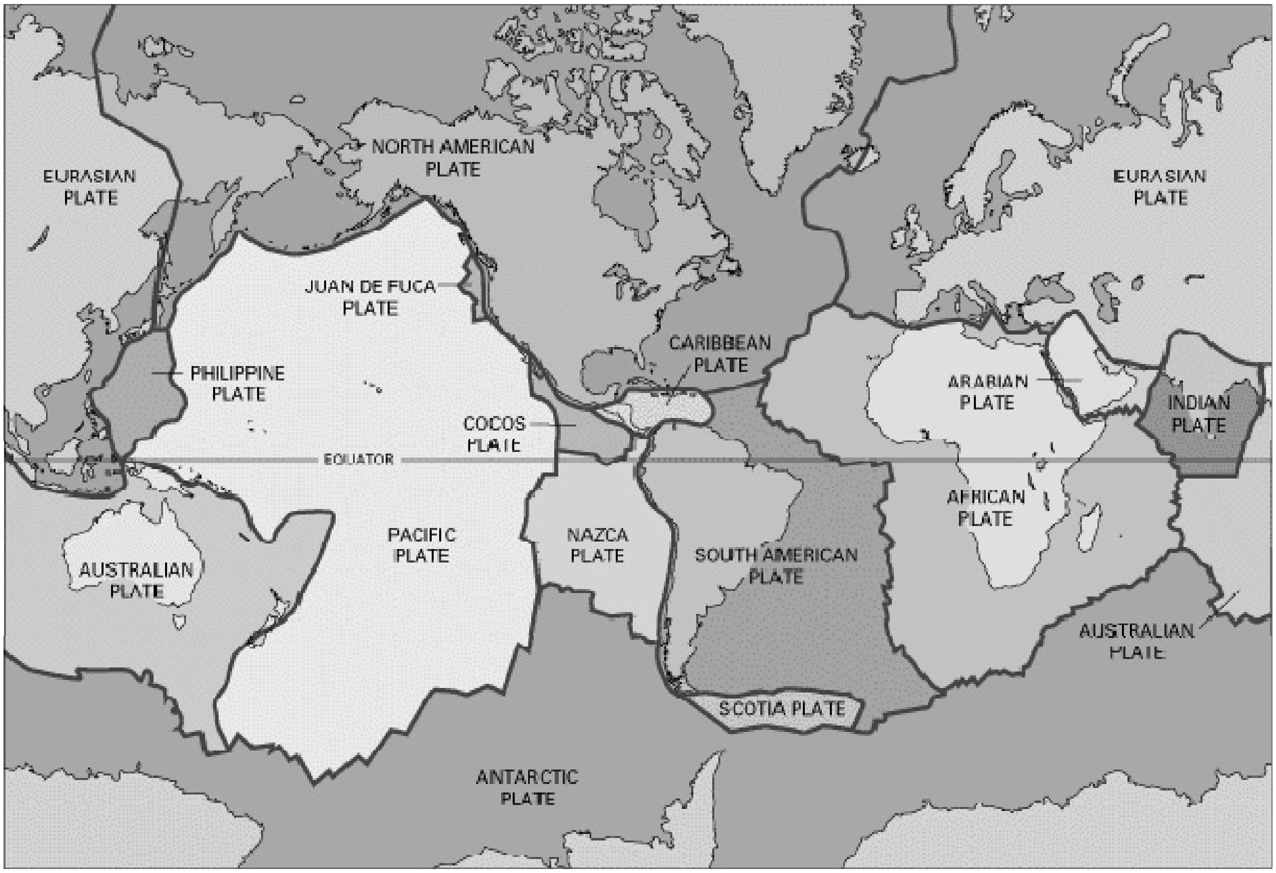


*Figure 13. Color map of the Earth's tectonic plates (http://geology.er.usgs.gov/eastern/plates.html).*

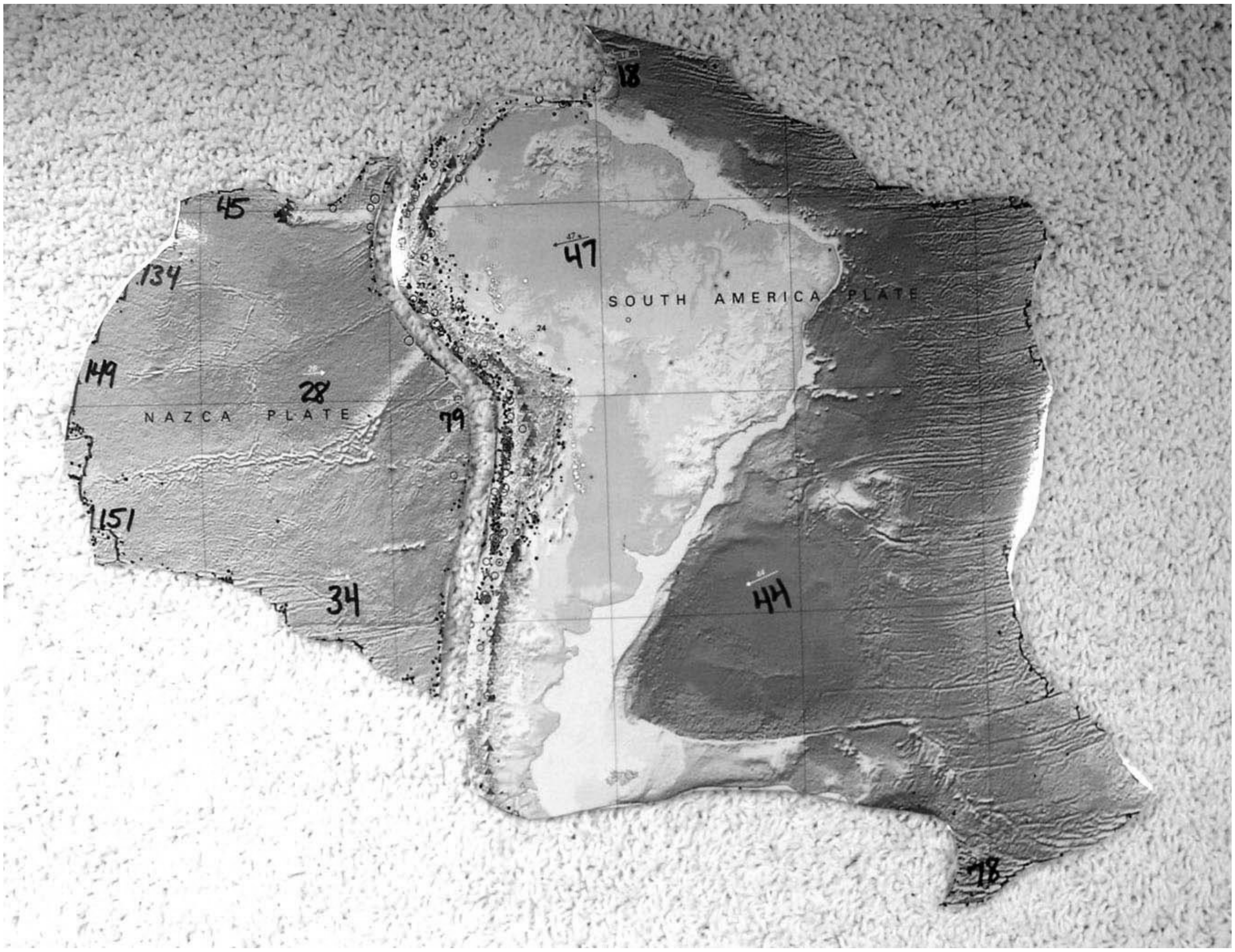


*Figure 14. Two pieces of the plate puzzle. Numbers are interpreted plate velocities in mm/yr. Arrows show directions of plate motion. Students should be able to describe the motion of their piece of the puzzle relative to adjacent pieces (plates or parts of plates), identify what type of plate boundary is involved (divergent, convergent or transform) and describe the features (trenches, earthquakes and volcanoes, mountain rages, etc.) that are associated with each boundary represented by their plate.*

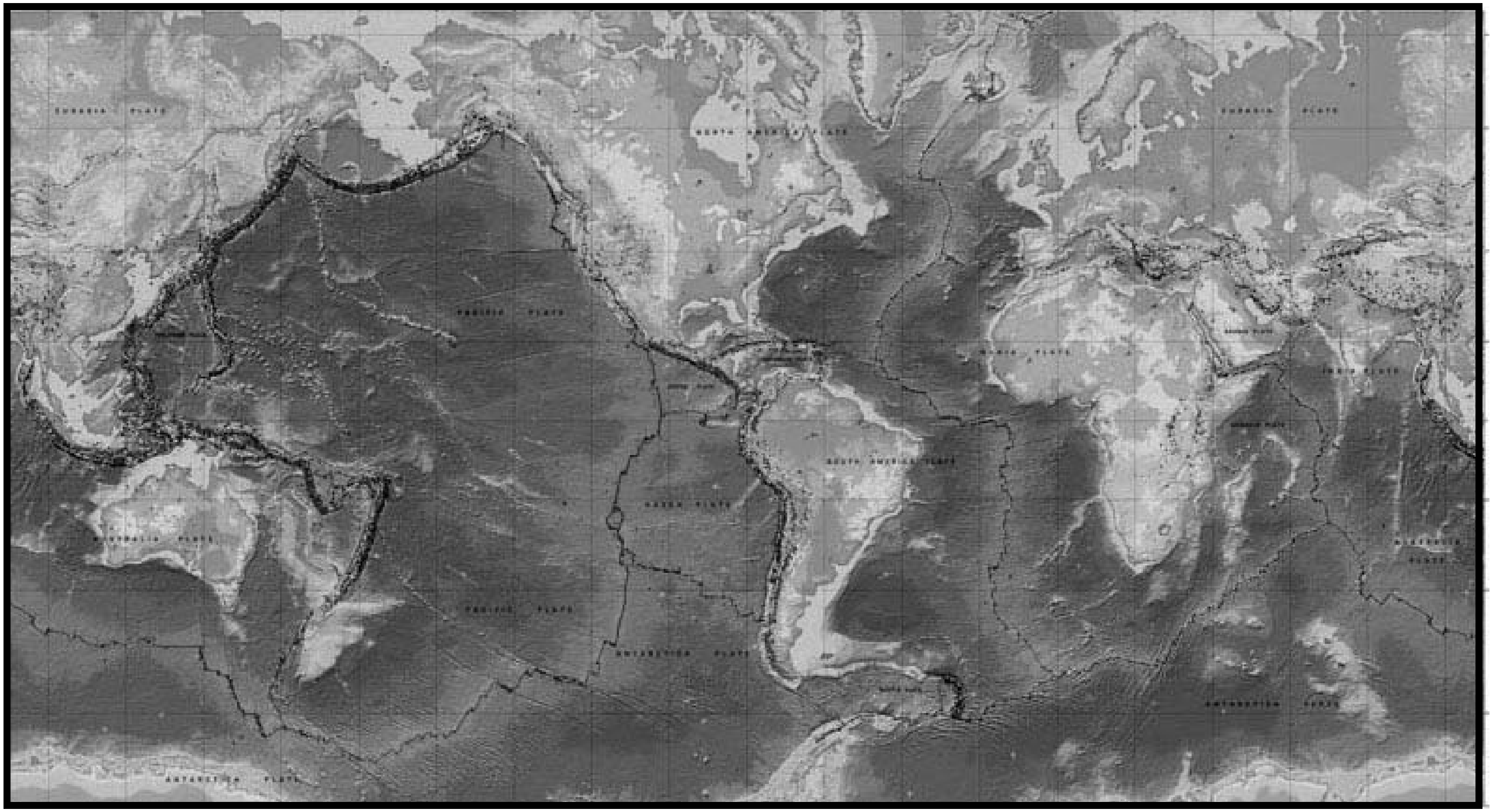


**Plate Puzzle** L.W. and S.J.Braile, **web.ics.purdue.edu/~braile**
This Dynamic Planet map from Simkin and others, 2006,
**http://www.minerals.si.edu/tdpmap/**
*Figure 15. This Dynamic Planet map (Simkin et al., 2006) for transparency (base map for Figure 16 overlay).*

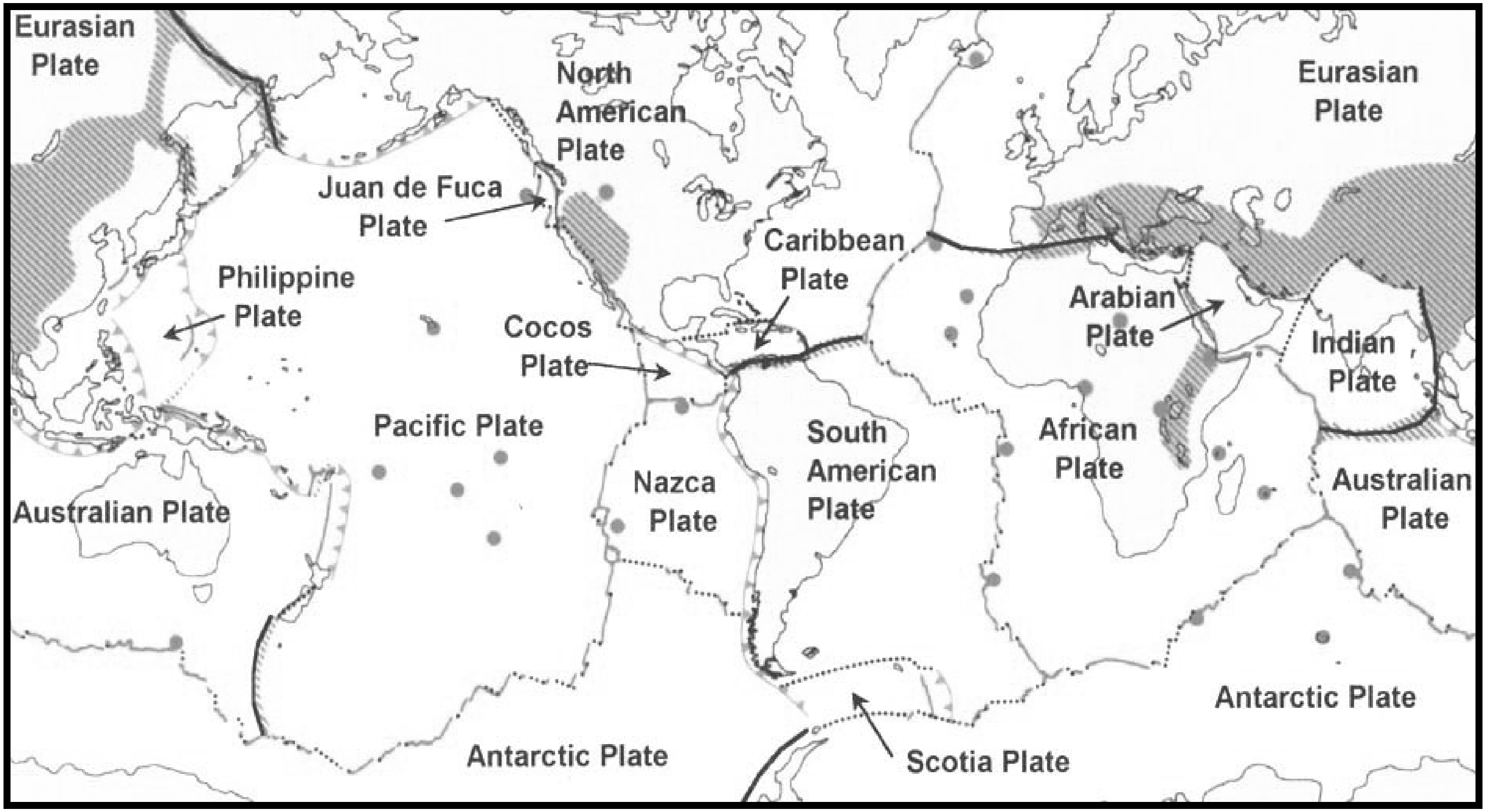


**Plate Puzzle** L.W. and S.J.Braile, **web.ics.purdue.edu/~braile**
This Dynamic Planet map from Simkin and others, 2006,
**http://www.minerals.si.edu/tdpmap/**

*Figure 16. Map of plates, boundaries and names for transparency (overlay on Figure 15).*

# Exploring Rates of Earthquake Occurrence

This activity can also be conducted using the online tool, the IRIS Earthquake Browser (IEB) http://www.iris.edu/ieb/

## Description

The activity allows the students to select their own region of interest and to interrogate the earthquake catalog to obtain quantitative data on the rate of occurrence of earthquakes of various magnitudes within their chosen region.

### Audience

Grades 5 to 12

### Time

90 Minutes

### Objective

1. Describe where earthquakes generally occur
2. Describe the frequency of occurence for various sized earthquakes
3. Describe how regional tectonics affect distribution and frequency of earthquakes
4. Describe strengths and weaknesses of using historic Earthquake occurrence to "predict" future occurrences

### Supporting Resources

Activity Description Barker, J. (2005) Student-centered experiments with earthquake occurrence data. The Earth Scientist 21(2), 21-23. (pdf download)

Seismic/Eruption Software (PC Only)

Graph for Data (G-R Plot)

Supporting Slide Show (Direct Download 2MB)

An example analysis of California and Nevada by Larry Braile

IRIS INCORPORATED RESEARCH INSTITUTIONS FOR SEISMOLOGY

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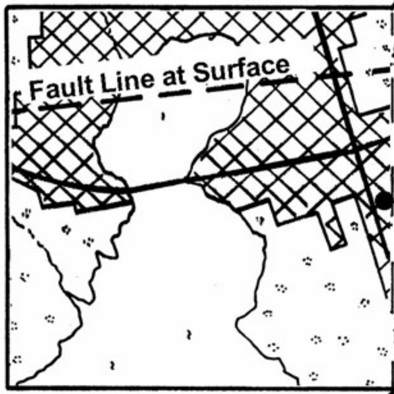
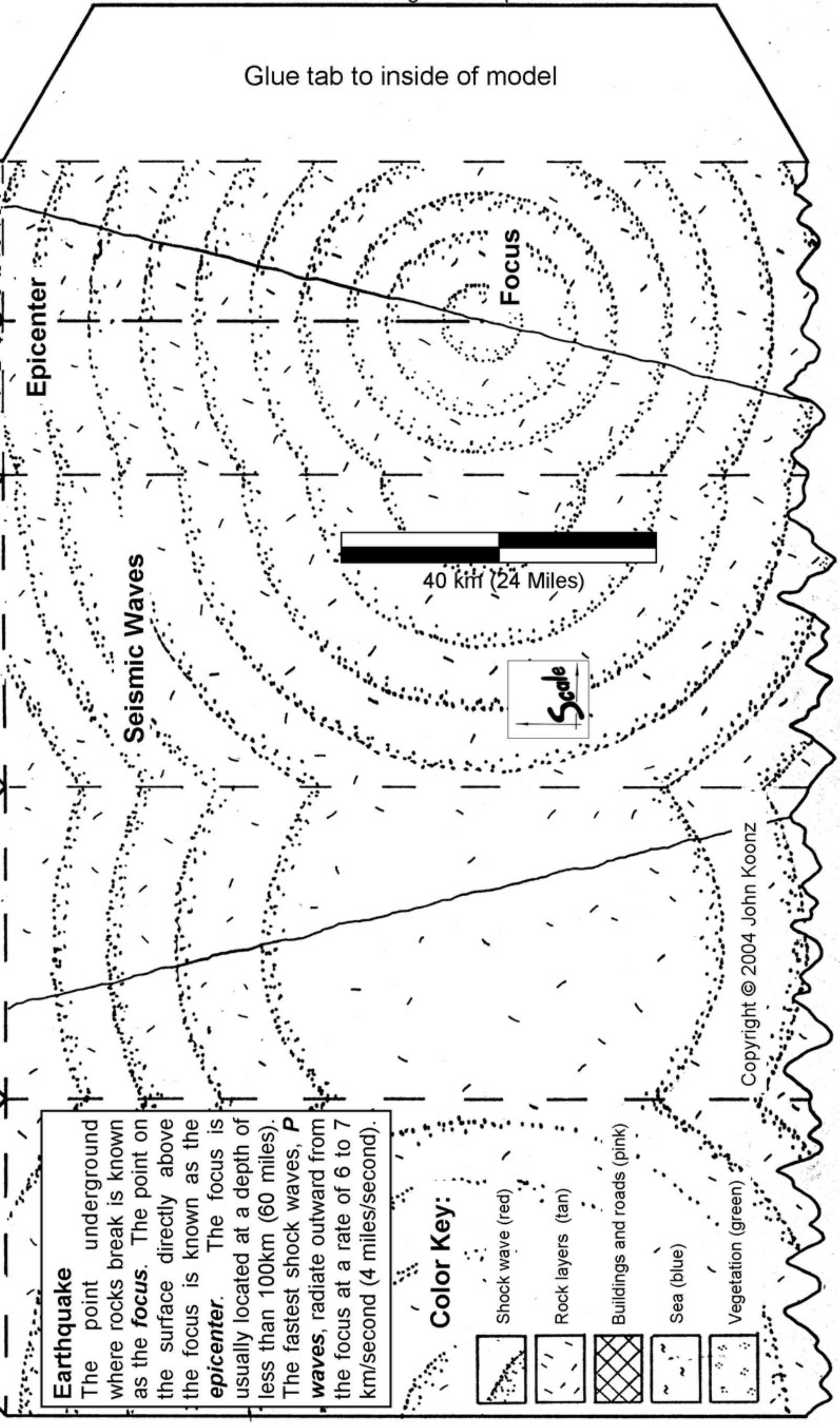
# Earthquake

Instructions:

1. For best results, copy this pattern onto cardstock.
2. Color the model before cutting out the parts.
3. Cut along solid lines, fold along dashed lines, and glue along dotted lines.
4. Assemble the *Base*.
5. See image of completed model below.

**Base**





**Earthquake**
The point underground where rocks break is known as the ***focus***. The point on the surface directly above the focus is known as the ***epicenter***. The focus is usually located at a depth of less than 100km (60 miles). The fastest shock waves, ***P waves***, radiate outward from the focus at a rate of 6 to 7 km/second (4 miles/second).

**Color Key:**

- Shock wave (red)
- Rock layers (tan)
- Buildings and roads (pink)
- Sea (blue)
- Vegetation (green)

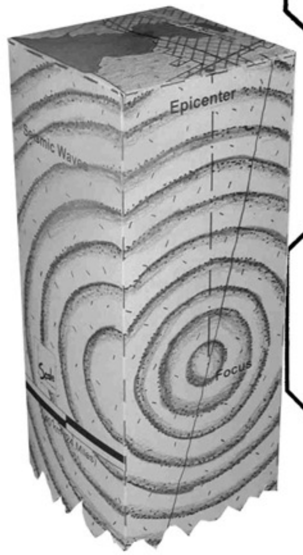


**Image of completed model**

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## Normal Fault

**Instructions:**

1. For best results, copy this pattern onto cardstock.
2. Color the model using the color key.
3. Cut along solid lines. Fold along dashed lines. Glue along the dotted lines.
4. See image of completed model at right.

### Normal Fault

The vertical movement in Normal faults results from tension forces in the Earth's crust. These faults are often covered with sediment and not visible from the surface. In a Normal fault the Hanging Wall moves down in relation to the Footwall.

**Color Key:**

- ⁘ Sandstone (yellow)
- ▦ Limestone (tan)
- — Shale (gray)
- ∴ Conglomerate (tan)
- ✻ Bushes (green)

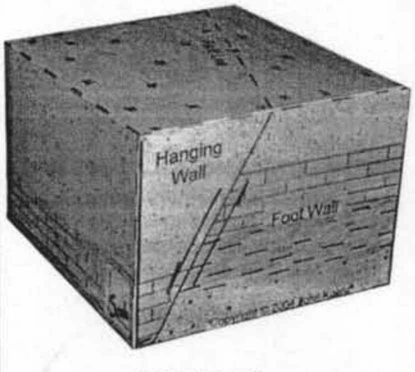
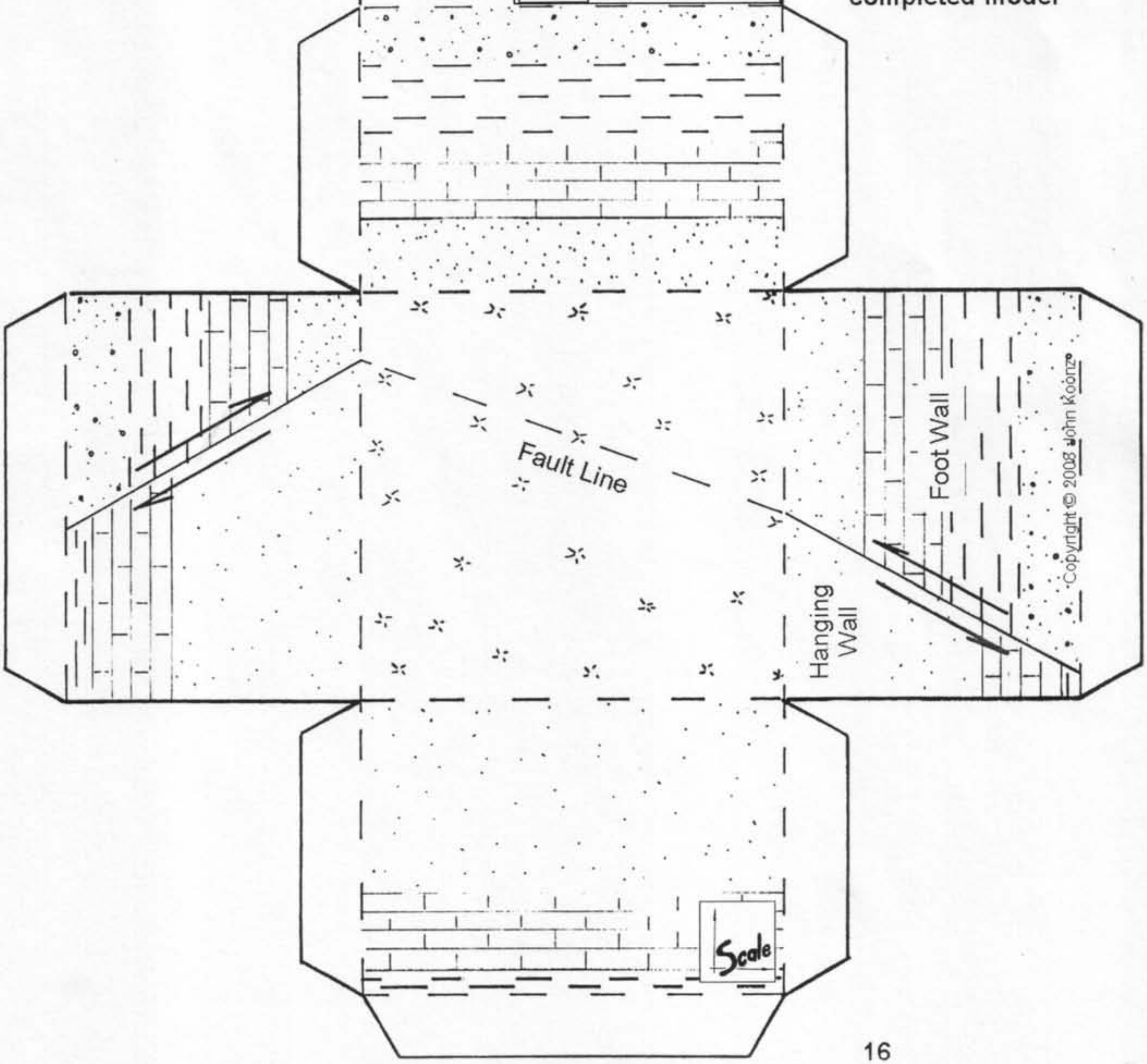


**Image of completed model**



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# Reverse Fault

**Instructions:**

1. For best results, copy this pattern onto cardstock.
2. Color the model using the color key.
3. Cut along solid lines. Fold along dashed lines. Glue along the dotted lines.
4. See image of completed model at right.

## Reverse Fault

The vertical movement in Reverse faults results from compression forces in the Earth's crust. These faults are often covered with sediment and not visible from the surface. In a Reverse fault the Hanging Wall moves up in relation to the Footwall.

### Color Key:

Sandstone (yellow)
Limestone (tan)
Shale (gray)
Conglomerate (tan)
Bushes (green)

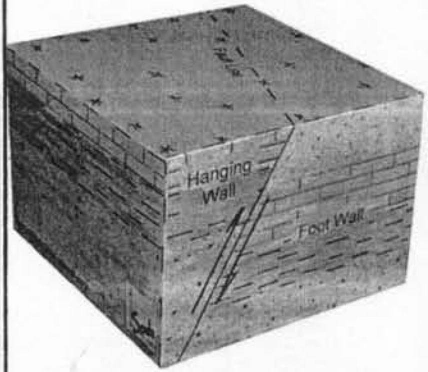
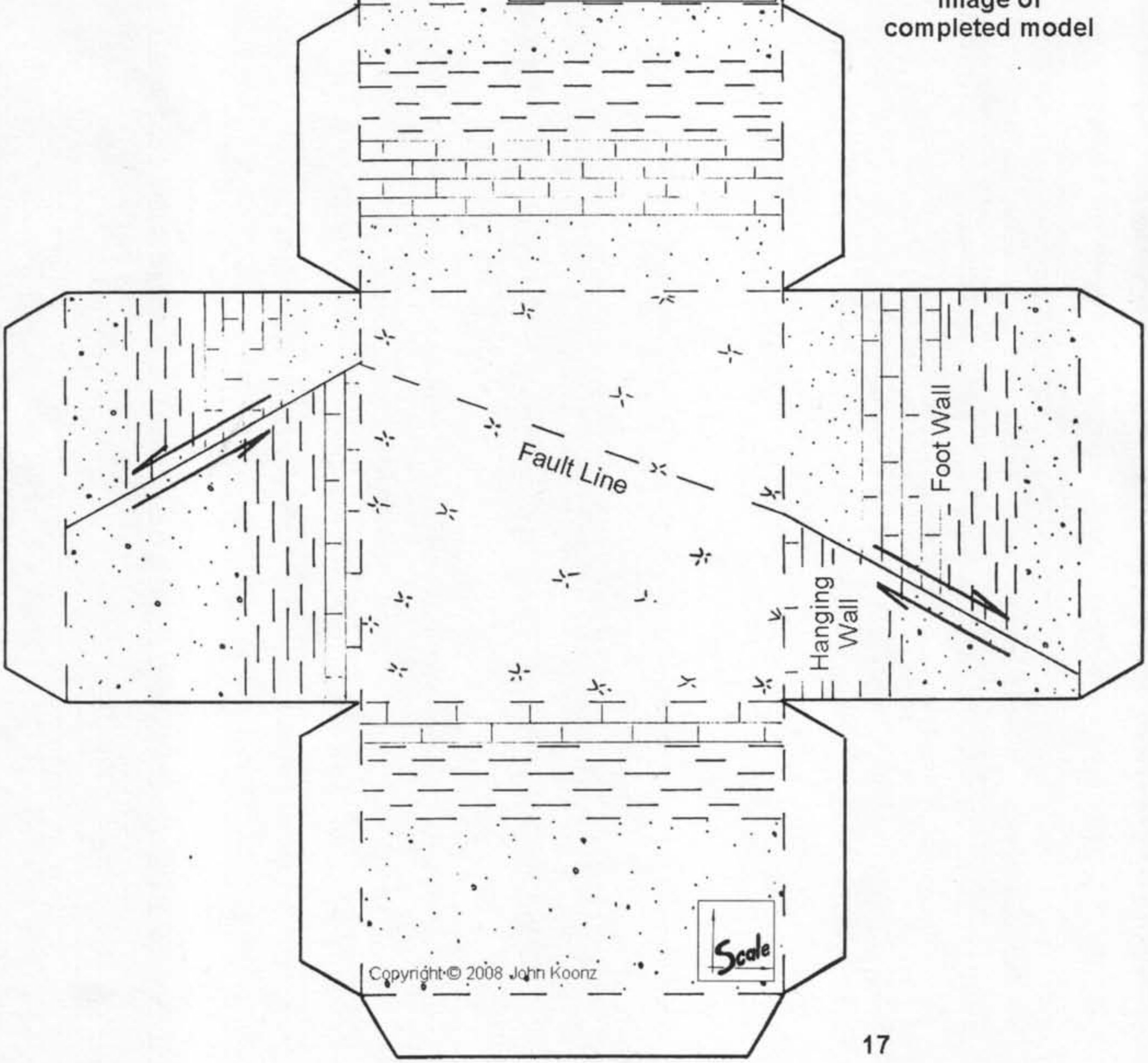


**Image of completed model**



# Thrust Fault

GEOBLOX

**Instructions:**

1. For best results, copy these patterns onto cardstock.
2. Color the model using the color key.
3. Cut along solid lines. Fold along dashed lines. Glue along the dotted lines.
4. See image of completed model below.

## Thrust Fault

Like a Reverse fault, a Thrust fault results from compression in the Earth's crust. In this type of Reverse fault the overlying block moves at a very shallow angle. In the case of Waterton-Lakes National Park in Alberta Canada a 3km (2 mile) thick slab of rock was displaced 50 km (30 miles).

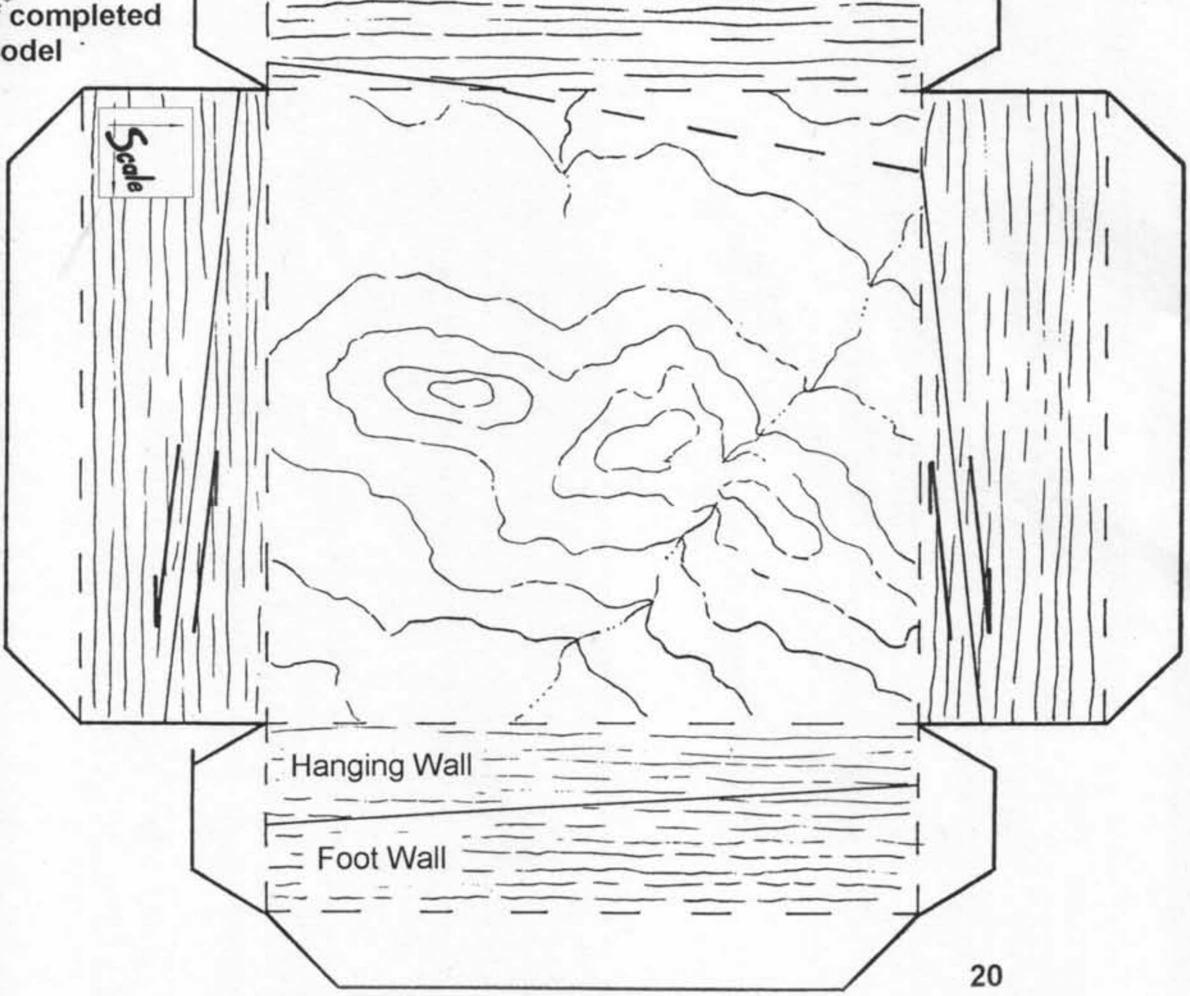
Thrust faults can transport much older rocks to rest above younger rocks. Later, erosion may leave the contact between the two exposed.

### Color Key:

▨ Surface contours (green and brown)

☰ Sedimentary Rocks (alternating gray and tan)

**Image of completed model**



# INSERT TAB
# WAVES
# MEASUREMENT

# Seismic Waves and the Slinky

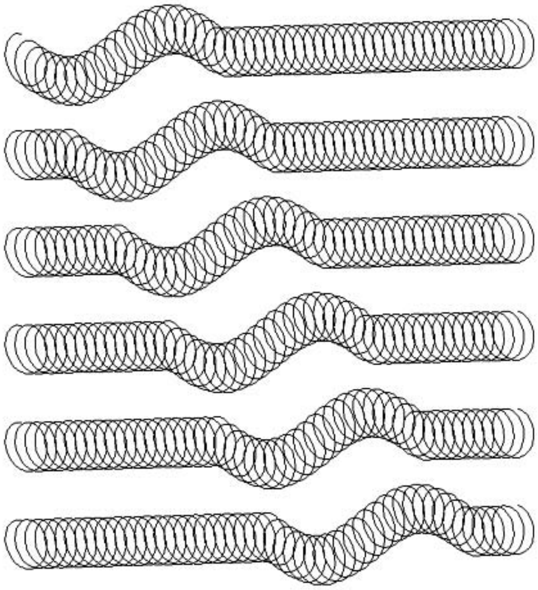
Prof. Lawrence W. Braile©
Purdue University

braile@purdue.edu
(March, 2006)

**Seismic Waves:** Because of the elastic properties of Earth materials (rocks) and the presence of the Earth's surface, four main types of seismic waves propagate within the Earth. *Compressional* (P) and *Shear* (S) waves propagate through the Earth's interior and are known as body waves. *Love* and *Rayleigh* waves propagate primarily at and near the Earth's surface and are called surface waves. Wave propagation and particle motion characteristics for the P, S, Rayleigh and Love waves are illustrated in Figures 1-4. Additional illustrations of P, S, Rayleigh and Love waves are contained in Bolt (1993, p. 27 and 37; 2004, p. 22) and in Shearer (1999, p. 32 and 152). Effective animations of P and S waves are contained in the Nova video "Earthquake" (1990; about 13 minutes into the program) and of P, S, Rayleigh and Love waves in the Discovery Channel video "Living with Violent Earth: We Live on Somewhat Shaky Ground" (1989, about 3 minutes into the program), and at: http://web.ics.purdue.edu/~braile/edumod/waves/WaveDemo.htm.

**Slinky Demonstrations of P and S Waves:** The P and S waves have distinctive particle motions (Figures 1-4) and travel at different speeds. P and S waves can be demonstrated effectively with a slinky (the original metal slinky works best). For the P or compressional wave, have two people hold the ends of the slinky about 3-4 meters apart. One person should cup his or her hand over the end (the last 3-4 coils) of the slinky and, when the slinky is nearly at rest, hit that hand with the fist of the other hand. The compressional disturbance that is transmitted to the slinky will propagate along the slinky to the other person. Note that the motion of each coil is either compressional or extensional with the movement parallel to the direction of propagation. Because the other person is holding the slinky firmly, the P wave will reflect at that end and travel back along the slinky. The propagation and reflection will continue until the wave energy dies out. The propagation of the P wave by the slinky is illustrated in Figure 5.

Demonstrating the S or Shear wave is performed in a similar fashion except that the person who creates the shear disturbance does so by moving his or her hand quickly up and then down. This motion generates a motion of the coils that is perpendicular to the direction of propagation, which is along the slinky. Note that the particle motion is not only perpendicular to the direction of motion but also in the vertical plane. One can also produce Shear waves with the slinky in which the motion is in the horizontal plane by the person creating the source moving his or her hand quickly left and then right. The propagation of the S wave by the slinky is illustrated in Figure 6. Notice that, although the motion of the disturbance was purely perpendicular to the direction of propagation (no motion in the disturbing source was directed along the slinky), the disturbance still propagates away from the source, along the slinky. The reason for this phenomenon (a good challenge question for students) is because the material is elastic and the individual coils are connected (like the individual particles of a solid) and thus transmit their motion (disturbance or deformation) to the adjacent coils. As this process continues, the shear disturbance travels along the entire slinky (elastic medium).



P and S waves can also be generated in the slinky by an additional method that reinforces the concept of elasticity and the elastic rebound theory which explains the generation of earthquakes by plate tectonic movements (Bolt, 1993, p. 74-77; 2004, p. 113-116). In this method, for the P wave, one person should slowly gather a few of the end coils of the slinky into his or her hand. This process stores elastic energy in the coils of the slinky that are compressed (as compared to the other coils in the stretched slinky) similar to the storage of elastic energy in rocks adjacent to a fault that are deformed by plate motions prior to slip along a fault plane in the elastic rebound process. When a few coils have been compressed, release them suddenly (holding on to the end coil of the slinky) and a compressional wave disturbance will propagate along the slinky. This method helps illustrate the concept of the elastic properties of the slinky and the storage of energy in the elastic rebound process. However, the compressional wave that it generates is not as simple or visible as the wave produced by using a blow of one's fist, so it is suggested that this method be demonstrated after the previously described method using the fist.

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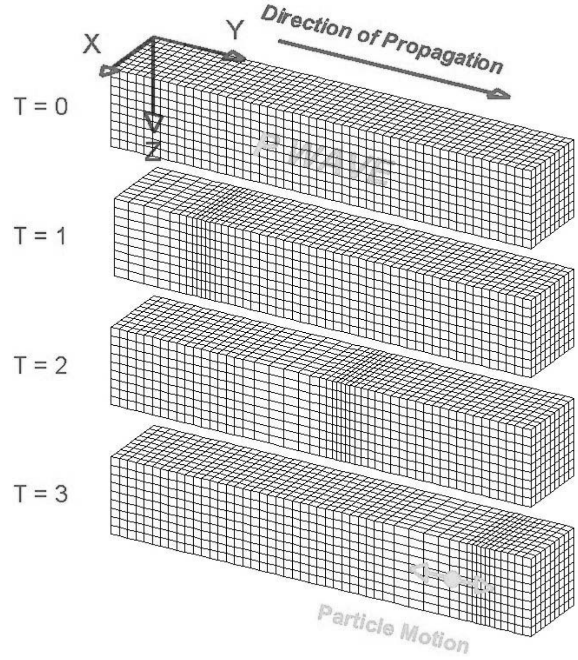

*Figure 1. Perspective view of elastic P-wave propagation through a grid representing a volume of material. The directions X and Y are parallel to the Earth's surface and the Z direction is depth. T = 0 through T = 3 indicate successive times. The disturbance that is propagated is a compression (grid lines are closer together) followed by a dilatation or extension (grid lines are farther apart). The particle motion is in the direction of propagation. The material returns to its original shape after the wave has passed.*

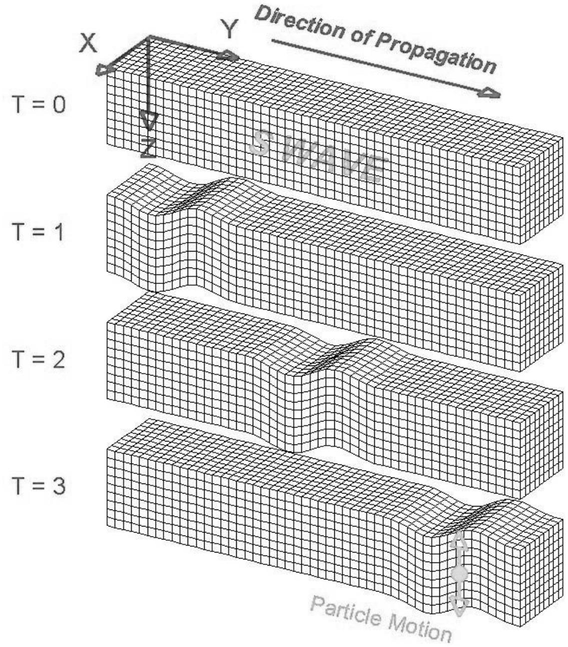

*Figure 2. Perspective view of S-wave propagation through a grid representing a volume of elastic material. The disturbance that is propagated is an up motion followed by a down motion (the shear motion could also be directed horizontally or any direction that is perpendicular to the direction of propagation). The particle motion is perpendicular to the direction of propagation. The material returns to its original shape after the wave has passed.*

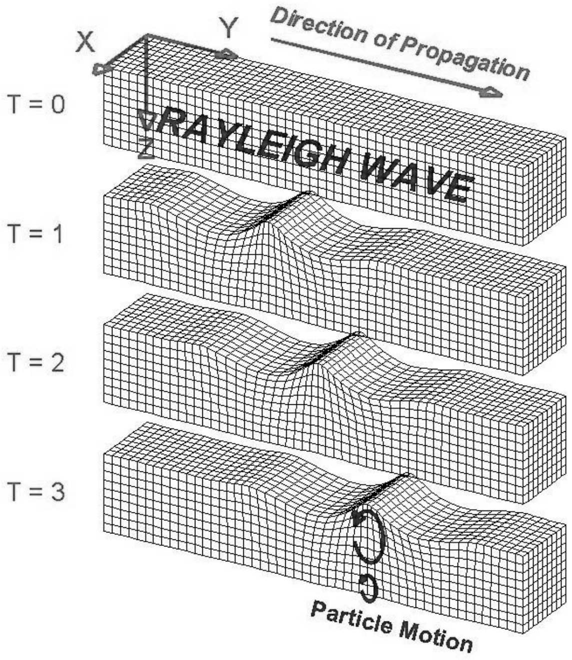

*Figure 3. Perspective view of Rayleigh-wave propagation through a grid representing a volume of elastic material. Rayleigh waves are surface waves. The disturbance that is propagated is, in general, an elliptical motion which consists of both vertical (shear; perpendicular to the direction of propagation but in the plane of the raypath) and horizontal (compression; in the direction of propagation) particle motion. The amplitudes of the Rayleigh wave motion decrease with distance away from the surface. The material returns to its original shape after the wave has passed.*

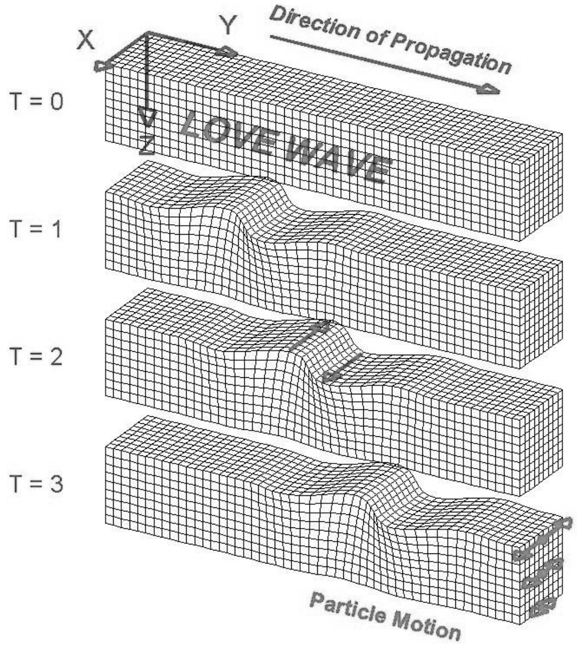

*Figure 4. Perspective view of Love-wave propagation through a grid representing a volume of elastic material. Love waves are surface waves. The disturbance that is propagated is horizontal and perpendicular to the direction of propagation. The amplitudes of the Love wave motion decrease with distance away from the surface. The material returns to its original shape after the wave has passed.*

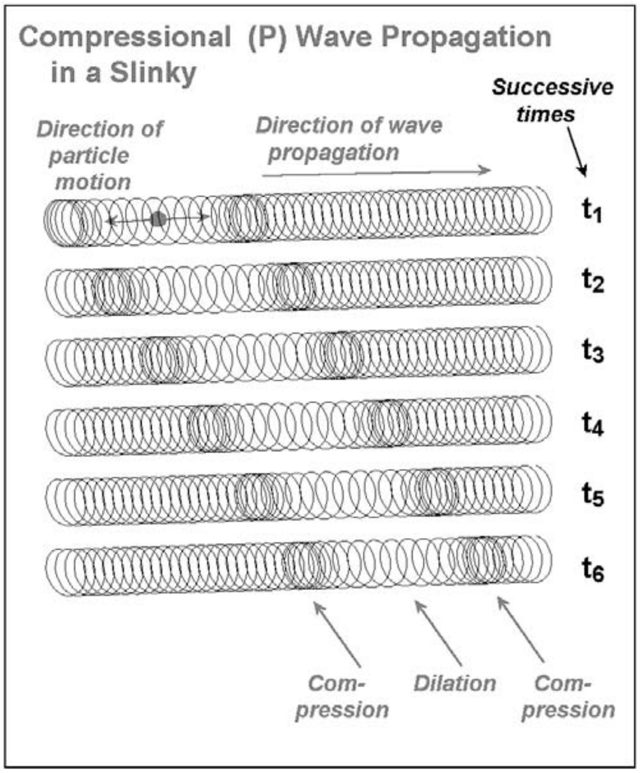

*Figure 5. Compressional (P) wave propagation in a slinky. A disturbance at one end results in a compression of the coils followed by dilation (extension), and then another compression. With time (successive times are shown by the diagrams of the slinky at times $t_1$ through $t_6$), the disturbance propagates along the slinky. After the energy passes, the coils of the slinky return to their original, undisturbed position. The direction of particle motion is in the direction of propagation.*

Similarly, using this "elastic rebound" method for the S waves, one person holding the end of the stretched slinky should use their other hand to grab one of the coils about 10-12 coils away from the end of the slinky. Slowly pull on this coil in a direction perpendicular to the direction defined by the stretched slinky. This process applies a shearing displacement to this end of the slinky and stores elastic energy (strain) in the slinky similar to the storage of strain energy in rocks adjacent to a fault or plate boundary by plate tectonic movements. After the coil has been displaced about 10 cm or so, release it suddenly (similar to the sudden slip along a fault plane in the elastic rebound process) and an S wave disturbance will propagate along the slinky away from the source.

**Surface Waves:** The Love wave (Figure 4) is easy to demonstrate with a slinky or a double length slinky. Stretch the slinky out on the floor or on a tabletop and have one person at each end hold on to the end of the slinky. Generate the Love wave motion by quickly moving one end of the slinky to the left and then to the right. The horizontal shearing motion will propagate along the slinky. Below the surface, the Love wave motion is the same except that the amplitudes decrease with depth. Using the slinky for the Rayleigh wave (Figure 3) is more difficult. With a regular slinky suspended between two people, one person can generate the motion of the Rayleigh wave by rapidly moving his or her hand in a circular or elliptical motion. The motion should be up, back (toward the person generating the motion), down, and then forward (away from the person), coming back to the original location and forming an ellipse or circle with the motion of the hand. This complex pattern will propagate along the slinky but will look very similar to an S wave. Rayleigh wave motion also decreases with depth below the surface. Excellent illustrations of the wave motion of Love and Rayleigh waves can also be found in Bolt (1993, p. 37). Further details on the characteristics and propagation of Love and Rayleigh waves can be found in Bolt (1993, p. 37-41).

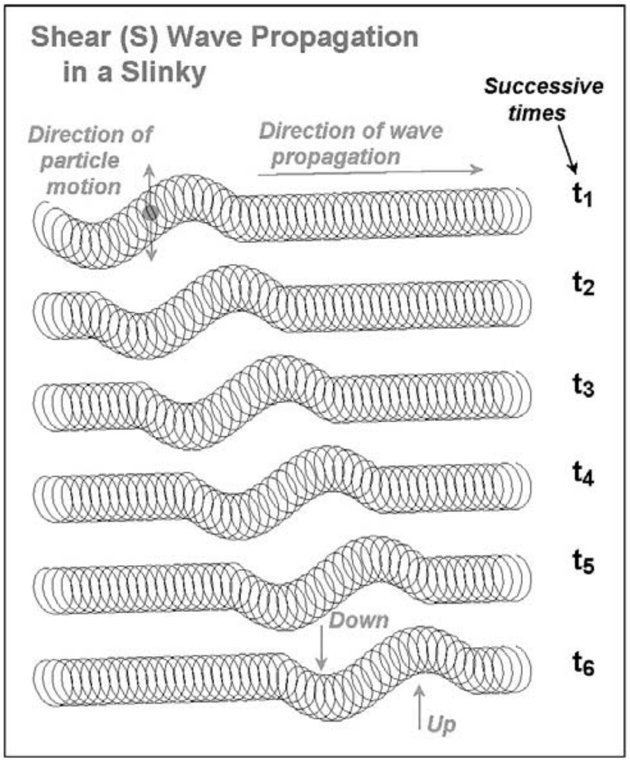

*Figure 6. Shear (S) wave propagation in a slinky. A disturbance at one end results in an up motion of the coils followed by a down motion of the coils. With time (successive times are shown by the diagrams of the slinky at times $t_1$ through $t_6$), the disturbance propagates along the slinky. After the energy passes, the coils of the slinky return to their original, undisturbed position. The direction of particle motion is perpendicular (for example, up and down or side to side) to the direction of propagation.*

**Wave Propagation in All Directions:** An additional demonstration with P and S waves can be performed with the 5-slinky model. By attaching 5 slinkys to a wood block as shown in Figure 7, 5 people can hold the ends of the 5 slinkys (stretched out in different directions to about 3-4 m each). One person holds the wood block and can generate P or S waves (or even a combination of both) by hitting the wood block with a closed fist or causing the block to move quickly up and then down or left and then right. The purpose of this demonstration is to show that the waves propagate in all directions in the Earth from the source (not just in the direction of a single slinky).

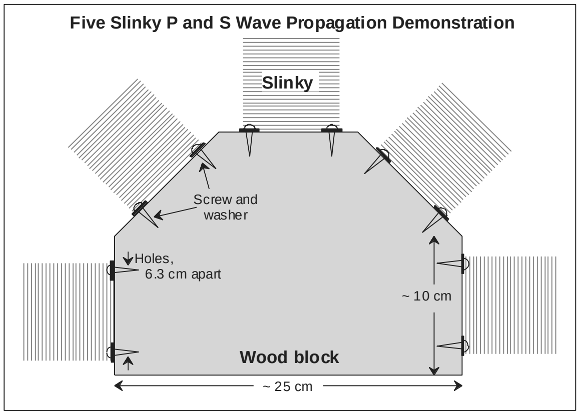

*Figure 7. Diagram showing how five slinkys can be attached to the edge of a wood block. Photographs of the five slinky model are shown in Figures 8 and 9. When the slinkys are stretched out to different positions (five people hold the end of one slinky each) and a P or S wave is generated at the wood block, the waves propagate out in all directions. The five slinky model can also be used to show that the travel times to different locations (such as to seismograph stations) will be different. To demonstrate this effect, wrap a small piece of tape around a coil near the middle one of the slinkys. Have the person holding that slinky compress all of the coils from the outer end to the coil with the tape so that only one half of the slinky is extended. Also, attach an additional (sixth) slinky, using plastic electrical tape, to the end of one of the slinkys. Have the person holding this double slinky stand farther away from the wood block so that the double slinky is fully extended. When a P or S wave is generated at the wood block, the waves that travel along the slinky will arrive at the end of the half slinky first, then at approximately the same time at the three regular slinkys, and finally, last at the double length slinky*

Attaching an additional slinky (with small pieces of plastic electrical tape) to one of the five slinkys attached to the wood block makes one slinky into a double length slinky which can be stretched out to 6-8 m. For one of the other four slinkys, have the person holding it collapse about half of the coils and hold them in his or her hands, forming a half slinky, stretched out about 1½ - 2 m. Now when a source is created at the wood block, one can see that the waves take different amounts of time to travel the different distances to the ends of the various slinkys. An effective way to demonstrate the different arrival times is to have the person holding each slinky call out the word "now" when the wave arrives at their location (if the people holding the slinkys close their eyes and call out when they feel the wave arrive, their responses may be more accurate). The difference in arrival times for the different distances will be obvious from the sequence of the call of "now." This variation in travel time is similar to what is observed for an earthquake whose waves travel to various seismograph stations that are different distances from the source (epicenter). Although these two demonstrations with the five slinky model represent fairly simple concepts, we have found the demonstrations to be very effective with all age groups. In fact, the five slinky demonstrations are often identified the “favorite activities” of participants.

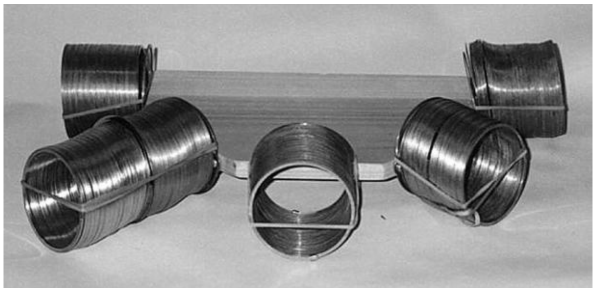

*Figure 8. Photograph of the five slinky model.*

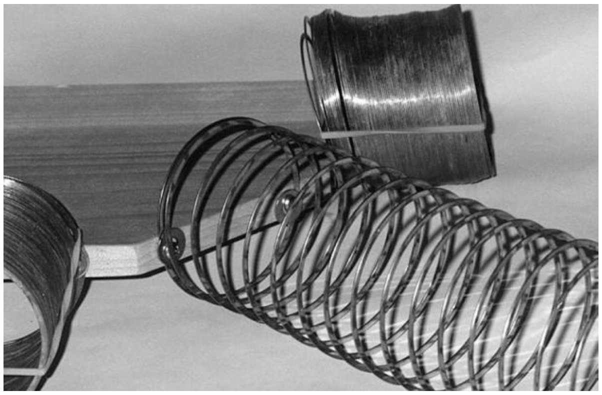

*Figure 9. Close-up view of five slinky model showing attachment of slinky using screws and washers (holes are 6.3 cm apart, screws are #6, ½” long, washers are 3/16”).*

**Exploration and Assessment:** After demonstrating seismic waves with the slinky, have students use the slinky to explore wave propagation and generation of different wave types and wave characteristics. One can also use slinky activities for authentic assessment by asking students to show their understanding by performing the demonstrations in class.

**Connections to National Science Education Standards (National Research Council, 1996):** *Teaching Standards:* inquiry-based (A,B); opportunity for assessment (C). *Professional Development Standards:* opportunity for learning new Earth science content (A,C); suggestions for effective teaching strategies (B). *Assessment Standards:* authentic assessment (C). *Content Standards: Science as Inquiry* – practice inquiry and fundamental science skills (grades 5-8 and 9-12, A); *Physical Science* – properties of matter, motion, transfer of energy (grades 5-8, B), structure of matter, motion, interactions of energy and matter (grades 9-12, B); *Earth and Space Science* – relate to energy in the Earth system (grades 9-12, D).

**References:**

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National Research Council, *National Science Education Standards*, National Academy of Sciences, Washington, D.C., 262 pp., 1996.

Shearer, P. M., *Introduction to Seismology*, Cambridge University Press, Cambridge, UK, 260pp, 1999.

(This description of seismic waves and the slinky is excerpted from **Seismic Waves and the Slinky: A Guide for Teachers** available at: web.ics.purdue.edu/~braile. Developed in cooperation with the IRIS Consortium [Incorporated Research Institutions for Seismology, www.iris.edu], supported by the National Science Foundation.)

**Title:** Human Wave Demonstration (DRAFT WRITE UP)

**Version:** 1.0

**Last Revision:** March, 2013

**What's included:**
- Overview
- Materials List
- Activity Flow
- Teacher Background

***URL Slug:*** http://www.iris.edu/hq/inclass/lesson/human_wave

***Thumbnail:***

***Suggested Leve*l:** Novice

**Time:** 15 minutes

**Learning Objectives:**
Students will be able to
1. Distinguish between a P wave and an S wave based on
    a. Speed
    b. Direction of particle motion relative to wave propagation
    c. Materials it can propagate through
2. Explain molecularly, why S waves are not able to travel in a liquid, while P waves are able to travel in a liquid.
3. Explain how P and S waves provide evidence for Earth's interior

**Material List**
1. Space in the front of the room for 10-15 students to line-up shoulder-to-shoulder.
2. Optional: Stopwatch
3. Projection system and computer
4. http://web.ics.purdue.edu/~braile/edumod/waves/Pwave.htm
5. http://web.ics.purdue.edu/~braile/edumod/waves/Swave.htm
6. Venn Diagram worksheet

**Abstract** (200 words or less)

Lined up shoulder-to-shoulder, students to “become” the material that P and S waves travel through in this demonstration. Once "performed," the principles of P and S waves will not be easily forgotten.

**Overview:**

This demonstration explores two of the four (P and S waves) main ways energy propagates from the hypocenter of an earthquake. In this demo, students “experience” the waves as they line up shoulder-to-shoulder to “become” the solid and then liquid material the waves travel through. The physical nature of the “Human wave” demonstration makes it a highly engaging activity for most students. Some find that this tactile/kinesthetic learning activity stretches them personally; while for others it channels disruptive energy into a creative endeavor. Either way, developing ways to physically involve students in learning helps students grasp, internalize and maintain abstract information. Once "performed," the principles of P and S waves will not be easily forgotten.

**Position in a teaching sequence or other related resources**

This activity is part of something larger… to see this as part of a teaching sequence visit www.IRIS:InClass/sequences

**Teacher Preparation –** None

**Safety –** Have a “spotter” at one end of the line to ensure that the last person is not bumped over.

**Vocabulary**

Elastic deformation
Primary (P) Wave
Propagate
Secondary (S) Wave
Seismic Waves
Shearing
Wave

**Activity Flow**

There are a number of ways to use this demo. It can precede or follow a slinky demonstration depending on the rest of your instruction. As written here it follows and reinforces instruction of seismic waves with the slinky.

**O**pen –

1. Today we are going to have an earthquake in class!

2. Ask for approximately 10 to 12 students to come to the front of the room and lineup tallest to shortest.

**TIP – Depending on the maturity of your students, this demonstration may work best with homogeneous grouping by gender.**

**TIP – Since this is a kinesthetic demonstration, it may not be appropriate for some students with physical disabilities to participate.**

**P**rior Knowledge

1. Tell the students that you are the earthquake and that they are a line of molecules in a material that the seismic energy will propagate through.

2. Instruct the line of "molecules" to become an elastic solid. If students have difficulty, coach them to the answer.

   ANSWER: The line should stand shoulder-to-shoulder with their feet shoulder-width apart. Molecules are tightly packed and are rigid in a solid. They can't slide past one another. Therefore, the students be very close together and should place their arms over the shoulders of the person next to them… chorus-line style.

3. Remind students that solids are elastic. Ask: What does that mean in terms of how the "molecules" should respond when seismic wave passes?

   ANSWER: The group should be rigid, but not overly so. Since they are an elastic material they should deform to the force that they feel and return to their original position. It is important that the molecules not be too rigid (e.g. not move when bumped) nor too limp (e.g. fall into the person next to them) for the demonstration to be effective.

**E**xplore/**E**xplain

Seated students should create a Venn diagram about P and S waves during the demo and discussions.

*Modeling a P wave in a solid*

1. From the tall end of the line, lightly push first student's shoulder so that they bump the student next to them. This causes them to move closer together temporarily, a compression, followed by spreading farther apart temporarily, a dilation. This pattern to propagates down the line.

2. Ask "I was the earthquake that released energy into the system. What was transmitted? Energy? Material? Neither? Both?" Be sure to encourage students to provide evidence for their claim.

   ANSWER: Energy was transmitted from one end of the line to the other end. The molecules returned to their original position and were NOT transmitted.

3. Ask "How did the molecules move as compared to the direction of the energy?"

   ANSWER: Parallel to the direction of wave propagation and since the material is elastic the molecules were deformed as the wave passed but they returned to their original position.

4. Ask "Did it take some time for the energy to move from one end of the material to the other?"

   ANSWER: Yes

5. Since it took x amount of time for the energy to move from one end of the material to the other, what does that mean about the wave?

ANSWER: It has a definite and measurable velocity

*Modeling an S wave in a solid*

1. Starting at the tallest end of the line, place one hand in the center of the first person's back, and a second hand on their waist. Bend them forward at the waist and then back up again.

2. This molecules resistance to shearing (e.g. arms over each others shoulders) will cause the shearing to propagate down the line of "molecules".

3. Again note that the wave has a velocity and that this time the deformation of the molecules was perpendicular to the direction of wave propagation.

4. Many students will note that the S wave is slower than the P wave though repeating the demo and having observers time the waves can emphasize this point dramatically. (Because the shear motion in the demonstration is more complicated than the compression. This velocity difference could be measured with a stopwatch if the P and the S demo were repeated.)

5. Ask "How was the S Wave different from the P wave?"
   ANSWER: Particles moved perpendicular to the direction of wave propagation and the S wave was slower than the P wave

6. Ask "How was the P Wave similar to the S wave?"
   ANSWER: They both had a definite velocity and transferred energy from on end to the other.

Figure 1. An S Wave traveling through the tightly spaced molecules of a solid

*Modeling A P Wave In A Liquid*

1. Instruct the line of "molecules" to now become a liquid. If students have difficulty, coach them to the answer.
   ANSWER: The line should stand shoulder-to-shoulder with their feet shoulder-width apart. Molecules in a liquid can slide past one another but there is little free space between them. Therefore, the students' shoulders should touch one another but they should no longer be linked chorus-line style.

2. Remind the “molecules” that they are still elastic. This means that even though they are liquids they should deform to the force that they feel and return to their original position. It is important that the molecules not be too rigid (e.g. not move when bumped) nor too limp (e.g. fall into the person next to them) for the demonstration to be effective.

3. From the tall end of the line, lightly push first student’s shoulder so that they bump the student next to them. This causes them to move closer together temporarily, a compression, followed by spreading farther apart temporarily, a dilation. This pattern to propagates down the line.

4. Ask “Was there a difference between a P Wave in a liquid vs a solid?”
ANSWER: There was no noticeable difference (though it should be noted that in the earth, the energy is transferred more slowly in a liquid. If time allows you might explore why this occurs with your students.)

Figure 2. A P wave traveling through the molecules of a liquid

*Modeling An S Wave In A Liquid*

1. Starting at the tallest end of the line, place one hand in the center of the first person’s back, and a second hand on their waist. Bend them forward at the waist and then back up again. This time the shear disturbance cannot propagate down the line.
TIP - When doing this demo, the second person in line frequently bends at the waist “sympathetically”. This should be anticipated and you should clarify their movement to the class by asking them if they “felt or saw” the disturbance. Once clarified, the demo should be repeated so that this time they only move when they feel the disturbance.

2. Ask “ Was there a difference between an S Wave in a liquid vs. a solid? What was it?
ANSWER: Yes, the wave did not travel through the liquid!

3. Ask “Based on these demonstrations, why can’t an S wave travel in a liquid?”
ANSWER: Because the molecules in a liquid are not rigid, they can slip past one another. As a result sharing motion is not resisted and does not propagate.

**R**eflect

1. Quickly reverse the students and repeat the demo with the remaining half of the class

2. Document this second demonstration by creating a Venn Diagram for P and S Waves on the board. Students should also complete their version at their seats.

3. Ask “We have examined this model (the line of students) for how can behave like seismic waves moving through Earth. Do you think it is completely acute? How could it be different from reality?”

> ANSWER: The Human wave demo is a functional model. Thus, it is both like and unlike the target it represents. Accept answers generated by students but be sure to supplement these with the ideas mentioned in the teacher’s background section.

**A**pply

1. Before the second group return to their seats, divide the students in the following way; the first quarter of the students should be solids, the middle half of the students should be liquids, and the final quarter should be solids.

2. Ask students to predict… “What do you think will happen if a P wave were to propagate through the line? An S wave?”

> ANSWER: Accept all responses

3. Test their hypothesis by sending a P wave and an S wave through the line. Because P waves propagate in both solids and liquids, the P wave will propagate from one end to the other. However, the S wave will stop when it reaches the solid/liquid boundary because liquids do not resist shearing. This final demo models the S wave shadow zone; evidence that Earth’s core is a liquid.

TIP – If you have not already covered Earth’s internal structure, don’t mention the connection to Earth’s structure yet. When get to this in a few weeks, refer back to or even repeat this demo for students when you discuss seismic evidence. However, if you have already provided instruction on Earth’s interior structure, a discussion connecting the demo to the S-wave shadow zone is warranted.

Teacher Background

This demonstration explores two of the four (P and S waves) main ways energy propagates from the hypocenter of an earthquake. In this demo, students “experience” the waves as they line up shoulder to shoulder to “become” the material the waves travel through. The physical nature of the “Human wave” demonstration makes it a highly engaging activity for most students. Some find that this tactile/kinesthetic learning activity stretches them personally; while for others it channels disruptive energy into a creative endeavor. Either way, developing ways to physically involve students in learning helps students grasp, internalize and maintain abstract information (Griss,1994). Once "performed," the principles of P and S waves will not be easily forgotten.

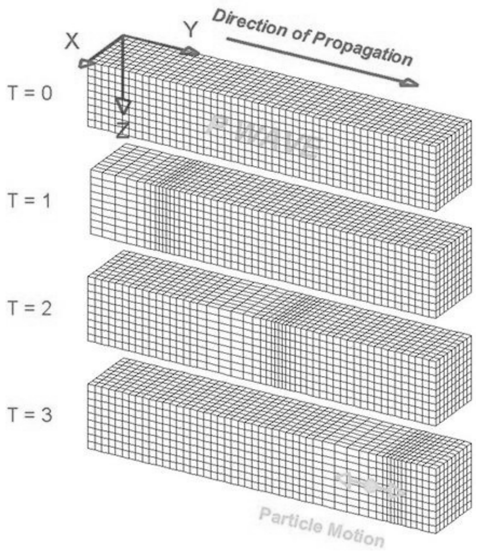
*Seismic Waves*

The energy from an earthquake radiates outwards in all directions. Because of the elastic properties of Earth materials (rocks) and the presence of the Earth's surface this energy propagates as four main types of seismic waves. Compressional or Primary (P) and Shear or Secondary (S) waves propagate through the Earth’s interior and are known as body waves. Love and Rayleigh waves propagate primarily at and near the Earth's surface and are called surface waves. Table 1 below summarizes detailed characteristics of the P, S Rayleigh and Love waves.

***Table 1: Seismic Waves***

| Wave Type (and names) | Particle Motion | Typical Velocity | Other Characteristics |
|---|---|---|---|
| **P**, **Compressional**, Primary, Longitudinal | Alternating compressions (“pushes”) and dilations (“pulls”) which are directed in the same direction as the wave is propagating (along the ray path); and therefore, perpendicular to the wavefront. | **$V_P$ ~ 5 – 7 km/s in typical Earth’s crust; >~ 8 km/s in Earth’s mantle and core; ~1.5 km/s in water; ~0.3 km/s in air.** | P motion travels fastest in materials, so the P-wave is the first-arriving energy on a seismogram. Generally smaller and higher frequency than the S and Surface-waves. P waves in a liquid or gas are pressure waves, including sound waves. |
| **S**, **Shear**, Secondary, Transverse | Alternating transverse motions (perpendicular to the direction of propagation, and the ray path); commonly approximately polarized such that particle motion is in | **$V_S$ ~ 3 – 4 km/s in typical Earth’s crust;**<br>>~ 4.5 km/s in Earth’s mantle;<br>~ 2.5-3.0 km/s in (solid) inner core. | S-waves do not travel through fluids, so do not exist in Earth’s outer core (inferred to be primarily liquid iron) or in air or water or molten rock (magma). S waves travel slower than P waves in a solid and, therefore, arrive after the P wave. |

| | | | |
|---|---|---|---|
| | vertical or horizontal planes. | | |
| **L**,<br>**Love**, Surface waves, Long waves | Transverse horizontal motion, perpendicular to the direction of propagation and generally parallel to the Earth's surface. | $V_L$ ~ 2.0 - 4.4 km/s in the Earth depending on frequency of the propagating wave, and therefore the depth of penetration of the waves. In general, the Love waves travel slightly faster than the Rayleigh waves. | Love waves exist because of the Earth's surface. They are largest at the surface and decrease in amplitude with depth. Love waves are dispersive, that is, the wave velocity is dependent on frequency, generally with low frequencies propagating at higher velocity. Depth of penetration of the Love waves is also dependent on frequency, with lower frequencies penetrating to greater depth. |
| **R**,<br>**Rayleigh**, Surface waves, Long waves, Ground roll | Motion is both in the direction of propagation and perpendicular (in a vertical plane), and "phased" so that the motion is generally elliptical – either prograde or retrograde. | $V_R$ ~ 2.0 - 4.2 km/s in the Earth depending on frequency of the propagating wave, and therefore the depth of penetration of the waves. | Rayleigh waves are also dispersive and the amplitudes generally decrease with depth in the Earth. Appearance and particle motion are similar to water waves. Depth of penetration of the Rayleigh waves is also dependent on frequency, with lower frequencies penetrating to greater depth. |



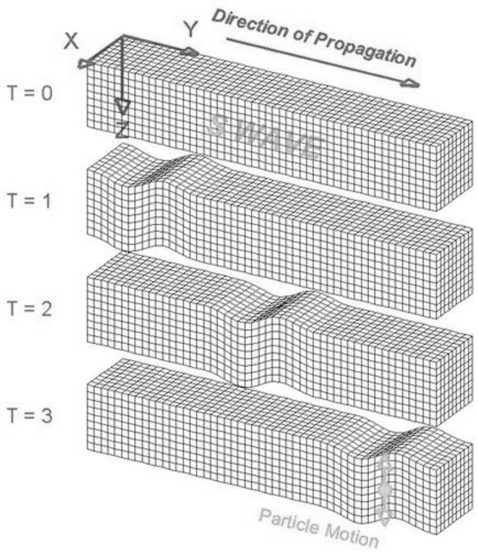


Figure 3. Perspective views of P-wave (left) and S wave (right) propagation through a grid representing a volume of material. The directions X and Y are parallel to the Earth's surface and the Z direction is depth. T = 0 through T = 3 indicate successive times. (Left) The disturbance that is propagated is a compression (grid lines are closer together) followed by a dilatation or extension (grid lines are farther apart). The particle motion is in the direction of propagation. The material returns to its original shape after the wave has passed. (Right) The disturbance that is propagated is an up motion followed by a down motion (though the motion could also be directed horizontally or any direction that is perpendicular to the direction of propagation). The particle motion is perpendicular to the direction of propagation. The material returns to its original shape after the wave has passed.

### S Wave Shadow Zone

Most of the direct evidence that we have about Earth's deep interior comes from the study of seismic waves that penetrate the Earth and are recorded on the other side. Years of study of travel times from earthquakes to stations at various distances suggest the speeds at which P- and S-waves traverse different regions of Earth's interior. From this seismologists infer the path the seismic waves takes to reach any point on Earth's surface. As illustrated in Figure 4b below, S waves are unable  this energy follows a curing path through the Earth. As a result of this, and the  below, there are points on Earth's surface were direct S waves don't arrive (S waves can't propagate through Earth's liquid core).

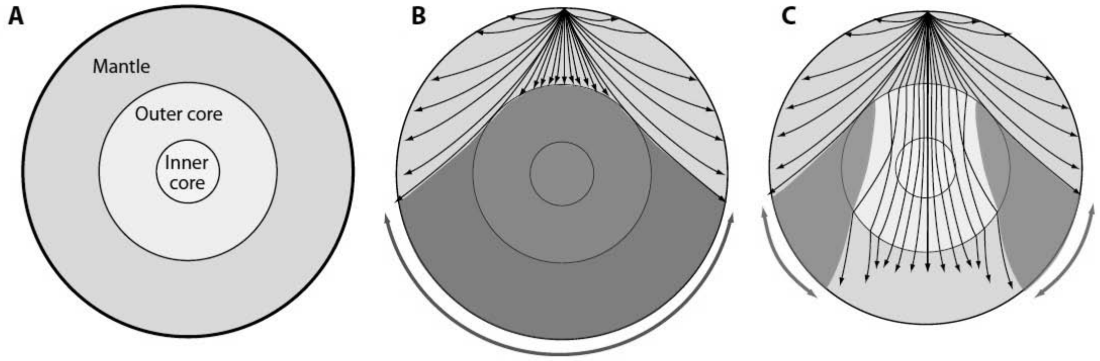
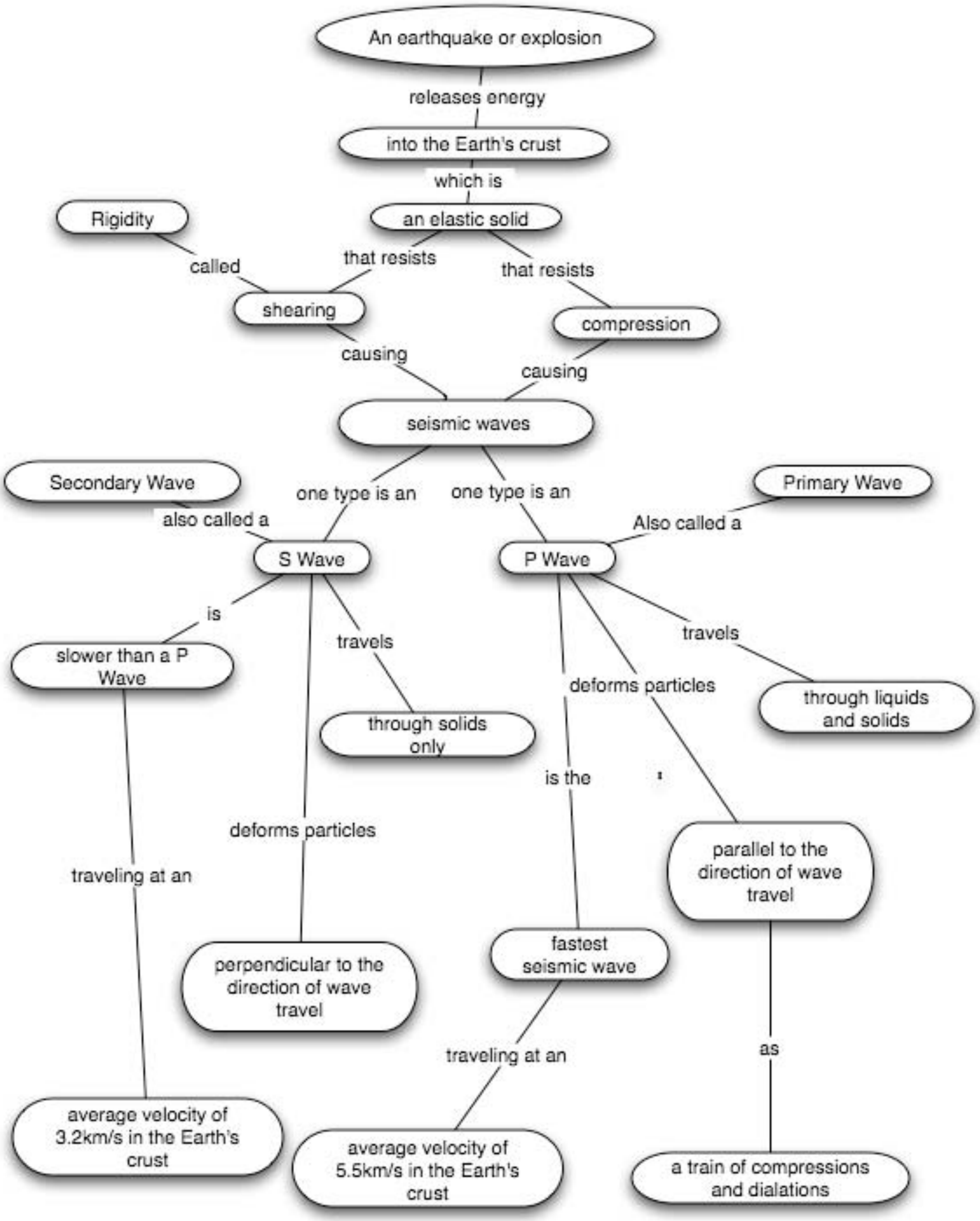


**Figure 1**—Simplifications of :
**A**) Cross section of the Earth, **B**) S-wave paths and shadow zone; and **C**) P-wave paths and shadow zone

Earthquake ray paths and arrival times are more complex than illustrated in the animations, because velocity in the Earth does not simply increase with depth. Velocities generally increase downward, according to Snell's Law, bending rays away from the vertical between layers on their downward journey; velocity generally decreases upward in layers, so that rays bend toward the vertical as they travel out of the Earth (See Hot Link above to learn more about why they travel a curving path.) Snell's Law also dictates that rays bend abruptly inward at the mantle/outercore boundary (sharp velocity decrease in the liquid) and outward at the outer core/inner core boundary (sharp velocity increase).

### Concept Map



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*Limitations of the Model*
While engaging, this demo is a simplified model of natural phenomena. As such it is especially important to emphasize both the strengths and weaknesses of the model to students. Such an explicit discussion helps students focus on the model as a conceptual

representations rather than a concrete copy of reality. Beyond the expected, scale and compositional limitations of the model, an instructor should point out that seismic waves only travel outward all directions; not just in one direction like the line of students. Seismic waves also travel at speeds that are much faster, about 3000x faster, than the waves in the Human Wave model. Next, the instructor should also point out that the particle motion of an S wave can be in any direction that is perpendicular to the direction of wave propagation; not just up and down as shown in the demo. Finally, even though kinetic theory is not the targeted learning outcome of this demonstration, instructors should be specific about pointing out that in this demo the student “particles” are stationary for the purposes of the demo, but actual particles are constantly in motion, even in a solid.

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# What's inside of the Earth?

(Black Box Activity)

**Earthquakes in NC workshop**

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**Background:**

Humans have explored from the depths of the sea, to the highest mountains on the planet, we have even explored our solar system neighbor, the Moon. We have sent robotic spacecraft to other planets, moons, asteroids, and even comets, yet we have never sent probes, sampled or drilled through the crust of our home planet. The deepest drilling project humans have ever undertaken was Kola Superdeep Borehole at 12.2 km (7.6 miles). Considering that the crust is less than one percent of the distance to the center of the Earth, How do scientists know about the composition and internal structure of the Earth?

**Remote Sensing using Seismic Waves.**

Seismic waves are vibrations that are caused by earthquakes and large explosions. These waves travel at different velocities through different material. Some waves (p-waves) travel through both solid and liquid material while others (s-waves) only travel through solid material. By carefully measuring and mapping the arrival of seismic waves, scientists can create models of the internal structure of the Earth.

*This is a rather abstract concept to explain to middle and high school students. However, since a young age, these students all have used similar techniques to explore the world in which they live.*

**Materials needed:**

4 opaque plastic containers with tight lids (preferably black)

Plaster of Paris, Sand, water

Mix plaster of Paris and fill one container. Fill the others with sand, water and with air (just put lid on the container).

**Procedure in class:**

Invite students to come to a demonstration table where the four "black-box" containers are placed. Instruct the student to place one hand on the side of the container and to tap the container with the other hand. Do not allow them to look in or lift the container. Have students guess the contents of each container.

Ask students how they were able to identify the composition of the materials in each container. (Most will respond with comments about "Feeling the vibrations.") While fingers do not have the sensitivity of seismometers, most will have sufficient real world experience to correctly identify the contents of each container.

Explain that seismic waves are vibrations in the Earth and that seismometers can record these vibrations. With careful analysis of seismograms, we can model the internal structure and composition of the Earth in the same way they "felt" and correctly identified the composition of the mystery containers.

# Journey to the Center of the Earth©

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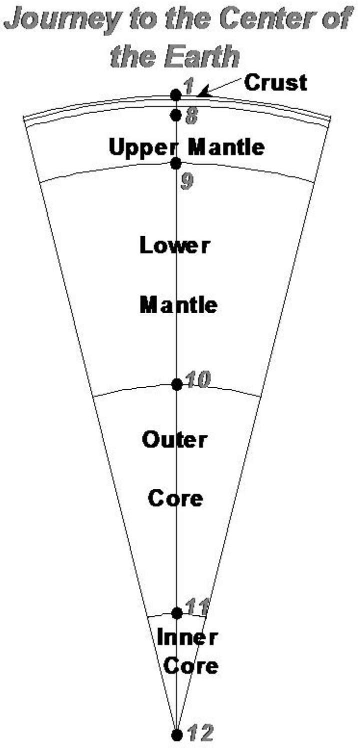
Explorations in Earth Science



**“But in the cause of science men are expected to suffer.”** (p. 28, *A Journey to the Center of the Earth*, Jules Verne, 1864)

**Objectives**: This virtual journey to the center of the Earth introduces the traveler to the structure, material properties and conditions within the Earth’s interior. The size and scale of the Earth and of the Earth’s internal structure are also emphasized because the journey utilizes a scale model of the depths within the Earth. Opportunities for creative writing and connections to literature are also provided through Jules Verne’s 1864 science fiction novel, *A Journey to the Center of the Earth*, and the 20th Century Fox 1959 movie adaptation (titled *Journey to the Center of the Earth*) starring James Mason, Pat Boone, Arlene Dahl, and Diane Baker.

**Background:** In the 1800’s there was considerable scientific and popular interest in what was in the interior of the Earth. The details of the internal structure (crust, mantle, outer core, and inner core; and their composition and thicknesses; Figure 1) had not yet been discovered. And, although volcanic eruptions demonstrated that at least part of the interior of the Earth was hot enough to melt rocks, temperatures within the Earth and the existence of radioactivity were unknown. Jules Verne’s book, *A Journey to the Center of the Earth* (1864, 272 pages; originally published in France as *Voyage au Centre de la Terre*), capitalized on this interest in the Earth and

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in adventure with an exciting science fiction story that is still popular today. Verne introduces us to a dedicated, and somewhat eccentric professor, and his nephew through whom the story is told (see selected quotations below), who eventually travel into the Earth's deep interior by entering into an opening in the crater of a volcano in Iceland.

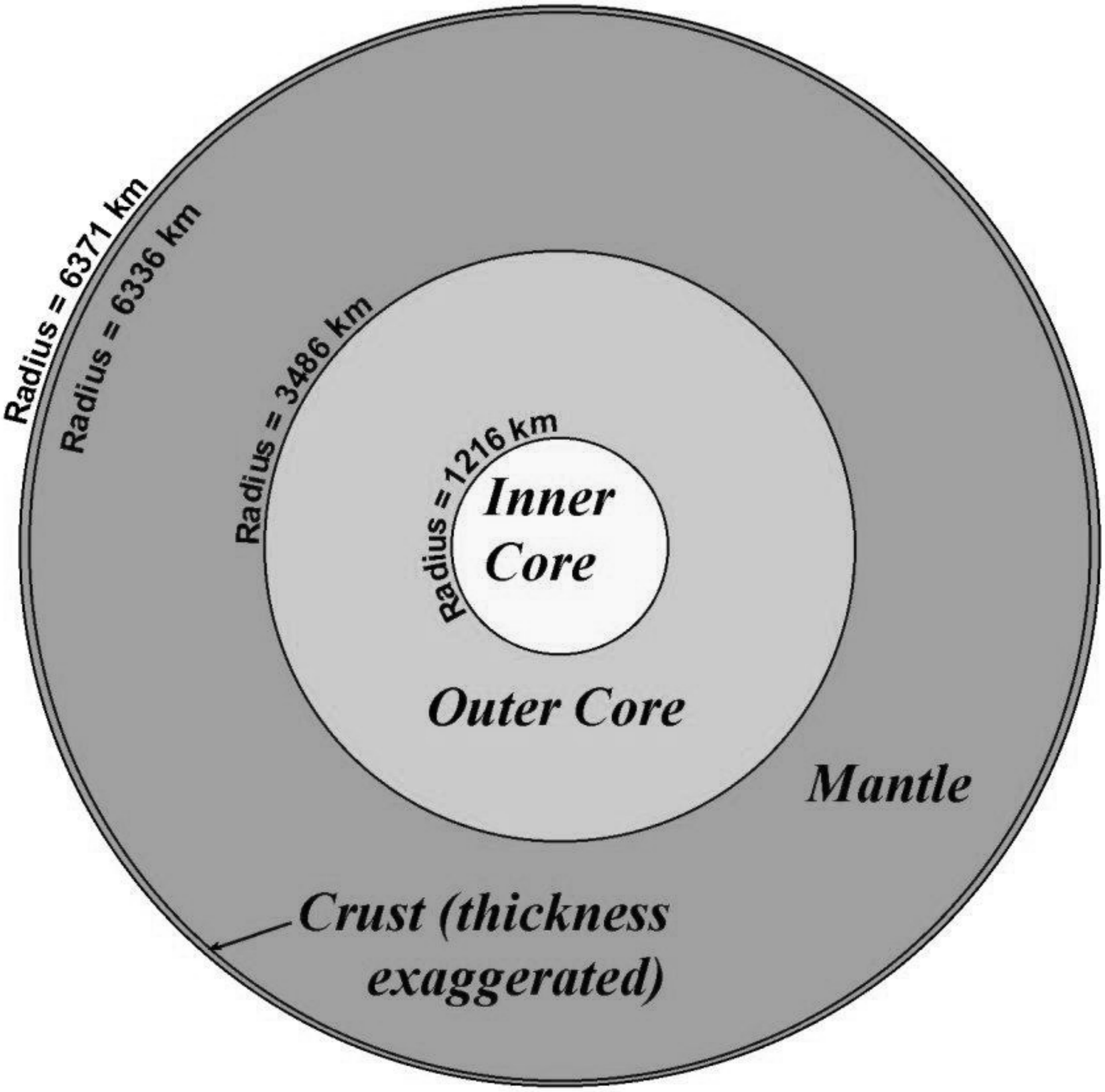

*Figure 1. Earth's interior structure. The Earth's crust is made up primarily of silicic (high percentage of Silicon and Oxygen) crystalline (distinct crystals of individual minerals are visible) rocks. The mantle makes up about 82% of the Earth by volume and consists of Iron- and magnesium-rich silicate rocks. The core is mostly iron, with a small percentage of nickel. The outer core is molten and the inner core is solid.*

"…and my uncle a professor of philosophy, chemistry, geology, mineralogy, and many other ologies." (p.1, Jules Verne, 1864)

"I loved mineralogy, I loved geology. To me there was nothing like pebbles—and if my uncle had been in a little less of a fury, we should have been the happiest of families." (p.3, Jules Verne, 1864)

"His imagination is a perfect volcano, and to make discoveries in the interest of geology he would sacrifice his life." (p. 14, Jules Verne, 1864)

Verne's novel is science fiction. We know today that such a journey would be impossible. The temperature and pressure conditions within the Earth are so extreme that humans could not survive below a few kilometers depth within the 6371 km radius Earth. Furthermore, we know of no significant openings that would provide access to the deep interior of the planet, and caves or cavities at great depth are nearly impossible based on our knowledge of temperature and pressure within the Earth and the properties of Earth materials. However, Verne's story is an interesting one and it is the inspiration (along with the desire to provide materials for learning about the Earth's interior) for this Earth science educational activity.

By the late 1800's, observations of temperature in mines and drill holes had demonstrated that temperature within the Earth increased with depth, and thus it is possible that the Earth's interior is very hot. Seismographic recordings in the early 1900's were used to identify the Earth's thin (about 5 – 75 km thick) crust (in 1909) and the existence of the core (in 1906). In 1936, Danish seismologist Inge Lehman presented evidence for the existence of a solid inner core. Since then, seismology and other geological and geophysical studies have provided considerably more detailed information about the structure, composition and conditions of the interior of the Earth. These features will be highlighted during our virtual "Journey to the Center of the Earth".

As it is commonly done, we have represented (Figure 1 and Table 1) the Earth as a layered sphere of 6371 km radius. The Earth is actually not quite spherical. Because of the rotation on its axis, the Earth is approximately an ellipsoid with the equatorial radius being about 21 km larger than the polar radius. Also, in detail, the Earth is not exactly spherically symmetric. Lateral as well as vertical variations in composition and rock properties have been recognized from seismological and other geophysical observations. Finally, because of plate tectonics, there are significant differences in shallow Earth structure in continental versus oceanic areas, near plate boundaries, and at different locations on the surface. For these reasons, the depths to the boundaries that we will encounter in our journey would be slightly different if we chose a different location for the start of our journey. The depths, properties and other descriptions listed in the scale model for our journey are reasonable average values for a continental region.

Once one realizes that the interior of the Earth is hot, it is natural to ask, why is it hot? Because the Earth is 4.5 billion years old, it would seem logical that the planet would have cooled by now. The heat within the Earth results primarily from two sources – original heat from the Earth's formation and radiogenic heat (Poirier, 2000). The largest of these sources, radiogenic heat, is mostly produced by three, naturally occurring, radioactive elements, Uranium, Thorium and Potassium. These elements are present in the mantle at concentrations of about 0.015 ppm (parts per million; meaning that only about 15 of every billion atoms in the mantle are Uranium) for

Uranium, 0.080 ppm for Thorium and 0.1% for Potassium (Brown and Mussett, 1981). Spontaneous radioactive decay of these elements releases heat. Although the major radioactive elements are more concentrated (10 to 100 times as abundant) in the Earth's crust, most of the radiogenic heat production comes from the mantle because of the much greater volume. The original heat from formation of the Earth dates from the accretion of the Earth from planetesimals that bombarded the early planet converting gravitational energy into heat.

Modern scientific information about the interior of the Earth comes from a variety of studies including: seismology in which seismic waves from earthquakes and other sources are used to generate images of the interior structure and determine the physical properties of Earth materials; analysis of the Earth's gravity field indicates density variations; high-pressure mineral experiments that are used to infer the composition of deep layers; thermal modeling of temperature measurements in drill holes; modeling of the Earth's magnetic field that is produced by convection currents in the electrically-conductive outer core; and chemical analysis of rock samples (called xenoliths) from deep within the Earth that are brought to the surface in volcanic eruptions. More information about the deep Earth and the methods of study of the Earth's interior can be found in the references listed below. A good starting point is the book by Bolt (1993), the American Scientist article by Wysession (1995) or a chapter on the Earth's interior by Wysession from an introductory geology textbook (see reference list). More advanced readers may wish to refer to Brown and Mussett (1981), Jeanloz (1993), Ahrens (1995), Wysession (1996), Poirier (2000) and Gurnis (2001). For younger readers, examine the children's book by Harris (1999). Much of the information about deep Earth properties and conditions given in Table 1 comes from Ahrens (1995). Information about microbes in the Earth's crust (mentioned in the Narrative, Stop number 3) is from Fredrickson and Onstott (1996).

**Procedure and Teaching Strategies:** A scale model (either a "classroom" scale or a "playground or hallway" scale; Figures 1 and 2 and Table 1) is used to provide the depths and locations of stops for a virtual journey to the center of the Earth.

Using a meter stick or meter wheel, mark out the locations of the 12 stops in the classroom (1:1,000,000 scale model; 6.37 m long) or playground or hallway (1:100,000 scale model; 63.7 m long). Masking tape placed on the floor or pavement is a convenient method for marking the stops. A felt pen can be used to label the stop number on the strip of masking tape. Folded index cards, labeled with the stop number, can also be used and have the advantage that the numbers can be seen from a distance (looking forward or backward to stops along the journey. Depths and the names of the locations can also be labeled using the masking tape, if desired. Provide each student in the class with a copy of the "Tour Guide" that can be produced as described near the end of this document. Folding the page in "thirds" creates a small brochure that each student can use on the tour and take home to help them remember the information that they learned and their experiences on the Journey to the Center of the Earth.

1. With the class, start at stop number 1 (the Earth's surface) and read the first part of the "Journey to the Center of the Earth Narrative" (below). Proceed to the other stops and read the appropriate section of the narrative at each stop. Be sure to point out the

distance that you've traveled in each move (by looking forward and backward along the model and using the scaled and actual distances from Table 1) and the distance that is remaining to travel to the Earth's center. Answer student (traveler) questions at each stop. The information in Table 1 may be useful for answering questions. Other questions may form the basis of class or individual student research ("let's find out") using the references listed below or library or Internet searches.

2. When back in the classroom, use transparencies (or copies) of Table 1 and Figures 1, 2 and 3 to review with the students the main features of the Earth's interior and the properties and conditions at various depths within the Earth. Note the increases in density, temperature and pressure with depth within the Earth and the abrupt changes in density at the major boundaries between layers. Additional questions can be answered or used to prompt additional study (such as other activities related to the Earth's interior structure or plate tectonics) or research or to provide an assessment of student learning from the activity.

3. As an extension, or to connect to reading, writing and literature study, have the class read Jules Verne's *A Journey to the Center to the Earth* (or selected chapters) or watch the movie (it is about 2 hours long, although one could skip the first approximately 30 minutes; starting as the explorers begin to climb the volcano). Relevant writing assignments for the students could be to write their own brief version of *A Journey to the Center of the Earth* based on the more accurate information about the nature of the Earth's interior; write a review of the book or movie, or write about the inaccuracies and misconceptions that are evident in the book and movie. The accuracies and misconceptions also can provide material for an effective class discussion and assessment of student learning after reading Verne's book or viewing the movie.

4. For younger students, reading *Journey to the Center of the Earth* (Harris, 1999) or *The Magic School Bus Inside the Earth* (Cole, 1987) before or after completing the journey is a useful extension and connection to literature.

5. Related Earth structure activities include Earth's Interior Structure (Braile, 2000) and Three-D Earth Structure Model (Braile and Braile, 2000). A useful and attractive color poster (Earth Anatomy poster) illustrating Earth's interior structure is available from the Wright Center for Science Education, Tufts University. A page size version of the poster can be downloaded from http://www.tufts.edu/as/wright_center/svl/posters/erth.html.

6. Additional extensions are also possible. An interesting assignment is to have each student or pair of students select one stop (depth) along the journey. Have the student or student team learn about the materials and conditions at that depth (some additional reading from the references provided below or from online sources would be necessary) and then draw an illustration that can be used to help describe each stop on the journey. Rock samples, if available (even photographs of rock or mineral samples from a book or from the Internet*), could also be placed at each stop to help illustrate the materials that

make up the Earth's interior. A piece of iron or steel can be used for the Earth's core remembering that it will be liquid iron in the outer core. The student experts from one class, stationed at each stop, could also be the tour guides that would provide information, show their illustration and rock sample, and read the appropriate section of the journey narrative for another class or group of students. The experience of students learning in-depth information about one area of the tour and serving as "experts" can be an excellent "students teaching students" approach to learning. To emphasize the long journey or tour experience in the "Journey to the Center of the Earth" activity, a glass of water, a piece of candy or other refreshments could be served at one of the stops, probably the core/mantle boundary (stop 10) which is a little less than half way along the journey in terms of depth.

7. Connections of this activity to the National Science Education Standards (National Research Council, 1996) are listed in Table 3 below.

* Photographs of appropriate rocks and minerals can be found at several online sources, including: http://www.soes.soton.ac.uk/resources/collection/minerals/ (these photos can be enlarged by clicking on the photo until the photograph is almost full screen size); examples of sedimentary rocks are appropriate for the surface stop, number 1, click on "Sedimentary Rocks" at top of web page; for example, see sample #8, a sandstone; Granite samples from the "Igneous Rocks" link can be used for stops 2, 3, 4, and 5, alternatively, Gneiss samples could be used to represent crustal rocks, particularly for stops 4 and 5 that are deeper in the upper continental crust; Gabbro or Basalt samples, also from the "Igneous Rocks" link can be used to represent lower crustal rocks; a photograph of Olivine, an iron-magnesium silicate that is a common mineral in the Earth's mantle – stops 6 – 10 – can be found in the "Minerals" section of the above web site or at: http://www.musee.ensmp.fr/gm/836.html; for the Earth's core, a photo of an iron-nickel meteorite (http://www-curator.jsc.nasa.gov/outreach1/expmetmys/slideset/IronMet.JPG) is a good representation of the material that forms the core. A selection of photos that are useful for representing typical rocks from the Earth's interior is provided in Table 2 below.

### Table 1. *Journey to the Center of the Earth*

| Stop Num. | Depth (km) | Scaled Depth (m) 1:1 million | Scaled Depth (m) 1:100,000 | Name or Location | Rock/ Material | Density (g/cm$^3$) | Pres-sure (MPa) | Temp. (Deg C) |
|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | Earth's Surface | Atmosphere<br>Sediments | 0.001<br>1.5 | 0.1 | ~10 |
| 2 | 1 | 0.001<br>(1 mm) | 0.01<br>(1 cm) | Top of "Basement" | Sed. Rocks<br>Granitic Rk. | 2.0<br>2.6 | 20 | ~16 |
| 3 | 3.6 | 0.0036<br>(3.6 mm) | 0.036<br>(3.6 cm) | Deepest Mine | Granitic Rock | 2.7 | 100 | ~50 |
| 4 | 10 | 0.01<br>(1 cm) | 0.1<br>(10 cm) | Upper Crust | Granitic Rock | 2.7 | 300 | ~180 |
| 5 | 12 | 0.012<br>(1.2 cm) | 0.12<br>(12 cm) | Deepest Drill Hole | Granitic Rock | 2.7 | 360 | ~200 |
| 6 | 35 | 0.035<br>(3.5 cm) | 0.35<br>(35 cm) | Base of Crust ("Moho") | Mafic Rock<br>Olivine-rich Rk. | 3.0<br>3.3 | 1100 | ~600 |
| 7 | 100 | 0.1<br>(10 cm) | 1 | Base of Lithosphere | Olivine-rich Rock | 3.4 | 3200 | ~1200 |
| 8 | 150 | 0.15<br>(15 cm) | 1.5 | Astheno-sphere | Olivine-rich Rock | 3.35 | 4800 | ~1300 |
| 9 | 670 | 0.67<br>(67 cm) | 6.7 | Upper Mantle Transition | Fe-Mg Silicate | 4.1 | 23800 | ~1700 |
| 10 | 2885 | 2.885 | 28.85 | Core/Mantle Boundary | Fe-Mg Silicate<br>Liquid Iron | 5.6<br>9.9 | 135800 | ~3500 |
| 11 | 5155 | 5.155 | 51.55 | Inner Core/Outer Core Bound. | Liquid Iron<br>Solid Iron | 12.2<br>12.8 | 329000 | ~5200 |
| 12 | 6371 | 6.37 | 63.7 | Center of Earth | Solid Iron | 13.1 | 364000 | ~5500 |

## **Table 1.** **(cont.)** *Journey to the Center of the Earth*

| Stop Num. | Description/Comments |
|---|---|
| 1 | The Earth's surface is a marked boundary, between the solid or liquid Earth below and the Atmosphere above, with distinct changes in properties. Surface materials on land are usually soil, sediments, sedimentary rocks or weathered crystalline rocks. |
| 2 | Beneath surface sedimentary rocks, lies a crystalline "basement" made up of igneous or metamorphic rocks, usually of granitic composition. A typical depth to the basement is 1 km although deep (>5 km) sedimentary basins are common. |
| 3 | The deepest depth that humans have explored on land is in a gold mine in South Africa -- almost 3.6 km deep. In the oceans, a special submarine carried explorers to the bottom of the Mariana trench at over 11 km below the Pacific Ocean's surface. |
| 4 | Upper layer of continental crust consists of granitic (high % of Silicon and Oxygen) rocks. Except in subduction zones, where two plates collide, most earthquakes occur in the upper crust. Lower crust is more mafic (higher % of Mg and Fe). |
| 5 | The deepest drill holes in the Earth are about 12 km deep. Rock samples have been recovered from these depths. The holes have been drilled for scientific study of the crust and to explore for petroleum in deep sedimentary basins. |
| 6 | The crust-mantle boundary, or "Moho", separates mafic rocks of the lower crust from Olivine-rich rocks that make up the Earth's mantle. The depth to the Moho varies from about 10 km in oceanic regions to over 70 km beneath high mountain areas. |
| 7 | The depth of this boundary is controlled by temperature. It is a gradual rather than an abupt boundary. The lithosphere (tectonic plates) above is relatively cool, rigid and brittle. Lower lithosphere is mantle. Beneath is the "soft" asthenosphere. |
| 8 | Partial melting of mantle rocks in this layer produces magma for volcanic eruptions and intrusions. Although a solid, asthenosphere is hot enough to flow in convection currents. Lithosphere/asthenosphere boundary is shallower in hot regions. |
| 9 | As pressure increases with depth in mantle, Fe and Mg silicate minerals compress into more dense crystalline forms in the transition zone and below. Mantle is relatively homogeneous chemically and forms ~82% of Earth by volume. Deep earthquakes in subduction zones are found to a depth of about 670 km. |
| 10 | Boundary separates liquid iron core from the silicate rock mantle. A transition zone (~200 km thick) exists just above the core-mantle boundary that may represent areas of partially melted mantle (the bottom of mantle plumes) from heat flowing from the outer core, or old lithospheric slabs that have descended to the bottom of the mantle. The core is ~16.5% of the Earth by volume but about 33% of the Earth by mass. No seismic shear waves travel in outer core. Convection currents in the electrically conductive outer core produce Earth's magnetic field. |
| 11 | This boundary separates the solid inner core from the liquid iron (and ~10% nickel, sulfur, silicon and oxygen) outer core. Although the radius of the inner core is about 1216 km, the inner core includes only about 0.7% of the volume of the Earth. |
| 12 | Earth's center is within the dense, iron inner core. Although the temperature is very high, the pressure is so great (~3.6 million times the pressure at the surface), that the inner core is solid. |

| **Table 1. (cont.)** *Journey to the Center of the Earth* **Description of Column Headings:** |
|---|
| **1. Stop Number** -- The stop number for our virtual "Journey to the Center of the Earth", in which we will travel from the Earth's surface to the Earth's center (using a scale model). |
| **2. Depth** -- The depth (in the Earth) in kilometers corresponding to each stop in our journey. Many of the depths are approximate and will vary by location. |
| **3. Scaled Depth** -- The depth (in meters) for each stop in the 1:1 million scale model. Total depth (surface to center) in the scale model is 6.37 m. "Classroom scale" model. |
| **4. Scaled Depth** -- The depth (in meters) for each stop in the 1:100,000 scale model. Total depth (surface to center) in the scale model is 63.7 m. "Playground or hallway scale" model. |
| **5. Name or Location** -- Description or name of the location of each stop. |
| **5. Rock/Material** -- Rock type, description or composition of the material at each stop. Two entries separated by a line give the rock type or material both above and below a boundary at the corresponding depth. |
| **6. Density** -- The approximate density (in grams per cubic centimeter; for comparison, the density of water is 1 g/cm$^3$) of the material at each stop. Two entries separated by a line give the density of the rock or material above and below the boundary. |
| **7. Pressure** -- The approximate pressure (in Mega-Pascals) at each stop (depth in the Earth). One atmosphere of pressure (the pressure at the Earth's surface due to the weight of the atmosphere above us) is about 0.1 MPa (1 Kg/cm$^2$ or ~14 lbs/in$^2$). The pressure in the tires of a car (and at about 10 meters depth under water) is about 2 atmospheres or about 0.2 MPa. |
| **8. Temperature** -- The approximate temperature in degrees Celsius at each stop (depth in the Earth). |
| **9. Description/Comments** -- Description and comments about the material and conditions at each stop in the journey. |

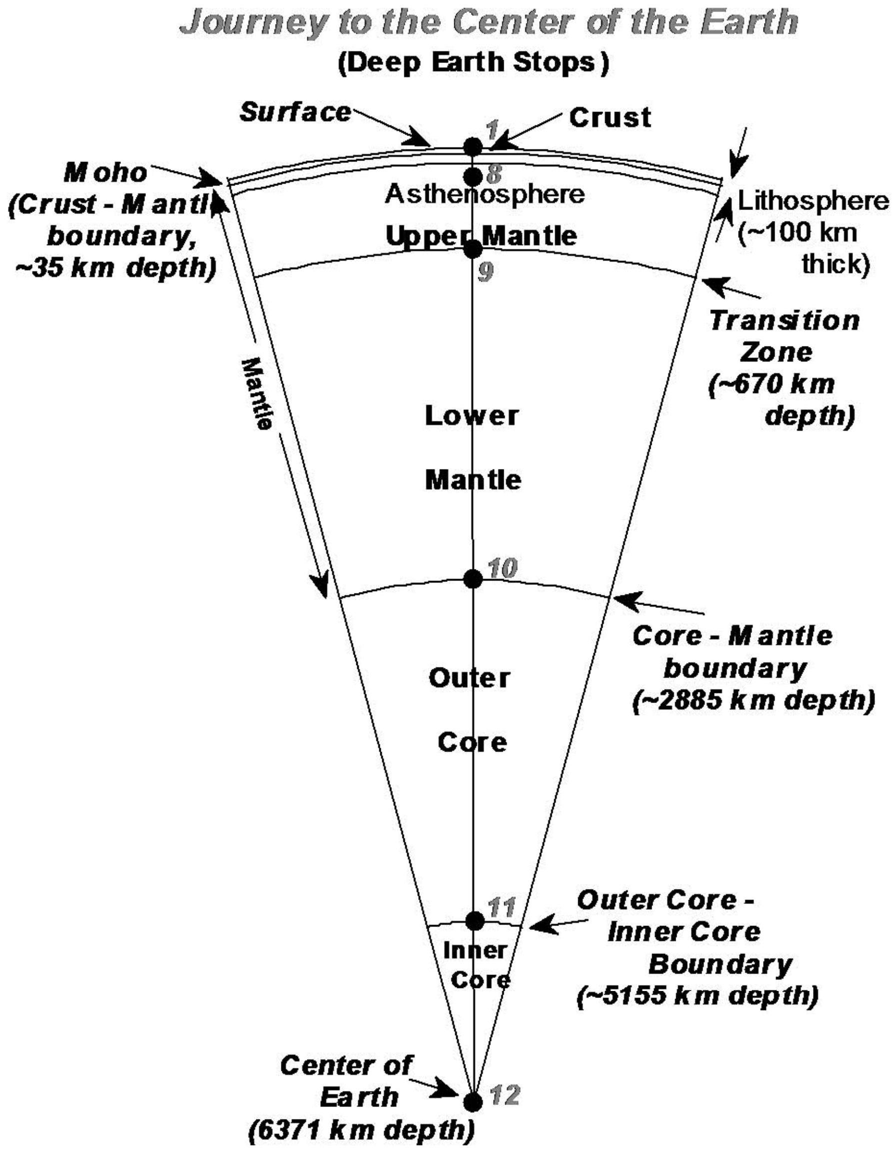

*Figure 2. Earth's interior (to scale) showing the depths to the major boundaries between the Earth's layers (spherical shells). The numbered dots indicate the locations of the stops (Table 1) in our virtual journey. A close-up view (Figure 3) of the upper 150 km of the Earth's interior shows the locations of the first eight stops.*

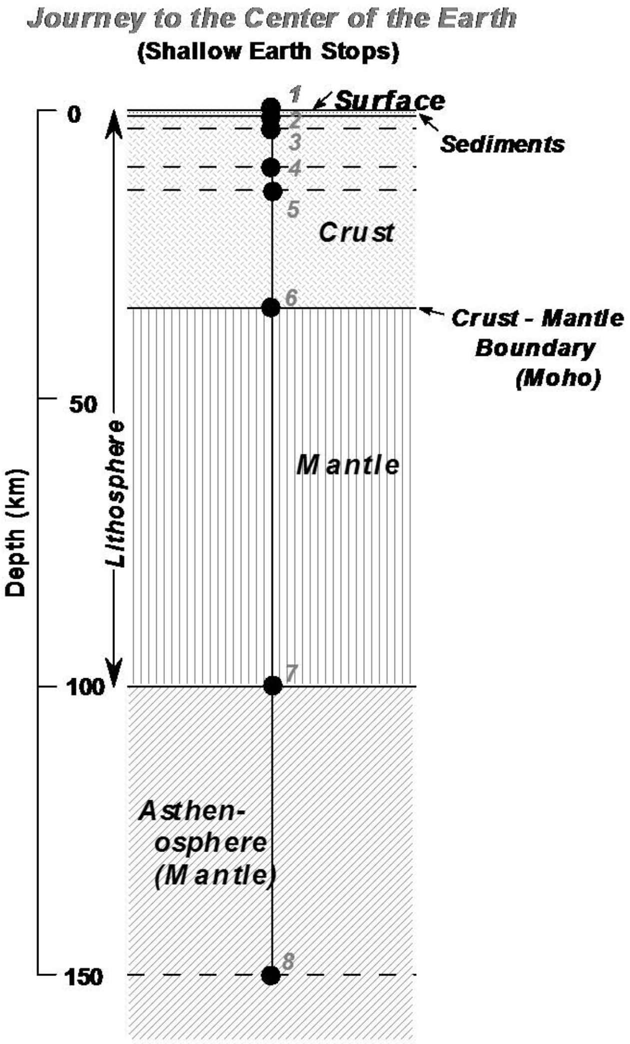

*Figure 3. Shallow Earth structure showing the depths to boundaries in the upper 150 km of the Earth. The numbered dots indicate the locations of the first 8 stops (Table 1) in our virtual journey.*

## Narrative for "Journey to the Center of the Earth":

Attention! Attention! We are ready to start our journey to the center of the Earth. My name is Mrs. Braile[1] and I will be your tour guide today. We are going to learn many fascinating things about the interior of the Earth. Please feel free to ask questions along the way and I will try to answer them. Our journey is long, so I hope that you've had a big breakfast. Also, there are no rest rooms along the way. So, prepare yourself for an exciting journey!

We will begin at the Earth's surface – our familiar home. Except for natural caves, tunnels, mine shafts, and drill holes that extend from the surface to depths of a few kilometers, we know of no large openings that could provide access to the Earth's deep interior. Furthermore, the very high temperature and pressure and the lack of air in the deep Earth create conditions that we could not survive. In addition, it is a long journey – it is 6371 kilometers to the Earth's center. If we were able to walk directly to the Earth's center, it would take about 53 days (at 5 km/hr, 24 hours per day) of walking. And then, we'd have to walk back! Even if there were a very fast elevator that would take us to the Earth's center, the time that our journey would take would only be reduced to about 4 ½ days. If there was a highway to the Earth's center, it would take about 64 hours to drive there at 100 km/hr. Because of these facts, we will be taking a *virtual* journey to the center of the Earth using a scale model. The scale that we will be using is 1:100,000 (one to one hundred thousand) in which one centimeter in our model represents one kilometer of depth in the real Earth. Using this scale, our model of the distance from the Earth's surface to its center is 63.7 meters long.[2] Another way to understand the concept of scale is to realize that we would have to multiply the depths in our scale model by *100,000* in order to produce the actual depths in the Earth! We will begin at the surface and make 12 stops along our journey to the center of the Earth. At each stop, we'll observe the relative distance that we've traveled in our scale model, and learn about the materials and conditions that exist at these locations within the Earth.

**Stop Number 1 – Earth's Surface:** We're already at our first stop – the Earth's surface. If we began our journey at a different location we would probably find different geological materials at the surface. For example, if we started in a desert region, we might find sand deposits or sandstones at the surface, or if we started in Hawaii, we would most likely begin on volcanic rock. If we began our journey in the middle of the ocean, we would find a layer of ocean water at the surface. Here in Indiana, the near-surface deposits are mostly glacial sediments deposited during the period of 15,000 to about a million years ago.[1] Beneath the glacial sediments are layers of Paleozoic sandstones, shales and limestones that were deposited in a shallow ocean over 300 million years ago. Of course, above us is the Earth's atmosphere, consisting of about 21% oxygen, which we breathe in order to live. Deep in the Earth, we would not have sufficient air to breath. However, that won't be a problem in our virtual journey.

Let's go to our next stop – it isn't far.

**Stop Number 2 – Top of the Crystalline Basement:** Here we are about 1 km beneath the surface. In continental regions, this is a typical depth to the bottom of the near-surface sediments and sedimentary rocks. The crystalline basement is immediately beneath us. In areas where there are deep sedimentary basins, or in ocean basins, the depth to the basement is significantly greater – up to 10 km or more. In continental areas, the crystalline basement usually consists of igneous and metamorphic rocks of granitic composition. These rocks have interlocking crystals made of minerals that are easily visible and have a composition that includes about 70% Silicon and Oxygen. You may be familiar with the common igneous rock of this type, called granite. The crystalline basement is the top of a layer that makes up most of the Earth's crust.

Our next stop is even deeper in the crust.

**Stop Number 3 – Depth of Deepest Mine:** This stop is at a depth of 3.6 km (3600 meters) below the surface and is the depth of the deepest mine in the world. It is a gold mine in South Africa, and it's the greatest depth that humans have gone beneath the continents. However, it is not the greatest depth where life exists. Subsurface bacteria (microbes) have been found in drill holes about 3 km beneath the surface and have been shown to be able to survive temperatures as high as 110 degrees Celsius. At this temperature, it is likely that microbes exist in the Earth's crust as deep as about 7 km beneath oceans and about 4-5 km beneath continents.

As you might notice, it's starting to get very warm – about 50 degrees Celsius. You can touch the rocks but don't leave your hand on the rocks for very long or you will burn your hand!

Let's move on.

**Stop Number 4 – Upper Crust:** We're now deep within the crust at a depth of 10 km. Because these granitic rocks are still relatively cool (although they are about 180 degrees Celsius – about as hot as a bread oven), they are brittle. Except in subduction zones, where two tectonic plates collide, most of the world's earthquakes occur within the upper crust within a few kilometers of our present depth. If we had begun our journey above a deep sedimentary basin, we might find petroleum deposits (oil or natural gas within the pore spaces of sandstones or other porous rocks) at this depth. If we had begun our journey at the surface of the ocean, we would be near the base of the oceanic crust at this depth. The oceanic crust consists of marine sediments overlying rocks of approximately basaltic composition.

If there are no questions, we'll go to the next depth.

**Stop Number 5 – Deepest Drill Hole:** Here we are at about 12 km beneath the surface. This is the depth of the world's deepest drill hole (in the Kola peninsula of Russia). The pressures and temperatures are so great that it is difficult to build drill bits and drilling equipment that will penetrate these rocks. The rocks are also so compacted that there is almost no space between the crystals or grains that make up the rocks. We definitely couldn't survive here.

Although our next stop is the base of the continental crust, it's only about one half of one percent of the way along our journey! We shouldn't delay.

**Stop Number 6 – Base of the Crust:** We've reached the base of the crust. It is also called the crust/mantle boundary, or "Moho", after Andrija Mohorovicic the Croatian seismologist who discovered this prominent boundary in 1909. If you'll look back toward the Earth's surface, you'll notice that we really haven't gone very far on our journey to the center of the Earth. The depth to the Moho averages about 35 km beneath continents but is about 10 – 15 km depth beneath oceans. The Moho is an abrupt boundary in composition and properties. Just above the Moho, the lowest layer of the crust consists of more mafic (higher in Magnesium and Iron) rocks than the granitic rocks that we've been traveling through in the upper crust. Below is the mantle – a thick layer that forms about 82% of the Earth's volume; so we'll be traveling through the mantle for a long time. Like the crust, the mantle is also made up of silicate (high percentage of Silicon and Oxygen) rocks. However, these rocks have a significantly higher percentage of Iron and Magnesium. A common material in the mantle is Olivine – an olive green mineral that is commonly found as large crystals in basaltic volcanic rocks such as in Hawaii.

Let’s go to the next stop.

**Stop Number 7 – Base of the Lithosphere:** Here we are at the base of the lithosphere. Notice that the lithosphere consists of the crust *and* the uppermost part of the mantle. This boundary is gradual with depth, not an abrupt “discontinuity”. The depth (~50 – 300 km) to the base of the lithosphere is controlled by temperature. Where temperatures in the upper mantle are higher than average, such as beneath mid ocean ridges and in active tectonic zones in continental areas, the lithosphere is thinner. Old, relatively cool lithosphere is much thicker. The lithosphere forms the tectonic plates that separate, collide, and slide past each other to create the Earth’s landscape and produce mountain ranges, faults, earthquakes and volcanic eruptions. Below the lithosphere, temperatures are hot enough to partially melt the mantle rocks, forming the asthenosphere – the primary source of magma that erupts from volcanoes on the surface.

The asthenosphere is our next stop.

**Stop Number 8 – Asthenosphere:** Except beneath areas that are very old (over about one billion years) and have relatively cool upper mantle, at our current depth of 150 km, we would find ourselves within a very hot (about 1300 degrees Celsius) mantle that is partially (probably less than 1-2 percent) molten and flowing. Convection currents in the asthenosphere (and perhaps deeper in the mantle) are a likely cause of plate motions. Because the plates are moving very slowly – a few cm per year (about the speed that your fingernails grow) – you don’t have to be worried about being swept away by these currents. Because seismic shear waves travel through the asthenosphere, we classify this part of the mantle (as well as the rest of the mantle) as a solid even though it flows. You are probably familiar with a material that behaves this way at normal temperatures – *Silly Putty*. Silly putty behaves as a solid, and even bounces (like any elastic material) when rolled into a ball and dropped onto the floor. However, it can be stretched, and slowly flows over longer periods of time. It even flows slowly into the form of the plastic egg-shaped container that it is sold in. This behavior, over longer periods of time, is more like a liquid.

Take a close look at the rocks here. You might find diamonds! Diamonds form in the upper mantle from Carbon atoms at high pressure at depths greater than about 150 km. The diamonds can be deposited closer to the surface in “Kimberlite pipes” – narrow vents that are created in brief explosive eruptions.

Well, we’ve got a long distance to go to our next stop, so we’d better start walking.

**Stop Number 9 – Upper Mantle Transition Zone:** We’re well below the asthenosphere now at about 670 km depth. The pressure is so great at this depth that some of the minerals that form mantle rocks undergo a transformation in their crystal structure that results in a tighter packing of the atoms that make up the mineral. Because of this tighter packing, mantle rocks in the upper mantle transition zone (about 400 – 700 km) become denser with depth even though the chemical composition of the rocks is virtually the same. Therefore, lower mantle rocks are similar in composition to the olivine-rich rocks of the upper mantle but are of higher density. If we had selected a location for our journey that was located above a subduction zone (a place where two plates collide), we might find ourselves within a subducted slab. These parts of lithospheric plates descend, normally at steep angles and at typical plate tectonic velocities – about 2-10 cm/year, from the collision zone at the surface into the mantle. Therefore, these slabs formerly were near the Earth's surface. Because the slabs remain cooler than the surrounding mantle for tens of millions of years, deep earthquakes occur within or at the edges of these slabs. The deepest earthquakes occur at about 670 km depth.

I know that you can feel the intense heat and pressure that are present at this depth, so we need to move on. Our destination, the center of the Earth, is still very distant; in fact, we've only traveled just over 10 percent of our journey. We'll make fewer stops for the rest of the journey.

**Stop Number 10 – Core/Mantle Boundary:** We're now 2885 km below the surface and at the core/mantle boundary. Let's turn around and look at the Earth's surface to see how far we've gone and to see how much of the Earth is mantle. Let's also look further down in depth to the Earth's center to see how far we have to go. This boundary is the most prominent boundary in the Earth's interior. It is a dramatic boundary in composition, and therefore density, with silicate rocks of the mantle above and dense iron and nickel below. In addition, the mantle above is solid and the outer core below is liquid. The boundary probably varies laterally, and in detail is a transition zone above the liquid outer core that is about 200 kilometers thick. The transition zone has been interpreted to consist of the bottom of mantle plumes where heat flowing from the outer core causes partial melting of the mantle rocks above the core mantle boundary and lithospheric plates (old subducted slabs) that have descended to the bottom of the mantle. The temperature here is about 3500 degrees Celsius, about 2 –3 times hotter than a blast furnace and hot enough to melt iron even under the great pressure that exists at this depth. Because of the dense rocks and high pressure, compressional seismic waves (P-waves) travel at nearly 14 km/s in the mantle just above this boundary. Because the outer core is liquid, the P-wave velocity decreases to about 8 km/s and shear (S) waves cannot propagate in the outer core. Also, the hot, electrically-conductive outer core liquid flows by convection, generating the Earth's magnetic field. It is this magnetic field that aligns the needle on our compass at the Earth's surface.

You may wonder why the temperature is so high in the Earth's interior. Most of the heat comes from radioactive decay of Uranium, Thorium and Potassium atoms that are found in the mantle. These elements are of fairly small concentration in the mantle, so the level of radioactivity is low. However, there are enough radioactive atoms in the mantle to generate significant heat. Some of the Earth's heat was also generated at the time of formation of the planet by bombardment of planetesimals (causing melting) during the accretion of the Earth. Because rocks are not good conductors of heat, the temperature in the interior has remained high.

Well, it's really getting hot, so I'm sure that you're anxious to complete our journey and get back to the Earth's surface. Let's hurry to our next stop.

**Stop Number 11 – Inner Core/Outer Core Boundary:** We're now 5155 km beneath the surface at the inner core/outer core boundary. The material both above and below us is iron, along with a small percentage of nickel and probably oxygen or sulfur. Above us the iron-nickel outer core is molten. Below us the pressure is so high that, even though it is very hot, the iron-nickel inner core is solid. Although the radius of the inner core is 1216 km (look toward the center of the Earth in our model; that's how far we have to go), the inner core is only 0.7 percent of the Earth by volume.

Let's hurry; only one more stop!

**Stop Number 12 – Center of the Earth:** Well, we made it. Congratulations, we're at the center of the Earth! It's 6371 km back to the surface. Take a look at how far we traveled from the surface. The temperature is about 5500 degrees Celsius. The pressure is over 3.6 million times the pressure at the Earth's surface. HOWEVER, I MUST WARN YOU TO HOLD ON! Because there is approximately the same amount of Earth all around us (we're in the center of a nearly spherical planet), Earth's gravity here is ZERO. *If* there was an opening here, we would feel weightless! However, the pressure and temperature are very high, so we could not survive. It's a good thing this is a *virtual* journey!

It's now time to go back to the surface. It's been a long journey, so let's go directly back.

**Back at Stop Number 1 – Earth's Surface:** Thank you for being such a good tour group! I hope that you've enjoyed our Journey to the Center of the Earth and that you've learned some interesting things about the Earth's interior. If you have any additional questions about our journey or about the interior of the Earth, I'd be glad to try to answer them for you.

[1] There are several places in the narrative that can be personalized for your use.

[2] The narrative is written assuming the playground or hallway (1:100,000, or 63.7 m long) scale model (Table 1). If the classroom (1:1,000,000, or 6.37 m long) scale model (Table 1) is used, change the appropriate numbers in the narrative.

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**Acknowledgments:** We thank Michael Wysession, Barry Marsh and John and Kathy Taber for providing information or assistance. The development of this activity was partially supported by the National Science Foundation.

**Tour Guide:** Provide each student in the class with a copy of the "Tour Guide" that can be produced by printing the next two pages of this document. Trim each image and enlarge each one to fit on one page. Or, print the Tour Guide from the .doc (recommended; margins are better) or .pdf files: guide.doc or guide.pdf. Copy (in color or black and white) on the front and back of a sheet of paper. Make copies for the class. Folding the page in "thirds" creates a small brochure that each student can use on the tour and take home to help them remember the information that they learned and their experiences on the Journey to the Center of the Earth.

To generate additional interest in the Journey to the Center of the Earth tour, one can make a construction paper "hardhat" (Figures 4 and 5) for the tour leader or for each participant in the tour (the idea of wearing a hat for the tour was provided by John and Kathy Taber).

**Labels:** A set of labels for the stops along the Journey tour is available in the MS Word document: http://web.ics.purdue.edu/~braile/edumod/journey/labels.doc. The labels include a single page to mark the first five stops. Labels that can be placed at the appropriate scaled distance for Stop 1 and Stops 6-12 are also included. The label for the first five stops is designed for the 1:100,000 scale (63.7 m scale model). The labels should be printed on card stock paper. Labels for Stops 1 and 6-12 can be folded to make a convenient and visible sign.

This document at:
MS Word format: http://web.ics.purdue.edu/~braile/edumod/journey/journey.doc
HTML format: http://web.ics.purdue.edu/~braile/edumod/journey/journey.htm
PDF format: http://web.ics.purdue.edu/~braile/edumod/journey/journey.pdf

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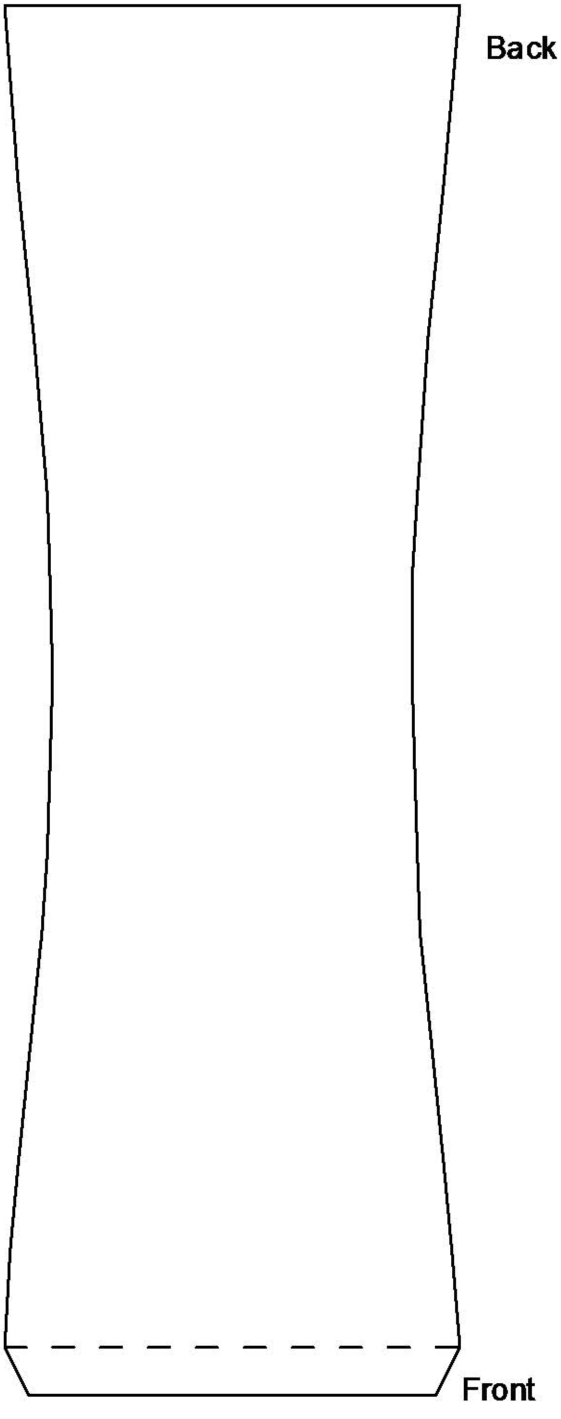
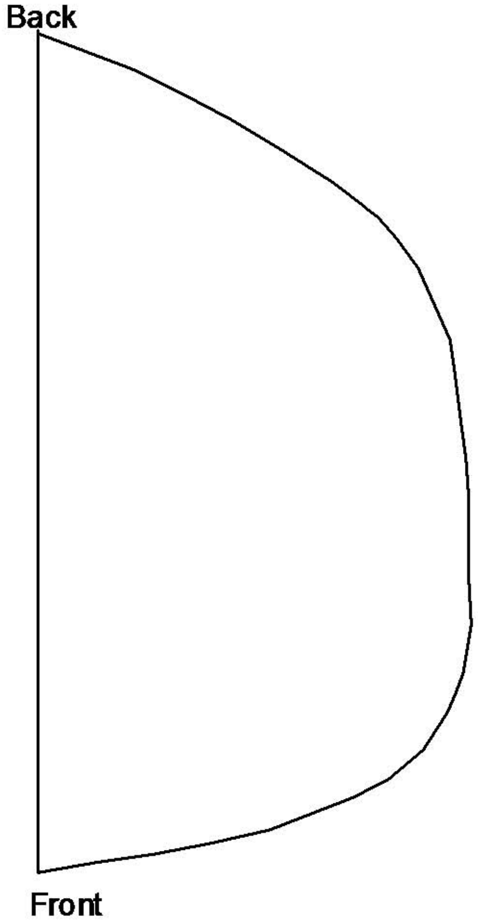
braile@purdue.edu





Template for paper hardhat sides. Enlarge 200% and cut out two sides using red, yellow or orange construction paper.

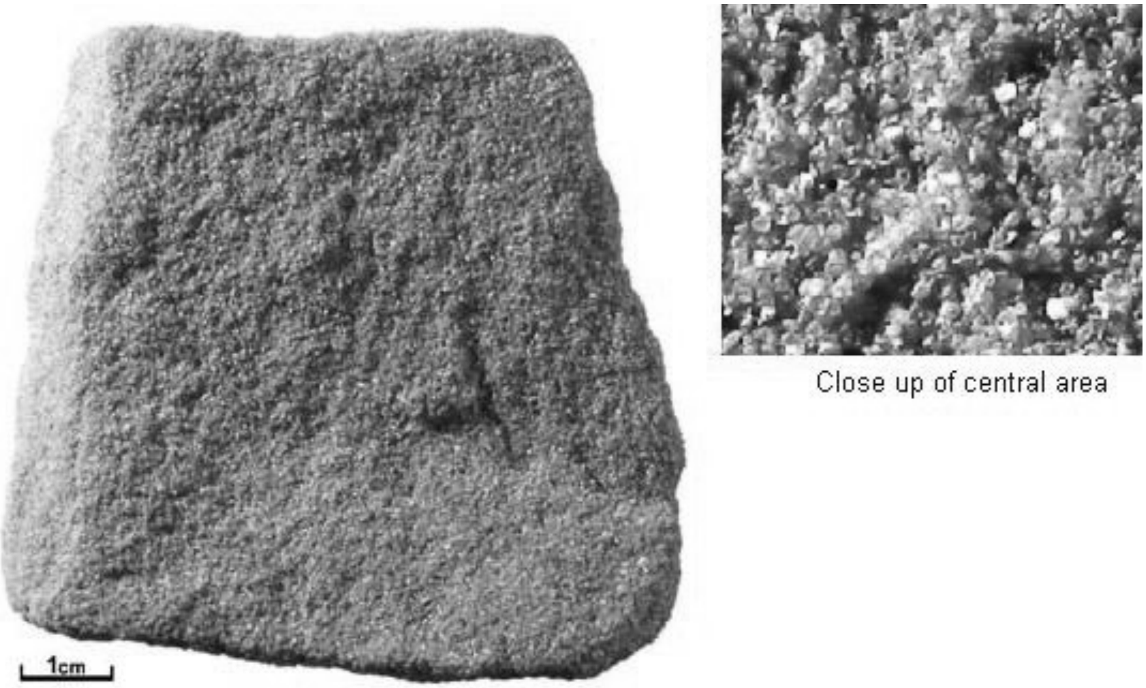
Template for paper hardhat top. Enlarge 200% and cut out one top using red, yellow or orange construction paper. Fold along dotted line to form the "bill" of the hat.

*Figure 4. Template for making a "hardhat" (Figure 5) out of construction paper for the Journey to the Center of the Earth tour.*

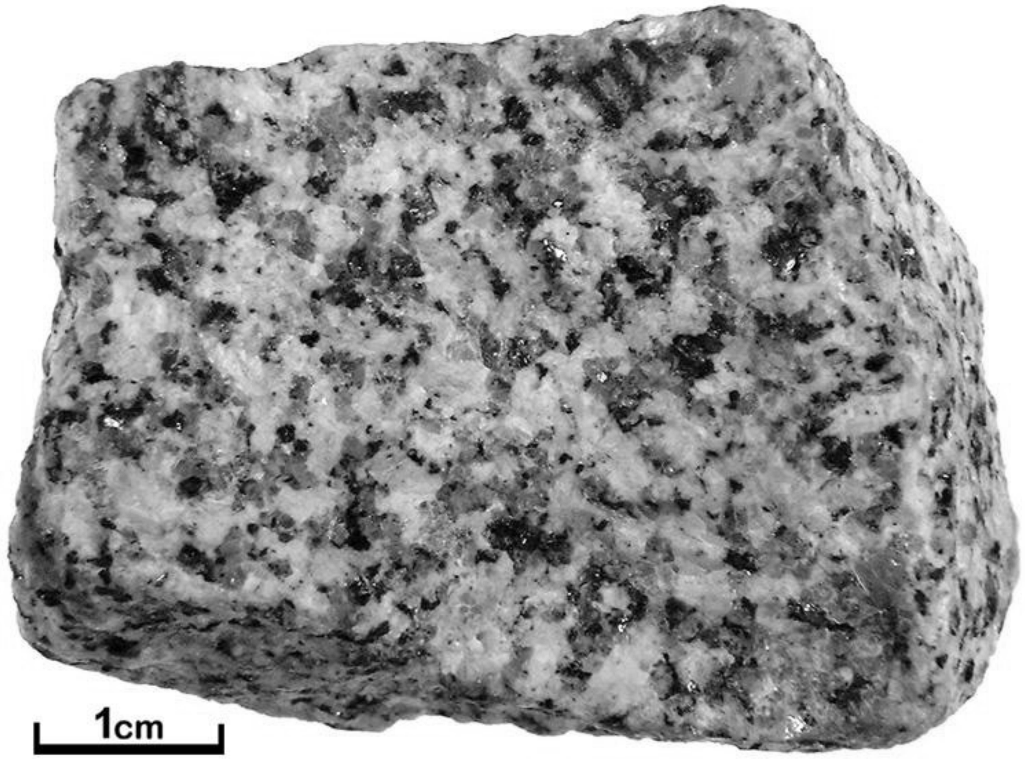
*Figure 5. Photograph of completed construction paper "hardhat." The templates for the sides and top are given in Figure 4. The two sides are joined to the top with small pieces of transparent tape in the inside of the hat. The Journey to the Center of the Earth logo (below) is taped to the front of the hat with two-sided tape.*

**Table 2. Photographs of rock samples that can be used to represent possible rock types for selected stops in the Earth's interior*.**

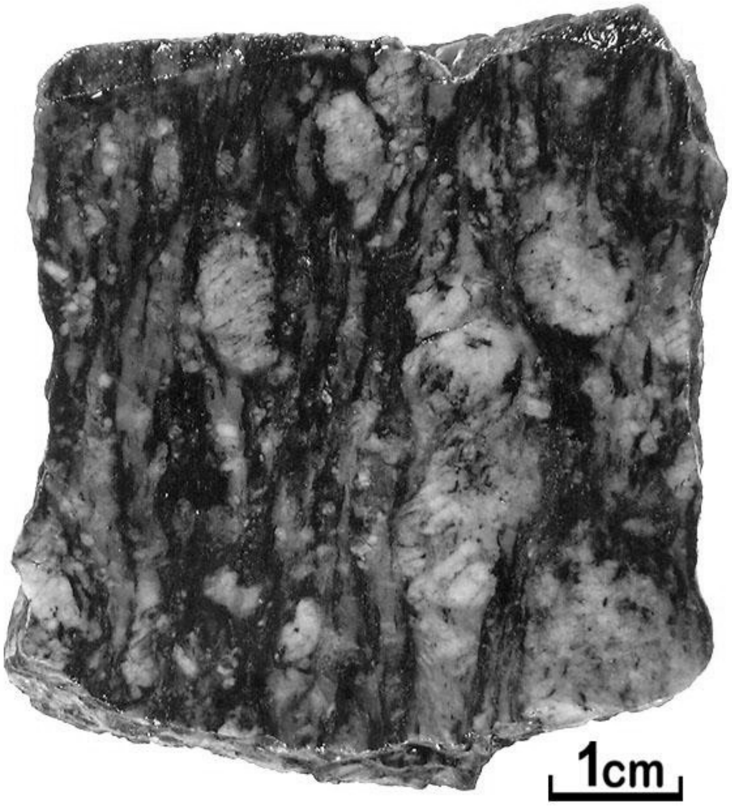
**1. Sandstone**



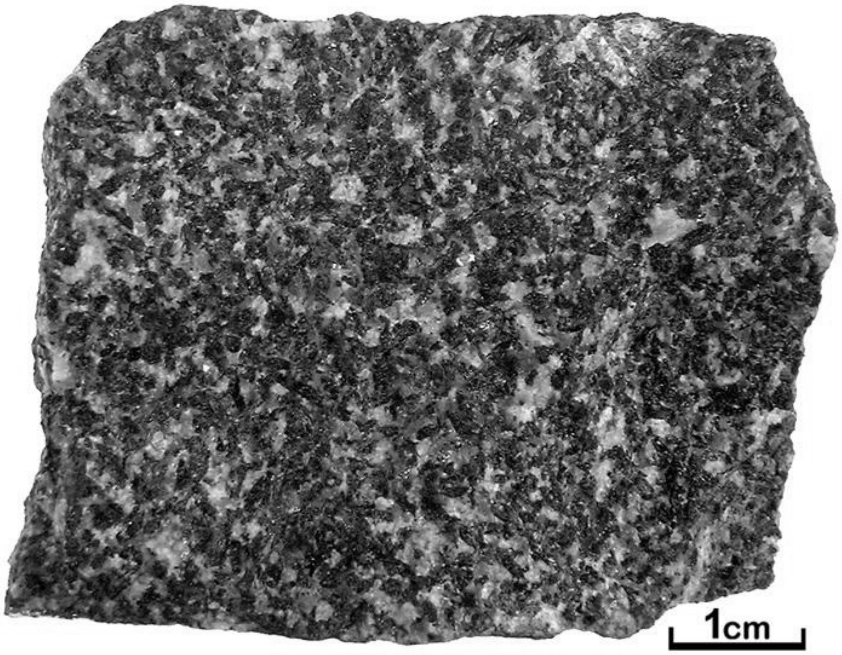
**2. Granite**



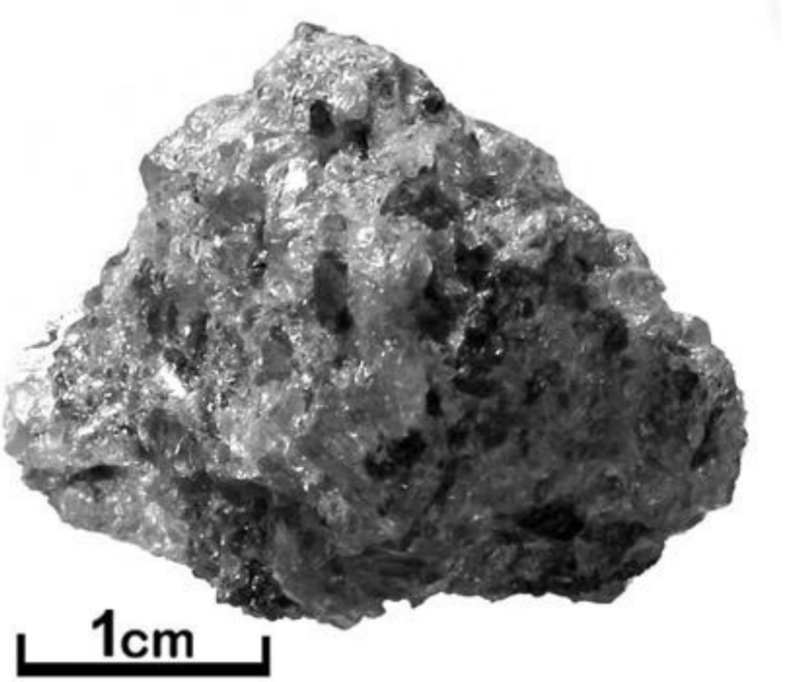
**2. Gneiss**



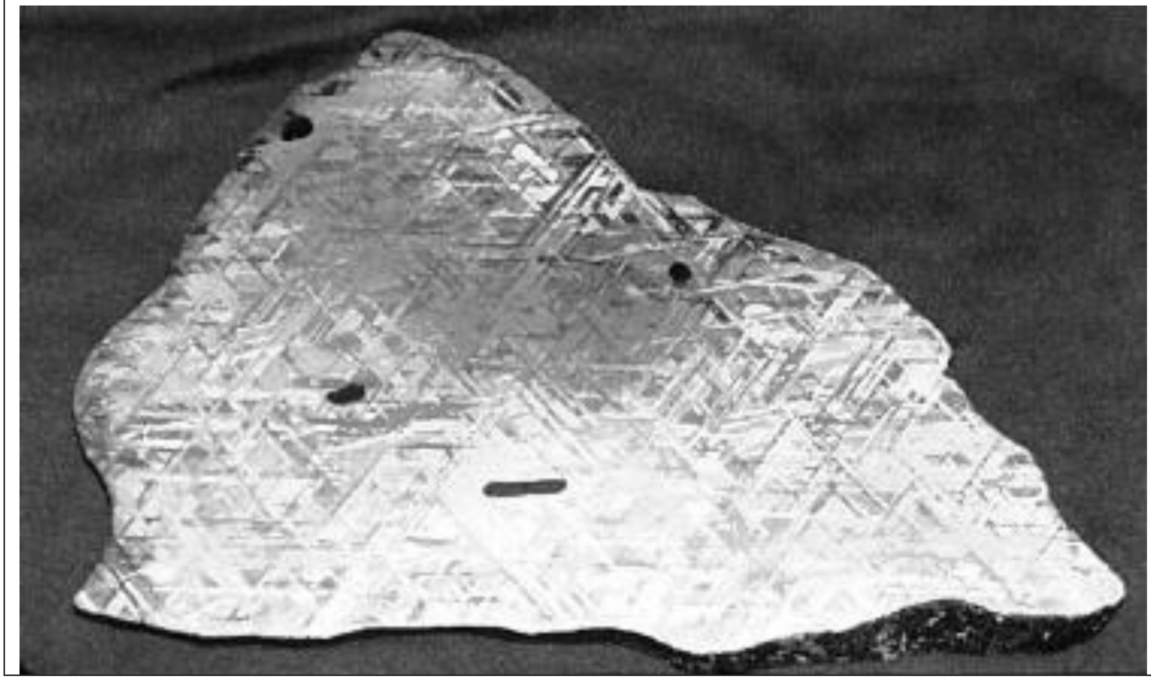
**3. Gabbro**



5. **Olivine**



6. **Iron-Nickel Meteorite**



* Photos 1 – 5 courtesy of Barry Marsh, School of Ocean and Earth Science, Southampton Oceanography Center, University of Southampton, UK; used with permission. For more information and additional rock and mineral sample photographs, see http://www.soes.soton.ac.uk/resources/collection/minerals/. Photo 6 is from NASA, http://www-curator.jsc.nasa.gov/outreach1/expmetmys/slideset/Slides35-42.htm.

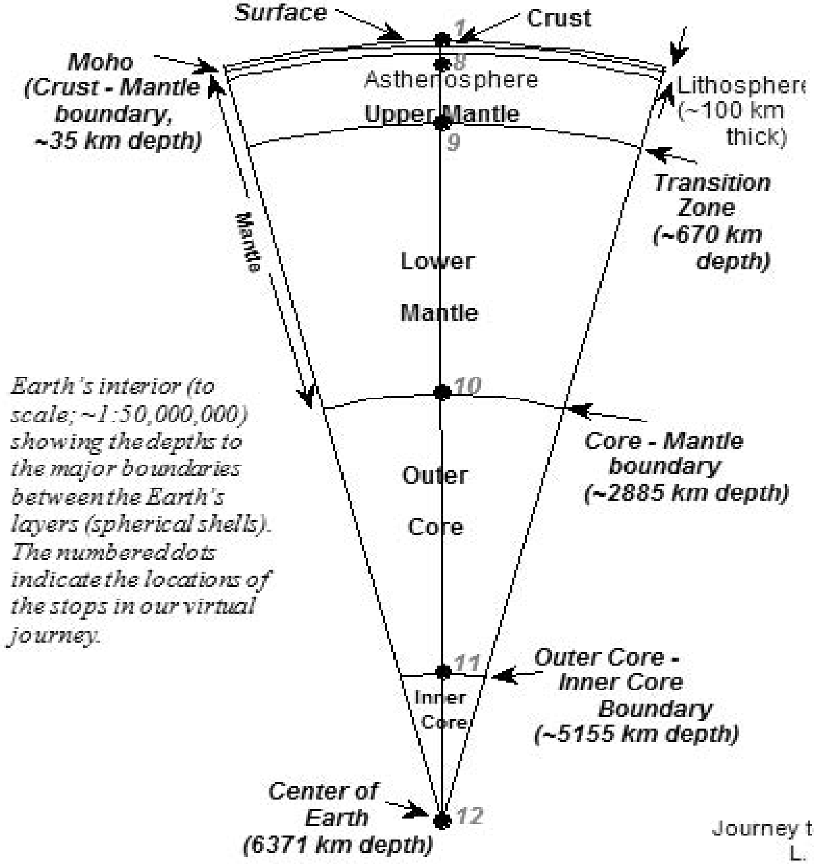
### Table 3. "Journey to the Center of the Earth" and the National Science Education Standards (NSES; National Research Council, 1996).

| **NSES Standard** | **How standard is addressed in Journey to the Center of the Earth activities (see Procedure and Teaching Strategies section for more details)*** |
|---|---|
| Science Teaching Standards | Activities include inquiry and opportunities for student involvement (A, B) and provide opportunities for ongoing assessment of student learning (C). |
| Professional Development Standards | The activity provides opportunities and appropriate resource material for teachers to learn about an Earth science topic that is not likely to have been included in their previous educational experiences and that build on their previous knowledge (A, C) and includes suggestions for effective teaching strategies (B). |
| Assessment Standards | Authentic assessment activities are suggested (C). |
| Science Content Standards | |
| - Unifying Concepts and Processes in Science | Activity provides experience with observation, evidence and explanation, and constancy, change and measurement. |
| - Science as Inquiry | Includes discussion of observations and evidence that result in conclusions about properties and conditions in the Earth's interior. |
| - Physical Science Standards | Activity explores properties and changes of properties in matter (Grades 5-8, B).<br>Activity explores structure and properties of matter (Grades 9-12, B). |
| - Earth and Space Science | Activity explores structure of the Earth system (Grades 5-8, D).<br>Activity relates to energy in the Earth system, origin and evolution of the Earth system (Grades 9-12, D). |
| - History and Nature of Science | Activity includes discussion of history of science, science as a human endeavor (and a connection to literature) (Grades 5-8, G).<br>Activity includes discussion of science as a human endeavor and historical perspectives (and a connection to literature) (Grades 9-12, G). |

**Return to Braile's Earth Science Education Activities page:**

### Journey to the Center of the Earth

(Deep Earth Stops)



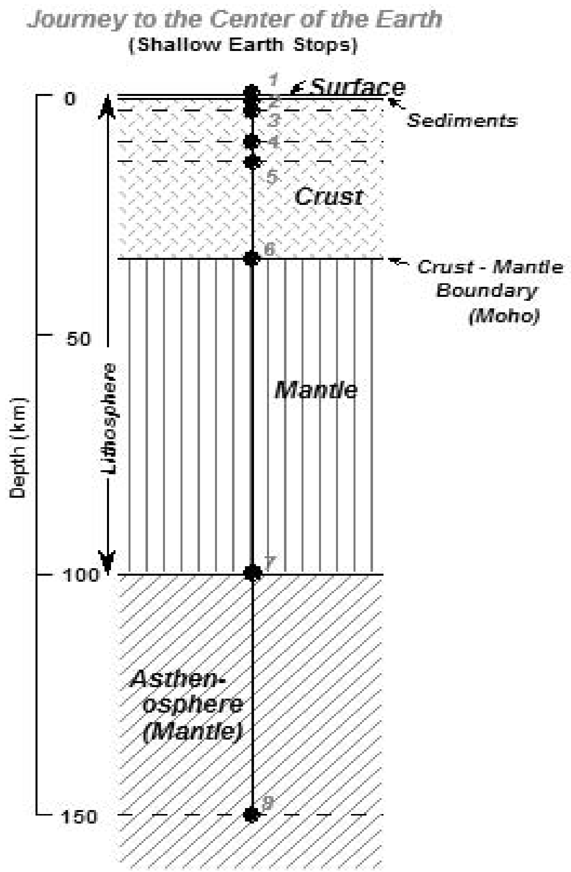
*Earth's interior (to scale; ~1:50,000,000) showing the depths to the major boundaries between the Earth's layers (spherical shells). The numbered dots indicate the locations of the stops in our virtual journey.*

"To conclude, I may say that our journey into the interior of the earth created an enormous sensation throughout the civilized world." (Jules Verne, *A Journey to the Center of the Earth*, 1864)

Journey to the Center of the Earth©
L. W. and S. J. Braile
web.ics.purdue.edu~/braile/
edumod/journey/journey.htm
Explorations in
Earth Science

A once in a lifetime opportunity!!! Join us in a...

**Tour the inside of the planet in under one hour! Discover the structure of the Earth's interior! Experience the conditions deep below the surface!**



*Shallow Earth structure showing the depths to boundaries in the upper 150 km of the Earth. The numbered dots indicate the locations of the first 8 stops in our virtual journey.*

## Scheduled stops on our *Journey to the Center of the Earth* (Depth in kilometers in parentheses):

### Shallow Earth stops:

1. Earth's surface (0 km) – Atmosphere above, Earth below.
2. Top of crystalline basement (~1 km) – Granitic igneous and metamorphic rocks.
3. Depth of deepest mine (3.6 km) – Temperature is ~50° C here.
4. Upper crust (10 km) – Many earthquakes occur near this depth.
5. Depth of deepest drill hole (12 km) – Drilling used for scientific study and oil exploration.
6. The Moho – crust/mantle boundary (~35 km [beneath continents]) – Crust is a thin shell; mantle is ~82% of Earth.
7. Base of the lithosphere (~100 km) – The Earth's plates (lithosphere) are moving at centimeters per year!
8. The asthenosphere (150 km) – Partially molten mantle and convection currents here.

### Deep Earth stops (see diagram on back page):

9. Upper mantle transition zone (~670 km) – Increased pressure transforms minerals to more compact crystal structure and higher density. This depth is only a little more than 10% of our journey.
10. Core/mantle boundary (2885 km) – Solid mantle (iron/magnesium silicate rock) above; liquid iron and nickel below in outer core.
11. Inner core/outer core boundary (5155 km) – Pressure is so great that the iron inner core is solid. Density is about 13 g/cm$^3$.
12. Center of the Earth (6371 km) – Temperature is ~5500° C, pressure is over 3.6 million times the pressure at the surface.

***Thanks for joining us on our Journey to the Center of the Earth! We hope you've enjoyed the tour and will come back again soon!***

# Measuring the Size of an Earthquake

Seismic waves are the vibrations from earthquakes that travel through the Earth; they are recorded on instruments called seismographs. Seismographs record a zig-zag trace that shows the varying amplitude of ground oscillations beneath the instrument. Sensitive seismographs, which greatly magnify these ground motions, can detect strong earthquakes from sources anywhere in the world. The time, locations, and magnitude of an earthquake can be determined from the data recorded by seismograph stations.

## The Richter Scale

The Richter magnitude scale was developed in 1935 by Charles F. Richter of the California Institute of Technology as a mathematical device to compare the size of earthquakes. The magnitude of an earthquake is determined from the logarithm of the amplitude of waves recorded by seismographs. Adjustments are included for the variation in the distance between the various seismographs and the epicenter of the earthquakes. On the Richter Scale, magnitude is expressed in whole numbers and decimal fractions. For example, a magnitude 5.3 might be computed for a moderate earthquake, and a strong earthquake might be rated as magnitude 6.3. Because of the logarithmic basis of the scale, each whole number increase in magnitude represents a tenfold increase in measured amplitude; as an estimate of energy, each whole number step in the magnitude scale corresponds to the release of about 31 times more energy than the amount associated with the preceding whole number value.

At first, the Richter Scale could be applied only to the records from instruments of identical manufacture. Now, instruments are carefully calibrated with respect to each other. Thus, magnitude can be computed from the record of any calibrated seismograph.

Earthquakes with magnitude of about 2.0 or less are usually called microearthquakes; they are not commonly felt by people and are generally recorded only on local seismographs. Events with magnitudes of about 4.5 or greater - there are several thousand such shocks annually - are strong enough to be recorded by sensitive seismographs all over the world. Great earthquakes, such as the 1964 Good Friday earthquake in Alaska, have magnitudes of 8.0 or higher. On the average, one earthquake of such size occurs somewhere in the world each year.

The Richter Scale is not commonly used anymore, as it has been replaced by another scale called the moment magnitude scale which is a more accurate measure of the earthquake size.

## Magnitude

Modern seismographic systems precisely amplify and record ground motion (typically at periods of between 0.1 and 100 seconds) as a function of time. This amplification and recording as a function of time is the source of instrumental amplitude and arrival-time data on near and distant earthquakes. Although similar seismographs have existed since the 1890's, it was only in the 1930's that Charles F. Richter, a California seismologist, introduced the concept of earthquake magnitude. His original definition held only for California earthquakes occurring within 600 km of a particular type of seismograph (the Woods-Anderson torsion instrument). His basic idea was quite simple: by knowing the distance from a seismograph to an earthquake and observing the maximum signal amplitude recorded on the seismograph, an empirical quantitative ranking of the earthquake's inherent size or strength could be made. Most California earthquakes occur within the top 16 km of the crust; to a first approximation, corrections for variations in earthquake focal depth were, therefore, unnecessary.

Richter's original magnitude scale ($M_L$) was then extended to observations of earthquakes of any distance and of focal depths ranging between 0 and 700 km. Because earthquakes excite both body waves, which travel into and through the Earth, and surface waves, which are constrained to follow the natural wave guide of the Earth's uppermost layers, two magnitude scales evolved - the $m_b$ and $M_S$ scales.

The standard body-wave magnitude formula is

$$m_b = \log_{10}(A/T) + Q(D,h) \,,$$

where $A$ is the amplitude of ground motion (in microns); $T$ is the corresponding period (in seconds); and $Q(D,h)$ is a correction factor that is a function of distance, $D$ (degrees), between epicenter and station and focal depth, $h$ (in kilometers), of the earthquake. The standard surface-wave formula is

$$M_S = \log_{10} (A/T) + 1.66 \log_{10} (D) + 3.30 \,.$$

There are many variations of these formulas that take into account effects of specific geographic regions, so that the final computed magnitude is reasonably consistent with Richter's original definition of $M_L$. Negative magnitude values are permissible.

A rough idea of frequency of occurrence of large earthquakes is given by the following table:

| $M_S$ | Earthquakes per year |
|---|---|
| 8.5 - 8.9 | 0.3 |
| 8.0 - 8.4 | 1.1 |
| 7.5 - 7.9 | 3.1 |
| 7.0 - 7.4 | 15 |
| 6.5 - 6.9 | 56 |
| 6.0 - 6.4 | 210 |

This table is based on data for a recent 47 year period. Perhaps the rates of earthquake occurrence are highly variable and some other 47 year period could give quite different results.

The original $m_b$ scale utilized compressional body P-wave amplitudes with periods of 4-5 s, but recent observations are generally of 1 s-period P waves. The $M_S$ scale has consistently used Rayleigh surface waves in the period range from 18 to 22 s.

When initially developed, these magnitude scales were considered to be equivalent; in other words, earthquakes of all sizes were thought to radiate fixed proportions of energy at different periods. But it turns out that larger earthquakes, which have larger rupture surfaces, systematically radiate more long-period energy. Thus, for very large earthquakes, body-wave magnitudes badly underestimate true earthquake size; the maximum body-wave magnitudes are about 6.5 - 6.8. In fact, the surface-wave magnitudes underestimate the size of very large earthquakes; the maximum observed values are about 8.3 - 8.7. Some investigators have suggested that the 100 s mantle Love waves (a type of surface wave) should be used to estimate magnitude of great earthquakes. However, even this approach ignores the fact that damage to structure is often caused by energy at shorter periods. Thus, modern seismologists are increasingly turning to two separate parameters to describe the physical effects of an earthquake: seismic moment and radiated energy.

## Fault Geometry and Seismic Moment, $M_O$

The orientation of the fault, direction of fault movement, and size of an earthquake can be described by the fault geometry and seismic moment. These parameters are determined from waveform analysis of the seismograms produced by an earthquake. The differing shapes and directions of motion of the waveforms recorded at different distances and azimuths from the earthquake are used to determine the fault geometry, and the wave amplitudes are used to compute moment. The seismic moment is related to fundamental parameters of the faulting process.

$$M_O = \mu S \langle d \rangle ,$$

where μ is the shear strength of the faulted rock, S is the area of the fault, and <d> is the average displacement on the fault. Because fault geometry and observer azimuth are a part of the computation, moment is a more consistent measure of earthquake size than is magnitude, and more importantly, moment does not have an intrinsic upper bound. These factors have led to the definition of a new magnitude scale $M_W$, based on seismic moment, where

$$M_W = 2/3 \log_{10}(M_O) - 10.7 .$$

The two largest reported moments are 2.5 X $10^{30}$ dyn·cm (dyne·centimeters) for the 1960 Chile earthquake ($M_S$ 8.5; $M_W$ 9.6) and 7.5 X $10^{29}$ dyn·cm for the 1964 Alaska earthquake ($M_S$ 8.3; $M_W$ 9.2). $M_S$ approaches it maximum value at a moment between $10^{28}$ and $10^{29}$ dyn·cm.

## Energy, *E*

The amount of energy radiated by an earthquake is a measure of the potential for damage to man-made structures. Theoretically, its computation requires summing the energy flux over a broad suite of frequencies generated by an earthquake as it ruptures a fault. Because of instrumental limitations, most estimates of energy have historically relied on the empirical relationship developed by Beno Gutenberg and Charles Richter:

$$\log_{10}E = 11.8 + 1.5M_S$$

where energy, *E,* is expressed in ergs. The drawback of this method is that $M_S$ is computed from an bandwidth between approximately 18 to 22 s. It is now known that the energy radiated by an earthquake is concentrated over a different bandwidth and at higher frequencies. With the worldwide deployment of modern digitally recording seismograph with broad bandwidth response, computerized methods are now able to make accurate and explicit estimates of energy on a routine basis for all major earthquakes. A magnitude based on energy radiated by an earthquake, $M_e$, can now be defined,

$$M_e = 2/3 \log_{10}E - 2.9.$$

For every increase in magnitude by 1 unit, the associated seismic energy increases by about 32 times.

Although $M_w$ and $M_e$ are both magnitudes, they describe different physical properites of the earthquake. $M_w$, computed from low-frequency seismic data, is a measure of the area ruptured by an earthquake. $M_e$, computed from high frequency seismic data, is a measure of seismic potential for damage. Consequently, $M_w$ and $M_e$ often do not have the same numerical value.

## Intensity

The increase in the degree of surface shaking (intensity) for each unit increase of magnitude of a shallow crustal earthquake is unknown. Intensity is based on an earthquake's local accelerations and how long these persist. Intensity and magnitude thus both depend on many variables that include exactly how rock breaks and how energy travels from an earthquake to a receiver. These factors make it difficult for engineers and others who use earthquake intensity and magnitude data to evaluate the error bounds that may exist for their particular applications.

An example of how local soil conditions can greatly influence local intensity is given by catastrophic damage in Mexico City from the 1985, $M_S$ 8.1 Mexico earthquake centered some 300 km away. Resonances of the soil-filled basin under parts of Mexico City amplified ground motions for periods of 2 seconds by a factor of 75 times. This shaking led to selective damage to buildings 15 - 25 stories high (same resonant period), resulting in losses to buildings of about $4.0 billion and at least 8,000 fatalities.

The occurrence of an earthquake is a complex physical process. When an earthquake occurs, much of the available local stress is used to power the earthquake fracture growth to produce heat rather that to generate seismic waves. Of an earthquake system's total energy, perhaps 10 percent to less that 1 percent is ultimately radiated as seismic energy. So the degree to which an earthquake lowers the Earth's available potential energy is only fractionally observed as radiated seismic energy.

## Determining the Depth of an Earthquake

Earthquakes can occur anywhere between the Earth's surface and about 700 kilometers below the surface. For scientific purposes, this earthquake depth range of 0 - 700 km is divided into three zones: shallow, intermediate, and deep.

Shallow earthquakes are between 0 and 70 km deep; intermediate earthquakes, 70 - 300 km deep; and deep earthquakes, 300 - 700 km deep. In general, the term "deep-focus earthquakes" is applied to earthquakes deeper than 70 km. All earthquakes deeper than 70 km are localized within great slabs of shallow lithosphere that are sinking into the Earth's mantle.

The evidence for deep-focus earthquakes was discovered in 1922 by H.H. Turner of Oxford, England. Previously, all earthquakes were considered to have shallow focal depths. The existence of deep-focus earthquakes was confirmed in 1931 from studies of the seismograms of several earthquakes, which in turn led to the construction of travel-time curves for intermediate and deep earthquakes.

The most obvious indication on a seismogram that a large earthquake has a deep focus is the small amplitude, or height, of the recorded surface waves and the uncomplicated character of the P and S waves. Although the surface-wave pattern does generally indicate that an earthquake is either shallow or may have some depth, the most accurate method of determining the focal depth of an earthquake is to read a depth phase recorded on the seismogram. The most characteristic depth phase is pP. This is the P wave that is reflected from the surface of the Earth at a point relatively near the epicenter. At distant seismograph stations, the pP follows the P wave by a time interval that changes slowly with distance but rapidly with depth. This time interval, pP-P (pP minus P), is used to compute depth-of-focus tables. Using the time difference of pP-P as read from the seismogram and the distance between the epicenter and the seismograph station, the depth of the earthquake can be determined from published travel-time curves or depth tables.

Another seismic wave used to determine focal depth is the sP phase - an S wave reflected as a P wave from the Earth's surface at a point near the epicenter. This wave is recorded after the pP by about one-half of the pP-P time interval. The depth of an earthquake can be determined from the sP phase in the same manner as the pP phase by using the appropriate travel-time curves or depth tables for sP.

If the pP and sP waves can be identified on the seismogram, an accurate focal depth can be determined.

by William Spence, Stuart A. Sipkin, and George L. Choy
Earthquakes and Volcanoes
Volume 21, Number 1, 1989

http://earthquake.usgs.gov/learn/topics/measure.php

# Pasta Quake—The San Francisco Treat

Demonstration to learn the concept of magnitude & log scale.

Activity is used with permission from Paul Doherty http://www.exo.net/~pauld/index.html. Worksheets by Roger Groom.

**Time**: 5-10 Minutes

**Target Grade Level:** 4th grade and up

**Content Objective**: Students will learn the earthquake magnitude scale by breaking different amounts of spaghetti. Visual scale of the pasta emphasizes the relative differences between magnitudes; each whole step in magnitude

**Background**

The severity of an earthquake can be expressed in terms of both intensity and magnitude. However, the two terms are quite different, and they are often confused.

*Intensity* is based on the observed effects of ground shaking on people, buildings, and natural features. It varies from place to place within the disturbed region depending on the location of the observer with respect to the earthquake epicenter.

*Magnitude* is related to the amount of seismic energy released at the hypocenter of the earthquake. It is based on the amplitude of the earthquake waves recorded on instruments which have a common calibration. The magnitude of an earthquake is thus represented by a single, instrumentally determined value.

**To Do and Notice**

Hold up one piece of spaghetti. Bend the piece between your hands until it breaks. Notice the work it takes to break the spaghetti. Call this a **5** on the Pasta Magnitude scale.

Hold up a bundle of 30 pieces of spaghetti. Bend the bundle until it breaks. Notice the work it takes to break the bundle. If the pasta magnitude scale were like the earthquake magnitude scale this would be a Pasta Magnitude **6** break.

Hold up 900 pieces of pasta, the remainder of the package. Bend the bundle until it breaks. Notice the work it takes to break the bundle. This is a Pasta Magnitude **7** break.

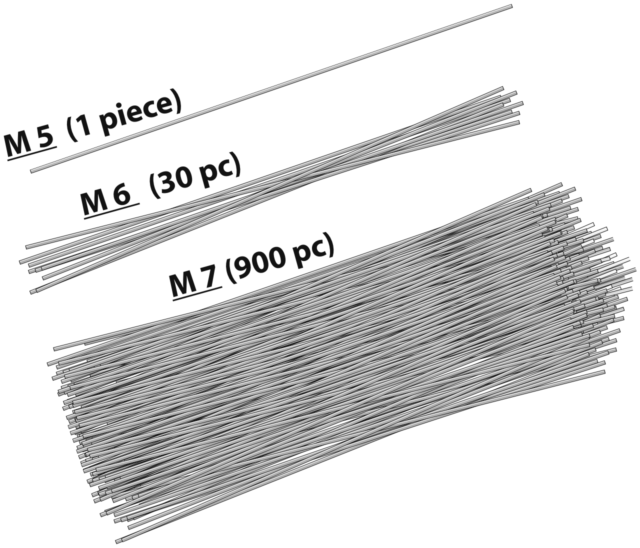
**What's Going On?**

The magnitude scales for earthquakes are logarithmic scales. In particular for the Richter scale, each increase of 1 unit on the scale, say from 6 to 7, represented an increase of one order of magnitude, i.e. times 10, in the amount of motion recorded on a particular type of seismograph.

The now-common *Moment Magnitude* scale was defined because the Richter scale does not adequately differentiate between the largest earthquakes. The new "moment magnitude" scale is a new technique of using the Richter scale.

**Materials**

1# package of thin spaghetti <u>or</u>
2# package of regular spaghetti.



In the moment-magnitude scale a magnitude increase of one unit corresponds to a factor of 30 increase in the energy released by the breaking of the fault in an earthquake. That's why we increased the number of spaghetti noodles from 1 to 30 to 900 (900 =30 x 30).

**So What?**—In order to release the energy of one M 7 earthquake you would have to have 30 M 6 quakes or 900 magnitude 5's. Notice also all the little "quakes" before and after the big-quake break.

In this model, *what does the spaghetti represent?* (The earth, rocks, tectonic plates) What do your hands represent? (Forces, stress, another plate) What does the breaking spaghetti represent? (An earthquake)

**Discussion**

Describe the energy transfers and transformations—what kind of energy does the spaghetti have when it is bent but not yet broken? (Potential) What kind of energy does the spaghetti have when it is breaking? (Sound, kinetic, heat) Is this an energy transfer or transformation? Explain your choice. (Transformation because the type of energy is changing) If energy cannot be created or destroyed, what happens to the energy released during an earthquake? (It transfers to move buildings, the ground, and the air, and transforms to sound, heat etc)

Are the forces in this investigation balanced or unbalanced? (Unbalanced) How do you know? (The spaghetti bends which is a change in direction (acceleration) and when the spaghetti breaks, it changes speed (acceleration)

Name: ________________________ Per: ____

Today's Date: _________________

Due Date: _________________

# Pasta Quake!

There are 3 main ways to measure the magnitude of an earthquake. The **magnitude** is a measurement of earthquake strength based on seismic waves and movement along faults.

First, let's review. What are the 3 types of seismic waves? For each, give a brief description.

1. ____________________________________________________________________
2. ____________________________________________________________________
3. ____________________________________________________________________

What about exactly where earthquakes happen? Draw a diagram in the space below to show the difference between the **<u>epicenter</u>** and the **<u>focus</u>**.

Now, match up the 3 main scales to measure earthquakes with their descriptions:

| | | |
|---|---|---|
| 4. | Richter Scale | Measures the intensity of an earthquake. This is a measure of the strength of ground motion and has a scale of 1 – 12, but in Roman numerals, it's I – XII. One earthquake may have different ratings depending on the damage at different locations. |
| 5. | Moment Magnitude Scale | Measures the size of the seismic waves as shown on a seismograph. Good for small or close-by earthquakes. |
| 6. | Modified Mercalli Scale | Measures the total energy released by an earthquake and can be used for all sizes, near or far. This is usually what is used today. |

Name________________________

On the Moment Magnitude Scale, each different number is a measure of the total energy released by an earthquake, and it's about 30 times greater between numbers of the scale (it's actually about 32 times greater). We can demonstrate with spaghetti:

| **Pasta Magnitude Scale** | **# of spaghetti pieces broken** |
|---|---|
| 3 | |
| 4 | |
| 5 | |
| 6 | |
| 7 | |
| 8 | |

Below is a list of some major earthquakes and their Moment Magnitude ratings:

| | | |
|---|---|---|
| 1811-12 | New Madrid (Midwestern US) | 8.1 |
| 1906 | San Francisco, California | 7.7 |
| 1960 | Arauco, Chile | 9.5 |
| 1964 | Anchorage, Alaska | 9.2 |
| 1971 | San Fernando, California | 6.7 |
| 1985 | Mexico City, Mexico | 8.1 |
| 1989 | San Francisco, California | 7.0 |
| 1995 | Kobe, Japan | 6.9 |

7. Which earthquake released about 30 times more energy than the Mexico City quake of 1985?

8. Two of the earthquakes released just a little more than 30 times more energy than the 1989 San Francisco quake. They were . . .

9. If the 1964 quake in Alaska released about 30 times more energy than the New Madrid quake, it released about 900 times more energy than which quake?

# TEACHER ANSWER KEY—PAGE 1/2

## MEASURING EARTHQUAKES

Name:________________________ Class______

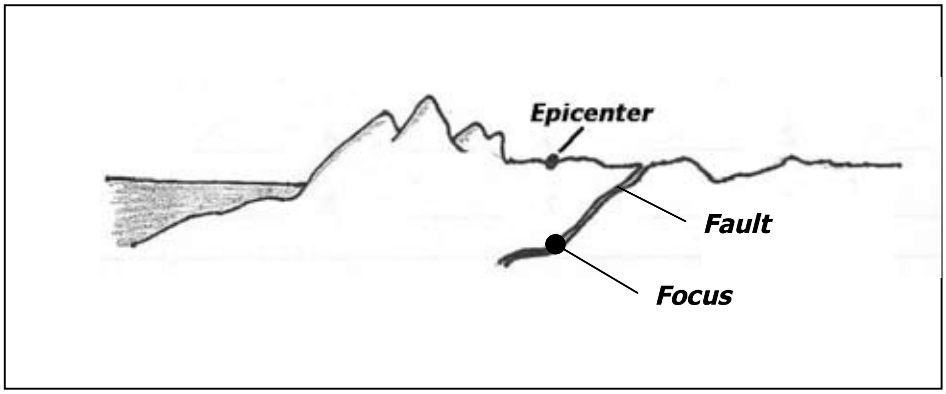
Today's Date: _________ Due Date: __________

There are 3 main ways to measure the magnitude of an earthquake. The **magnitude** is a measurement of earthquake strength based on seismic waves and movement along faults.

First, let's review. What are the 3 types of seismic waves? For each, give a brief description.

1. *P-Waves – primary waves – fastest, move straight through solids and liquids*
2. *S-Waves – secondary/shear waves – second fastest, cannot move through liquids*
3. *L-Waves – surface waves – slowest, travels along surface only*

What about exactly where earthquakes happen? Draw a diagram in the space below to show the difference between the **<u>epicenter</u>** and the **<u>focus</u>**.



Now, match up the 3 main scales to measure earthquakes with their descriptions:

| | |
|---|---|
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| 5. Moment Magnitude Scale | Measures the size of the seismic waves as shown on a seismograph. Good for small or close-by earthquakes. |
| 6. Modified Mercalli Scale | Measures the total energy released by an earthquake and can be used for all sizes, near or far. This is usually what is used today. |

# ANSWER KEY—PAGE 2/2

On the Moment Magnitude Scale, each different number is a measure of the total energy released by an earthquake, and it's about 30 times greater between numbers of the scale (it's actually about 32 times greater). We can demonstrate with spaghetti:

| Pasta Magnitude Scale | # of spaghetti pieces broken |
|---|---|
| 3 | ***1/30*** |
| 4 | ***1*** |
| 5 | ***30*** |
| 6 | ***900*** |
| 7 | ***27,000*** |
| 8 | ***810,000*** |

Below is a list of some major earthquakes and their Moment Magnitude ratings:

| | | |
|---|---|---|
| 1811-12 | New Madrid (Midwestern US) | 8.1 |
| 1906 | San Francisco, California | 7.7 |
| 1960 | Arauco, Chile | 9.5 |
| 1964 | Anchorage, Alaska | 9.2 |
| 1971 | San Fernando, California | 6.7 |
| 1985 | Mexico City, Mexico | 8.1 |
| 1989 | San Francisco, California | 7.0 |
| 1995 | Kobe, Japan | 6.9 |

7. Which earthquake released about 30 times more energy than the Mexico City quake of 1985?

***1964 Anchorage, Alaska***

8. Two of the earthquakes released just a little more than 30 times more energy than the 1989 San Francisco quake. They were . . .

***1811 New Madrid and 1985 Mexico City***

9. If the 1964 quake in Alaska released about 30 times more energy than the New Madrid quake, it released about 900 times more energy than which quake?

***1989 San Francisco***

# Human Seismometer

## Earthquakes in NC workshop

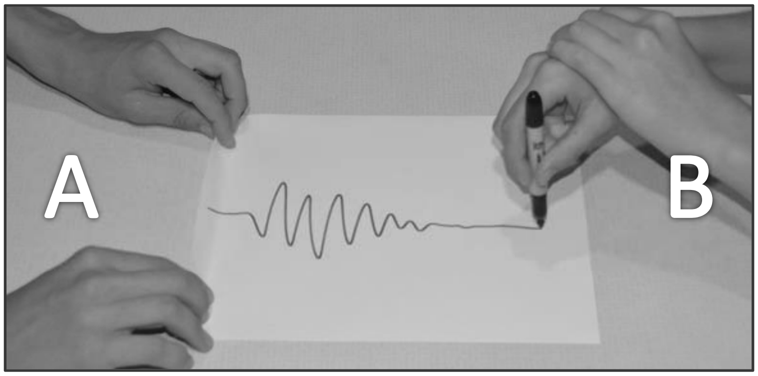
**Tim Martin** tmartin@greensboroday.org

**Background:**

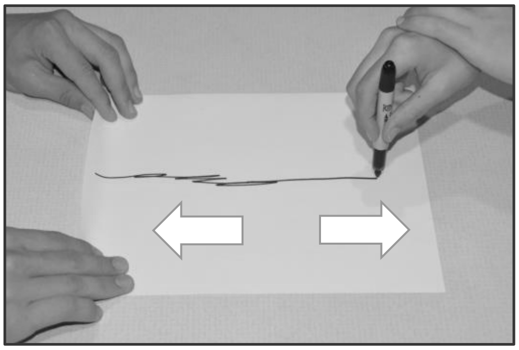
Seismometers are instruments designed to record the Earth's movement during an earthquake. Today most seismic recording stations have sensitive electronic motion and position sensors (accelerometers) as well as associated electronics to process the data. Historical seismometers consist of an isolated mass connected to levers holding a pen that touches a rotating drum. With the drum mount anchored firmly to the ground, the isolated mass will stay relatively stationary when the ground (and drum) move during an earthquake. The pen will record the drum motion as the seismic waves pass.

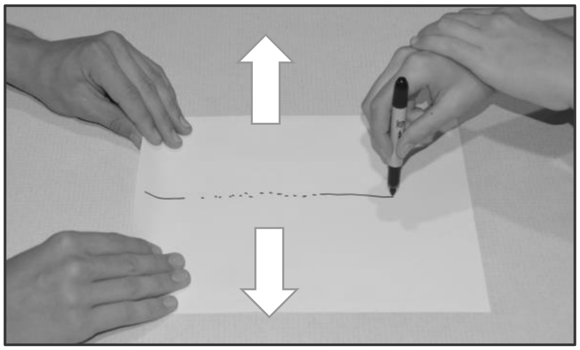
**The Demonstration:**

The human seismometer is a simple and effective way to introduce students to the basic principles of how an historical seismometer works. Instruct two students to sit on opposite sides of a small table. Instruct student A to slowly pull the paper while student B firmly holds a pen/pencil in contact with the paper. (Student B should avoid all contact with the table while student A should rest his/her hands on the table.) Vigorously shake the table perpendicular to the motion of the paper. The pen will record the table motion and produce a seismogram.



Ask students if this type of device will accurately record all of the motion during an earthquake. For the second demonstration, shake the table parallel with the motion of the paper. Have students discuss or explain that it is necessary to have one seismometer operating on a North/South axis and another on an East/West axis. Reiterate the same question about recording all motion during an earthquake. For the third demonstration shake the table up and down, thus demonstrating the need for a Z axis seismometer to record motion in the up/down direction as well.





**EXTRA:** Explore electronic seismometers on a smart phone with free iseismometer (iphone) or Seismo (Android).

## What causes an earthquake?

Earthquakes happen because of a sudden slip on a fault in the earth's surface where the rock on one side moves up, down, or sideways relative to the other side. An earthquake is felt as a sudden, rapid shaking on the surface of earth. This shaking can last a few seconds or even few minutes. The motion causes waves that move through the Earth.

Earthquakes are detected with instruments that measure and record the seismic waves (like the Quake-Catcher Network sensors). The record is called a seismogram.

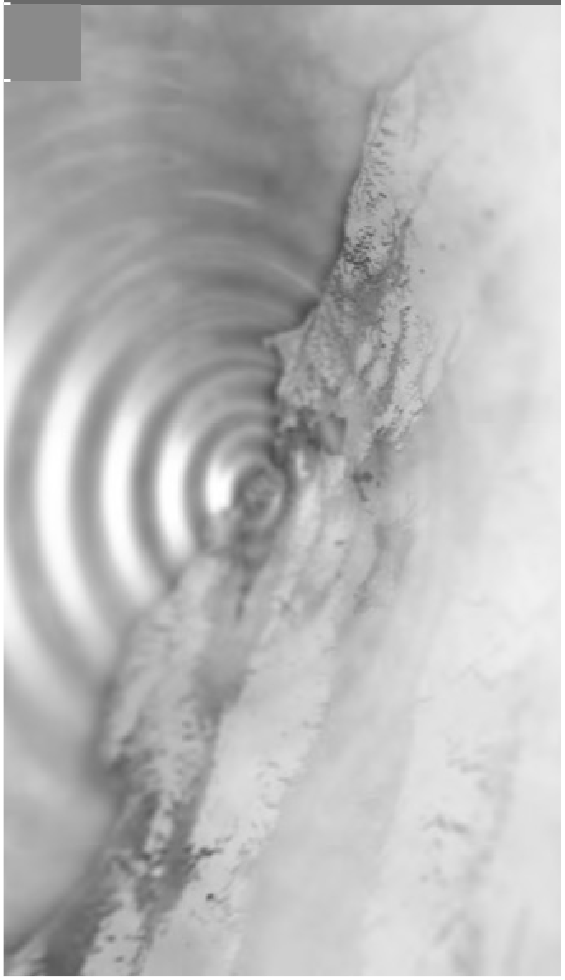
## Thank you for participating in the Quake-Catcher Network!

**To learn more visit:**
**http://qcn.stanford.edu**

**The Quake-Catcher Network**
Stanford University – Department of Geophysics
397 Panama Mall Mitchell Building
Stanford, CA 94305-2215

# The Quake-Catcher Network

Bringing Seismology to
Homes, Schools, and Museums



# The Quake-Catcher Network
## Frequently Asked Questions

**What Is the Quake-Catcher Network?**

The Quake-Catcher Network (QCN) is a collaborative initiative for developing the world's largest, low-cost strong motion seismic network by utilizing sensors in and attached to Internet-connected computers. With your help QCN can provide better understanding of earthquakes, give early warning to schools, emergency response systems, and others. QCN also provides educational software designed to help teach about earthquake and its hazards.

**How do the sensors record an earthquake?**

The sensors can measure and record acceleration (ground movement) in three directions. The easiest way to think of these directions is as the 1) up/down, 2) front/back, and 3) side to side bobbing motions of a boat. With these three components of direction it is possible to find the direction of the Earth's movement.

**How does QCN know if there is an earthquake?**

Sensors connect to the QCN over the Internet. Typically, when the QCN software is running, there isn't much need to transfer the data to our headquarters. Instead, the computer monitors the data locally for new high-energy signals and only sends a single time and a single significance measurement for strong new signals. If our server receives many of these signals all at once, then it is likely that an earthquake is happening.

**How does the sensor know which way is North?**

The USB sensors come with a mini compass so you can align the sensor with the X direction pointing toward the North Pole (note: magnetic North is not always the same as true North). The better we know the directions of motion, the more precisely we can pinpoint the earthquake.

**How can I set my location?**

When you install the software on a desktop you can set a permanent location through Google maps in your BOINC account. There is no GPS on the sensors. This location can be updated (in case you move, for example). By setting the location of your computer as precisely as you can, you will help seismologists much more.

**Does my computer have to be on all the time?**

In order to record as many earthquakes as possible, yes, your computer should be on at all times (or as much as possible). The sensors cannot record earthquakes if the power is off.

**Do I have to be connected to the Internet?**

Yes! The sensors can only send data to the server when connected to the Internet. The QCN program BOINC runs in the background and sends very small amounts of data over the Internet when the computer is not being used. There isn't much need to transfer data to our headquarters continuously. Instead, the computer monitors the data locally for new high-energy signals and only sends a single time and single significance measurements for strong new signals.

**What happens if there is a power outage?**

The power sometimes goes out for a short period after earthquakes because of broken power lines. If the power goes out, your desktop will usually power off without a proper shutdown. When you turn your computer back on, the QCN program BOINC will automatically start up.

**How do I update my QCN account?**

Visit http://qcn.stanford.edu and click on the "My Account" button found under "My QCN/BOINC" tab at the upper right corner. You can change your location by clicking the "My Location" button found under the same tab.

2/2/12

# EPIcenter-Quake Catcher Seismic Network Fact Sheet

## Background

The Quake Catcher Network (QCN) is a collaborative initiative for developing the world's largest, low-cost strong-motion seismic network by utilizing motion sensors in and attached to internet-connected computers. QCN links volunteer hosted computers into a real-time motion-sensing network. The volunteer computers monitor vibrational sensors called micro electro-mechanical systems (MEMS) accelerometers and digitally transmit "triggers" to QCN's servers whenever strong motions are observed. QCN's servers sift through these signals, and determine which ones represent earthquakes, and which ones represent cultural noise.

QCN will be providing you with a MEMS accelerometer and QCN staff will be installing the sensor and the required compatible software.

QCN Website: http://qcn.stanford.edu

Many of our participants use their QCN computer for other purposes. Several questions have been asked if QCN affects computer performance, uses a lot of memory, and/or uses significant hard disk space. The short answer is that you should see no difference in performance. At any given time QCN uses about 1% of your processor capacity. The Berkeley Open Infrastructure for Network Computing (BOINC) software and QCN sensor driver software will occupy only 2.6 MB of disk space.

BOINC is an open source middleware system for volunteer and grid computing. It was originally developed to support the SETI@home project before it became useful as a platform for other distributed applications in areas as diverse as mathematics, medicine, molecular biology, climatology, geophysics, and astrophysics. The intent of BOINC is to make it possible for researchers to tap into the enormous processing power of personal computers around the world.

If you have a metered data Internet plan (e.g. if you have 5 GB per month), QCN will not impact your data use in any significant way. QCN data is made up of text files which are not data intensive. Under normal circumstances QCN might use 25 MB of your data allotment per month. If you have a 5 GB allotment per month, this amounts to 0.5% of your data allotment.

## Requirements

To successfully complete the installation, we will need a few things from your end:

1) A computer (either PC or Apple) which is either located in or can be relocated to a room with as little traffic and disturbance as possible. An ideal spot for this would be either in a basement, a library-type room, or even a very quiet office. This computer should have an available USB port for the sensor to connect to, and should be running and connected to the internet at all times.

2) An IT administrator at your site who can assist with (a) installation of the BOINC software, (b) installation of the driver for the sensor, and (c) set any permissions which will allow that

computer to send seismic data to the QCN server at Stanford. The BOINC software, or the program which uploads the MEMS accelerometer data to the servers, must be able to access the Internet at all times. Because of this, we will require someone on-hand who will be able to troubleshoot any internet-related issues we may encounter.

**PC**

Operating system
- Windows 2000 SP5 or XP, SP2, or later

Hardware

- Pentium 233 MHz (Recommended: Pentium 500 MHz or greater)
- 64 MB RAM (Recommended: 128 MB RAM or greater)
- 200 MB disk space (maximum)

Permissions

- You must have administrator privileges to install BOINC.

Nvidia Support

- Must have driver version 185.85 or better installed in order to use your GPU.

ATI Support

- You must have driver version 8.12 or better installed in order to use your GPU.

**Apple**

Operating system

Mac OS X 10.6.0 and later

Hardware

- Apple computer with an Intel x86 or PowerPC G3, G4, or G5 processor

- 28 MB RAM (Recommended: 256 MB RAM or greater)

- 200 MB hard disk space (the BOINC software and sensor driver take up 2.6 MB of hard disk space).

As of 7/2013

# Quake-Catcher Network
# qcn.stanford.edu

To Purchase a Sensor:

On website, right navigation under Request A Sensor, click on K-12 Program. (http://qcn.stanford.edu/join-qcn/request-a-sensor)

- Sensors are $5 for teachers (up to 3 sensors). For teachers at schools with
  - underserved students, QCN will send one free sensor.
  - Sensors can be purchased with a credit card online or with a check by printing and
  - mailing in the print form.

Two Ways to Use the Sensor

One way is as a teaching tool using the software called QCNLive.
The second way is to use the sensor as a monitoring station using the BONIC software. We recommend that you use your sensors as in both ways. When the sensors are not being handled and used by students, they should be attached to the floor and connected to the monitoring software.

Sensors and software run on Mac and Windows systems.
You may need to download a driver, depending on your computer and sensor.

1. QCN Live

On the website, right navigation, under Download Now, click on QCN Interactive Software. (http://qcn.stanford.edu/join-qcn/download)
Download the appropriate software for your computer. A manual is available at: http://qcn.stanford.edu/downloads/QCNLive_User_Manual.pdf
This is what you should use with your students. Find activities at: http://qcn.stanford.edu/learning-center/lessons-and-activities

2. QCN Network Software

To turn your computer and sensor into a seismic monitoring station, you need to attach the sensor to the floor, connect the computer to the internet and use the BONIC software. The software runs in the background, so you won't notice a thing.

Begin with the instructions- http://qcn.stanford.edu/join-qcn/manualsinstructions
These instructions will show you the steps to set up the monitoring station.

Message Boards - http://qcn.stanford.edu/sensor/forum_index.php
There is a QCN community of users. Many questions are answered on the message boards.

## Welcome to Virtual Earthquake

***Virtual Earthquake*** is an interactive Web-based activity designed to introduce you to the concepts of how an earthquake **EPICENTER** is located and how the **RICHTER MAGNITUDE** of an earthquake is determined. The *Virtual Earthquake* program is running on a Web Server at California State University at Los Angeles. You can interact with *Virtual Earthquake* using either a Netscape or Internet Explorer Web Browser running on Macs or PCs.

NEW: A completely revised version of Virtual Earthquake can be found HERE. This new Java applet based version is more inquiry-based than the original version and contains tools so instructors can assess student learning.

(After you complete Virtual Earthquake, check out the Geology Labs On-Line home page for the latest information about project activities. Activities about age dating, river discharge and river flooding are available.)

**Instructors:** here is some important information

*Virtual Earthquake* will show you the recordings of an earthquake's seismic waves detected by instruments far away from the earthquake. The instrument recording the seismic waves is called a **seismograph** and the recording is a **seismogram**. The point of origin of an earthquake is called its **focus** and the point on the earth's surface directly above the focus is the **epicenter**. You are to locate the epicenter of an earthquake by making simple measurement on three seismograms that will be sent to you by the *Virtual Earthquake* program. Additionally, you will be required to determine the **Richter Magnitude** of that quake from the same recordings. **Richter Magnitude** is an estimate of the amount of energy released during and earthquake.

---

Virtual Seismologist
Certificate of Completion
YOUR NAME HERE

Upon completion of this activity you will be given the opportunity to receive a personalized **Certificate as a "Virtual Seismologist."**

In order to get this certificate, you must make careful measurements throughout the activity. The actual certificate is much larger than the one displayed above.

This work was supported in part by grants from the U.S. National Science Foundation. All opinions expressed are those of the authors and not necessarily those of the NSF.

# Virtual Earthquake

Here is the direct link to the good version: http://www.sciencecourseware.org/eec/earthquake/

The alternate version for slow computers is also good:
http://www.sciencecourseware.com/virtualearthquake/

Excerpt from the webpage:

"The activity, "Earthquake" is a part of the Virtual Courseware in the Earth and Environmental Science project. It is an inquiry-based activity that helps a user learn about the fundamental concepts of how earthquake (seismic) waves are used to locate an earthquake's epicenter and to determine its Richter magnitude.  There are two major components to this activity: 1) an experiment about how a Travel Time graph is constructed and used and 2) an Epicenter Location and Richter magnitude activity.  These activities require the user to use mqaps and seismograms to carefully record observations and measurements in a journal.  At the completion of the Epicenter and Magnitude part, student learning is "assessed" with a quiz.  A CERTIFICATE OF COMPLETION AS A VIRTUAL SEISMOLOGIST will be granted once the activity and quiz are successfully completed."

Virtual Courseware for Earth and Environmental Sciences is supported in part by grants from the U.S. National Science Foundation and the California State University System. All opinions expressed herein are those of the authors and not necessarily those of the NSF or the CSU.

# jAmaSeis

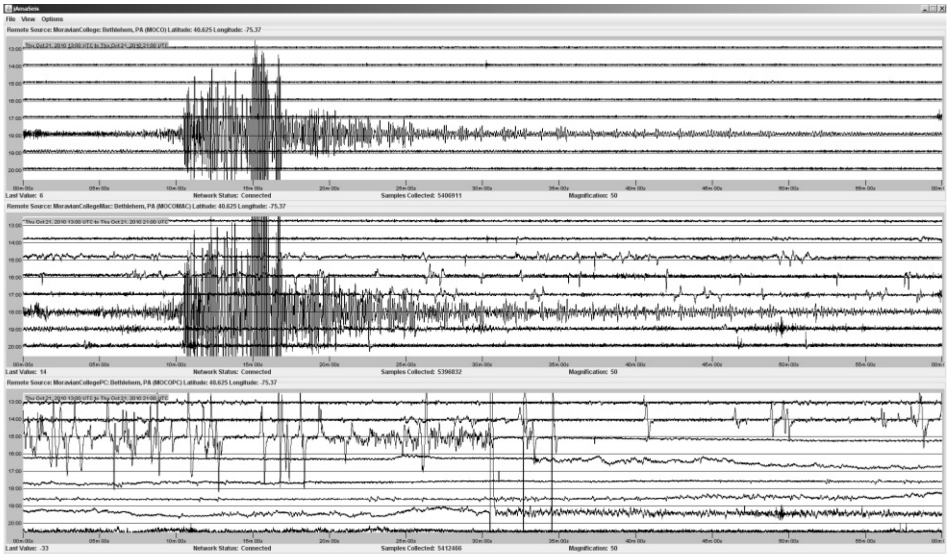
**jAmaSeis is now available!**

If you don't have your own educational seismometer, you can watch data from a nearby research station!

Download now!  http://www.iris.edu/hq/jamaseis

This software replaces the AmaSeis software that is currently being used in the Seismographs in Schools program. It is a significant advancement over what was previously available because it allows users to obtain data in real-time from either a local instrument or from remote stations. As a result, users without an instrument can utilize the software. Additionally, this software includes easy to use analysis tools for users to quickly extract and analyze data from either their recording device or remote data stream.

**Stream View**- The helicorder screen now has the flexibility to display up to three streams of data simultaneously. These can include a local educational seismometer, a remote educational seismometer over the jAmaseis network (in true real-time), or research-quality seismometers stored at the IRIS Data Management Center (in near real-time).



Remote Source: MoravianCollege: Bethlehem, PA (MOCO) Latitude: 40.625 Longitude: -75.37

Thu Oct 21, 2010 13:00 UTC to Thu Oct 21, 2010 21:00 UTC

Last Value: 6 Network Status: Connected Samples Collected: 5406911 Magnification: 50

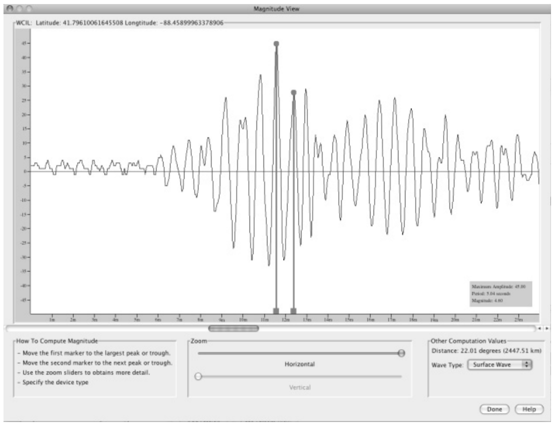
Remote Source: MoravianCollegeMac: Bethlehem, PA (MOCOMAC) Latitude: 40.625 Longitude: -75.37

Last Value: 14 Network Status: Connected Samples Collected: 5396832 Magnification: 50

Remote Source: MoravianCollegePC: Bethlehem, PA (MOCOPC) Latitude: 40.625 Longitude: -75.37

Last Value: -33 Network Status: Connected Samples Collected: 5412466 Magnification: 50

**Computing Magnitude**- For each stream, an event can be extracted allowing the user to pick amplitudes to calculate either a body wave or surface wave magnitude.

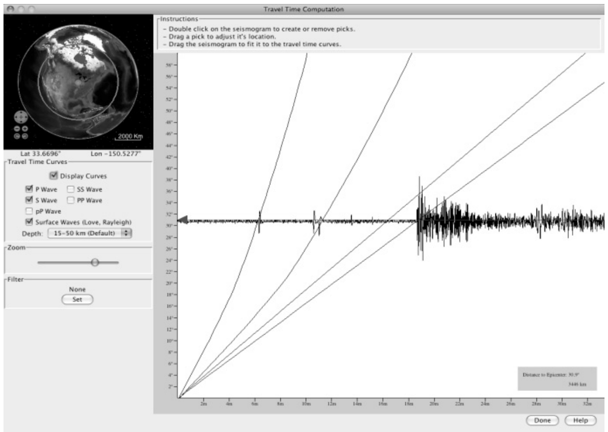


WCIL: Latitude: 41.79610061645508 Longitude: -88.45899963378906

Maximum Amplitude: 45.00
Period: 5.04 seconds
Magnitude: 4.60

How To Compute Magnitude
- Move the first marker to the largest peak or trough.
- Move the second marker to the next peak or trough.
- Use the zoom sliders to obtains more detail.
- Specify the device type

Other Computation Values
Distance: 22.01 degrees (2447.51 km)
Wave Type: Surface Wave



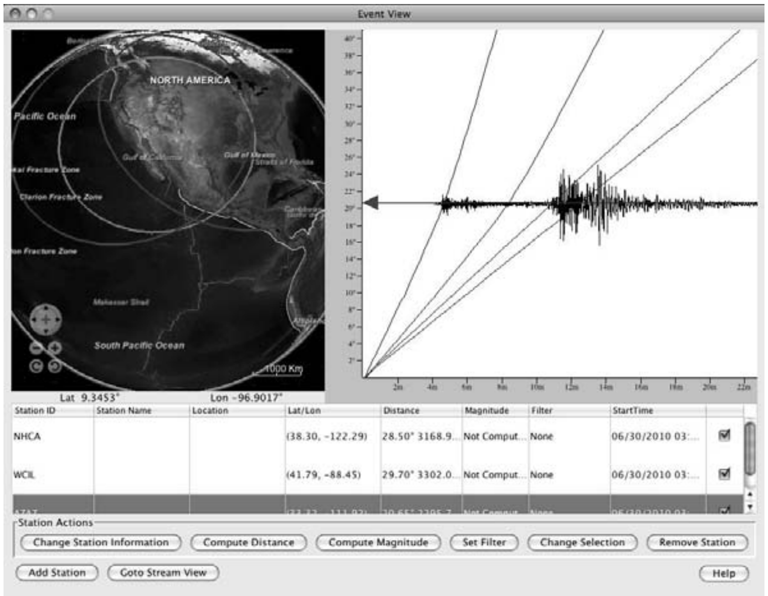
Instructions
- Double click on the seismogram to create or remove picks.
- Drag a pick to adjust it's location.
- Drag the seismogram to fit it to the travel time curves.

Lat 33.6696°    Lon -150.5277°

Travel Time Curves
☑ Display Curves
☑ P Wave ☐ SS Wave
☑ S Wave ☐ PP Wave
☐ pP Wave
☑ Surface Waves (Love, Rayleigh)
Depth: 15-50 km (Default)

Filter: None

**Computing Distance-** For each stream, an event can be extracted allowing the user to pick arrivals by double-clicking on the seismogram. A travel time curve is available to align the picks, and as the seismogram is slid along the travel time curve, the numeric values update and a circle with the appropriate radius is shown on the globe.



| Station ID | Station Name | Location | Lat/Lon | Distance | Magnitude | Filter | StartTime | |
|---|---|---|---|---|---|---|---|---|
| NHCA | | | (38.30, -122.29) | 28.50° 3168.9... | Not Comput... | None | 06/30/2010 03:... | ☑ |
| WCIL | | | (41.79, -88.45) | 29.70° 3302.0... | Not Comput... | None | 06/30/2010 03:... | ☑ |

**Event View-** All of the analysis for an earthquake comes together in the event view. Multiple traces can be loaded, either from the stream view or from a sac file. All of the individual distance calculations are displayed in both table and map form in addition to the individual magnitude calculations. In this view, a user can make the final determination of the location and size of the earthquake.

IRIS INCORPORATED RESEARCH INSTITUTIONS FOR SEISMOLOGY

# INSERT TAB
# RISKS
# HAZARDS
# PREPAREDNESS

# Asperities

Background page to accompany the animations on the website: **IRIS Animations**

LINK To P. 2
Vocabulary

## Introduction

### What is an asperity?

An asperity (is an area on a fault that is stuck or locked. In the Earth, tectonic earthquakes are caused by slip along a fault plane, where two rock bodies are in rigid contact. The friction along the fault plane is not uniform in strength, so overall movement involves slip on one or more asperities, or “stuck patches” where the friction is highest. Most of the energy that is released by earthquakes comes from the patches that become “unstuck.”

### More About Asperities*

Total fault offset accumulates through time in an uneven fashion, primarily by movement on first one, and then another section of the fault. The portions of the fault that produce great earthquakes can remain “locked” and quiet for one hundred or more years, while the strain is building up; then, in great lurches, the strain is released, producing a great earthquake.

Asperities, which may be caused by roughness, or protrusions on the fault, act like welded contacts between the sides of the fault. Younger faults have rougher surfaces with more asperities. As a fault repeatedly ruptures, the asperities can be worn down, creating fault gouge and smoothing the fault. The gouge material often decomposes to a fine clay and forms a thin layer which “greases” the fault for easier sliding. Fluids can also facilitate slip by reducing the normal stress on the fault.

The San Andreas Fault is actually a fault system that is more than 800 miles long and the seismically active portion extends to depths of at least 10 miles within the Earth and ranges from a few hundred feet to a mile or more wide. It doesn’t slip all at once, but rather, earthquakes jump around on it as local asperities break. On some stretches of some faults, however, such as around Hollister on the Calaveras fault, date movement occurs primarily by constant repeated creep events rather than by sudden earthquake offsets. In historical times, these creeping sections have not generated earthquakes of the magnitude seen on “locked” sections.

The dynamics of fault rupture are complex, but general fault behavior can be explained with a simple model in which slip promotes fault weakening.

Fault slip occurs in three stages:

1) initiation of sliding on a small portion of the fault,
2) growth of the slip surface, and
3) termination of slip and fault healing. Earthquakes occur on preexisting faults operating in a “stick- slip” mode. Earthquakes are “slip” episodes; they are followed by periods of no slip (“stick”), during which elastic strain increases away from the fault. Although some growth of the fault may occur with each earthquake, we can generally assume that for large earthquakes (M>6) the faulting process primarily involves repeated breaking of the same fault segment rather than creation of a new fault surface.”

### Asperity Quakes Compared to Chopstick Breaks

Most earthquakes happen on faults. The process that causes them is similar to what happens if you bend a chopstick until it breaks.

Comparing the multiple asperities along a fault zone with the multiple failures of a bamboo chopstick:

Regional compression and extension are acting on the “fault zone” (plate tectonics is acting on fault zones; hands are acting on the chopstick)

There is a build-up of stress (hold the tips of the chopstick with the tips of your fingers and feel the stress build up as elastic energy is stored in the chopstick ). If you release the energy before the chopstick breaks, it will return to its pre-stressed shape.

Knowledge of the rate of strain buildup allows one to “forecast” that it (the chopstick or the fault) will break. But it is difficult to predict the time and place where it will breaks next.

The weakest zones will break first.

One may hear some precursors (weakest asperities breaking).

There is elastic deformation and brittle failure.

There is elastic rebound as the stored energy in the deformed material is released, the material rebounds to its previous shape.

Sound waves generated by the breaking chopstick can be compared to the compressive seismic waves (P waves) of an earthquake.

Bottom line: Tectonic earthquakes will occur anywhere within the earth where there is sufficient stored elastic strain energy to drive fracture propagation along a fault plane. Most boundaries do have such asperities and this leads to a form of stick-slip behaviour. Once the boundary has locked, continued relative motion between the plates leads to increasing stress and therefore, stored strain energy in the volume around the fault surface. This continues until the stress has risen sufficiently to break through the asperity, suddenly allowing sliding over the locked portion of the fault, releasing the stored energy. This energy is released as a combination of radiated elastic strain seismic waves, frictional heating of the fault surface, and cracking of the rock, thus causing an earthquake.

---

*From “**Can Earthquakes be Predicted?**” by Michelle Kathleen Hall-Wallace

## Vocabulary

**Asperity**—literally "roughness. It is an area on a fault that is stuck or locked. A type of surface roughness appearing along the interface of two faults. Physics the elastically compressed region of contact between two surfaces caused by the normal force

**Elastic strain**—Earthquakes are caused by the sudden release of energy within some limited region of the rocks of the Earth. The energy can be released by elastic strain, gravity, chemical reactions, or even the motion of massive bodies. Of all these the release of elastic strain is the most important cause, because this form of energy is the only kind...

**Fault plane**—The plane along which the break or shear of a fault occurs. It is a plane of differential movement, that can be vertical as in a strike slip fault or inclined like a subduction zone fault.

**Fault zone**—Since faults do not usually consist of a single, clean fracture, the term fault zone is used when referring to the zone of complex deformation that is associated with the fault plane.

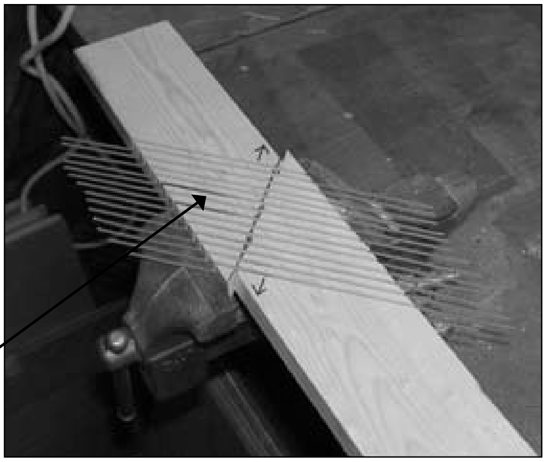
**Strain**—Strain is defined as the amount of deformation an object experiences compared to its original size and shape. For example, if a block 10 cm on a side is deformed so that it becomes 9 cm long, the strain is (10-9)/10 or 0.1 (sometimes expressed in percent, in this case 10 percent.) Note that strain is dimensionless.
Learn more: **http://www.uwgb.edu/DutchS/structge/stress.htm**

.**Stress**—Stress is defined as force per unit area. It has the same units as pressure, and in fact pressure is one special variety of stress. However, stress is a much more complex quantity than pressure because it varies both with direction and with the surface it acts on.
Learn more: **http://www.uwgb.edu/DutchS/structge/stress.htm**

**Tectonic earthquake**—an earthquake that is due to the movement of the tectonic plates. Tectonic earthquakes will occur anywhere within the earth where there is sufficient stored elastic strain energy to drive fracture propagation along a fault plane. Other earthquakes can be caused by blasts.

# Strike-slip Fault with Spaghetti Asperities—Vice Method

From John Lahr's Fun With Science "Spaghetti Fault" (**www.jclahr.com/science/earth_science/spagh_fault/index.html**).
This fault model is a variation of one invented by Paul Doherty **http://www.exo.net/~pauld/index.html**).



## Time

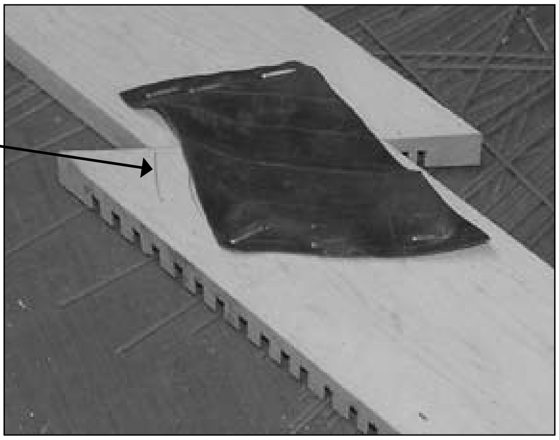
Construction 1 hour; demo 5-15 minutes

## Content

Students will learn about forces in the Earth and be able to describe sequential earthquakes on a fault when steady force is applied. In this model, each piece of spaghetti acts as an asperity that must be broken for slip to occur.

## Materials

- 1 x 6 board 12-18 inches long. Cut shallow grooves in it with table saw at an angle of 45° to the length of the board. Then cut the board in two on the opposite 45° diagonal as shown in the picture (upper photo).
- Scrap of plastic or rubber sheet to staple on the back to hold the wood together, but loose enough so it doesn't resist the vice. (center)
- Vice
- Spaghetti noodles

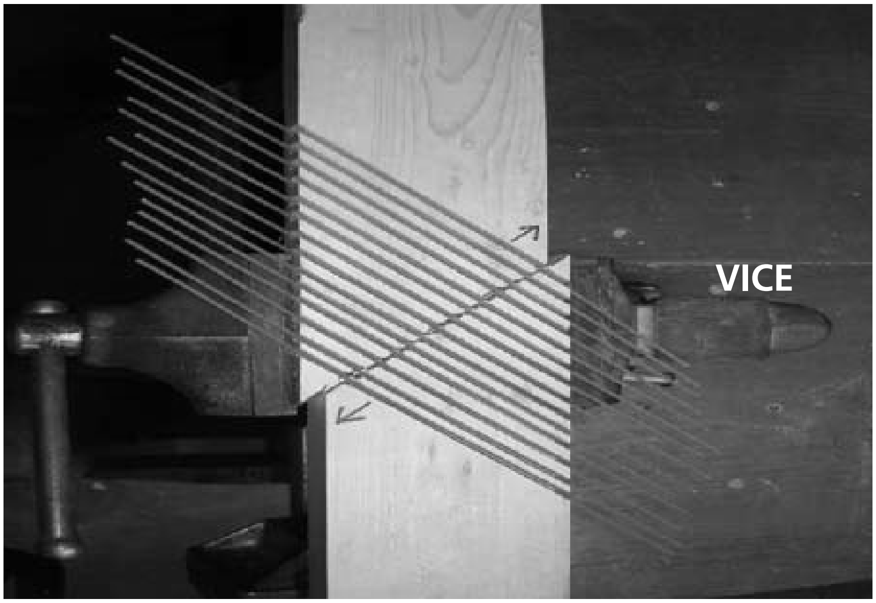


**Tools:** Table saw, vice, staple gun

## Set up and Demonstration

Prepare board as described under **Materials**. Staple the plastic to the back. Place it in the vice with just enough pressure to hold it in place and have the grooves lined up perfectly. Set spaghetti noodles in the grooves. Turn vice very slowly at a controlled rate throughout the process. TIn this model, each piece of spaghetti acts as an asperity that must be broken for slip to occur. Sometime just one noodle breaks, somewhat analogous a small earthquake.

Quite a few break (foreshocks) a few seconds prior to a "massive event" (main shock) in which many break in rapid succession.  This is followed by one or two remaining pops (aftershocks).



**RETURN to ASPERITIES: http://www.iris.edu/about/ENO/aotw/**

# Strike-slip Fault with Spaghetti Asperities—Clamp Method

## Modified from "Strike-slip Fault with Spaghetti Asperities"

This is the same concept as the Vice Model, but lacks the control on the rate of block movement.

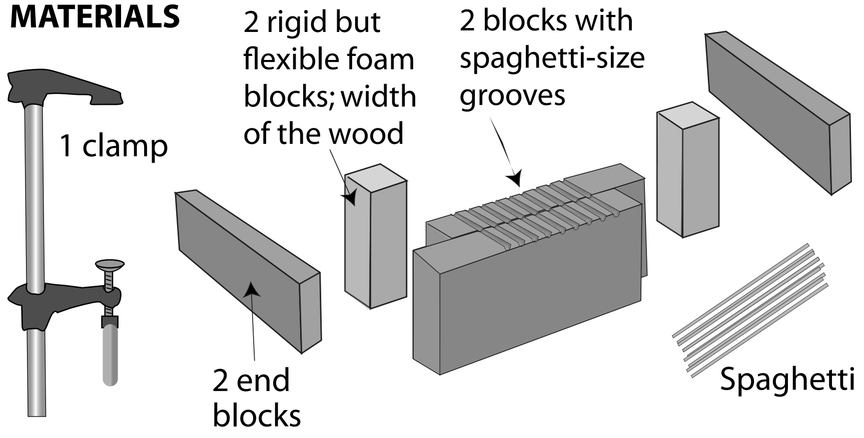
## Time:

Construction 1 hour;
demo 5-15 minutes

## Content:

Students will learn about forces in the Earth and be able to describe sequential earthquakes on a fault when steady force is applied. In this model, each piece of spaghetti acts as an asperity that must be broken for slip to occur.

**MATERIALS**



**Tool**: Table saw to cut grooves

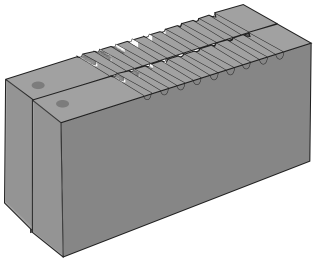
## Procedure

Clamp two equal-length blocks together matching the ends. Cut shallow, narrow grooves in the two larger blocks with a table saw. Note that the pink dots (●) on the ends are together for groove cuts, but are flipped 180° horizontally for the assembly.

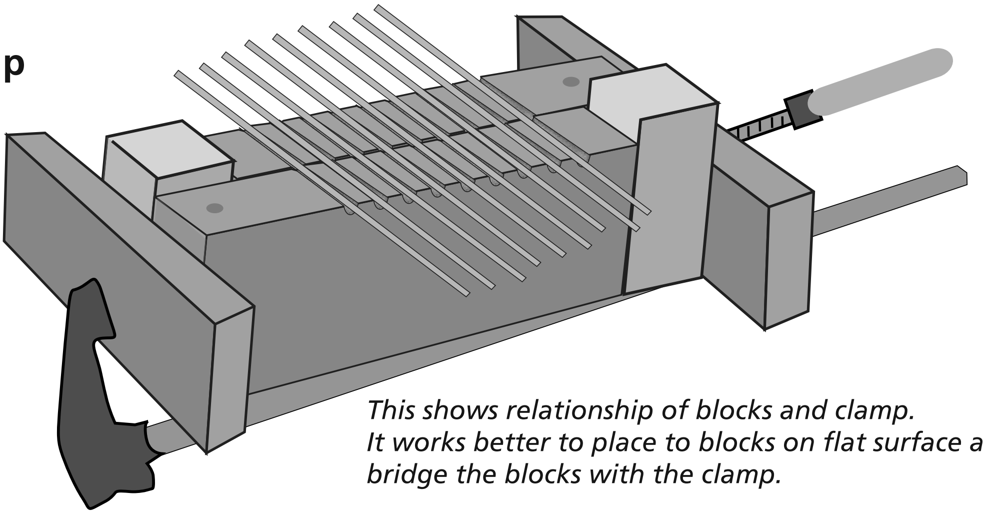
Assemble according to drawing below. Foam needs to be compressible, yet firm, and cut to the width of the gaps left at the grooved-wood ends when the grooves are aligned.

Set spaghetti noodles in the grooves. Turn clamp very slowly at a controlled rate throughout the process. In this model, each piece of spaghetti acts as an asperity that must be broken for slip to occur. Sometime just one noodle breaks, somewhat analogous a small earthquake.

Quite a few break (foreshocks) a few seconds prior to a "massive event" (main shock) in which many break in rapid succession. This is followed by one or two remaining pops (aftershocks).



**Setup**



*This shows relationship of blocks and clamp.*
*It works better to place to blocks on flat surface and bridge the blocks with the clamp.*

**RETURN to ASPERITIES: http://www.iris.edu/about/ENO/aotw/**

# Buildings and earthquakes—Which stands? Which falls?

Background pages with links to particular animations or lectures on site: **IRIS' Animations** and/or **Videos**
This has been assembled quickly and will be replaced as updated.

## Introduction

The two most important variables affecting earthquake damage are (1) the intensity of ground shaking caused by the quake coupled with (2) the quality of the engineering of structures in the region. The level of shaking, in turn, is controlled by the proximity of the earthquake source to the affected region and the types of rocks that seismic waves pass through en route (particularly those at or near the ground surface).

Generally, the bigger and closer the earthquake, the stronger the shaking. But there have been large earthquakes with very little damage either because they caused little shaking or because the buildings were built to withstand that kind of shaking. In other cases, moderate earthquakes have caused significant damage either because the shaking was locally amplified, or more likely because the structures were poorly engineered.

## Tall or Small? Which is Safer? It depends!!

Resonance is the oscillation, or up-and-down or back-and-forth motion caused by a seismic wave. During an earthquake, buildings oscillate (figure at right). Not all buildings respond to an earthquake equally. If the frequency of an oscillation is close to the natural frequency of the building, resonance may cause severe damage. (see video lecture on "**Resonance**" figure on page 3.)

### Damage during an earthquake results from several factors:

**Strength of shaking.** The strong shaking produced by a magnitude 7 earthquake becomes half as strong at a distance of 8 miles, a quarter as strong at a distance of 17 miles, an eighth as strong at a distance of 30 miles, and a sixteenth as strong at a distance of 50 miles.

**Length of shaking.** Length depends on how the fault breaks during the earthquake. The maximum shaking during the Loma Prieta earthquake lasted only 10 to 15 seconds. During other magnitude 7 earthquakes in the Bay Area, the shaking may last 30 to 40 seconds. The longer buildings shake, the greater the damage.

**Type of soil.** Shaking is increased in soft, thick, wet soils. In certain soils the ground surface may settle or slide.

**Type of building.** Certain types of buildings, discussed in the reducing earthquake damage section, are not resistant enough to the side-to-side shaking common during earthquakes.

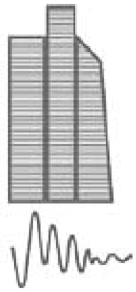
*Information in this collected from USGS.gov, Fema.gov, IRIS.edu, Exploratorium (www.exo.net) and other sources.*

**Activities pages 4-5 (touch to go there)**

**Haiti devastation exposes shoddy construction:**
**see page 6 for text and link to video!!!!**

### Small Buildings:

Small building are more affected, or shaken, by high-frequency waves (short and frequent). For example, a small boat sailing in the ocean will not be greatly affected by a large swell. On the other hand several small waves in quick succession can overturn, or capsize, the boat. In much the same way, a small building experiences more shaking by high-frequency earthquake waves.



### Tall High Rises:

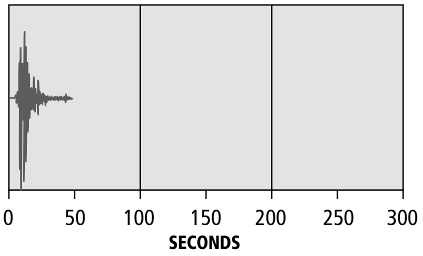
Large structures or high rise buildings are more affected by long period, or slow shaking. For instance, an ocean liner will experience little disturbance by short waves in quick succession. However, a large swell will significantly affect the ship. Similarly, a skyscraper will sustain greater shaking by long-period earthquake waves than by the shorter waves.

The two scenarios below are Seattle-area earthquake scenarios show the possible effects on buildings of different structural integrity of a shallow, magnitude 7 (**M7**) earthquake and a **M9** subduction-zone earthquake. These scenarios could apply to any cities on the coast or inland valleys of Washington and Oregon (as well as Chile, Alaska, British Columbia, Japan, N.Zealand).

## M7 shallow earthquake

***UPDATE: This can be equated to the Magnitude 7 earthquake in Haiti on Jan. 12, 2010***

### DURATION, INTENSITY AND STRUCTURAL DAMAGE

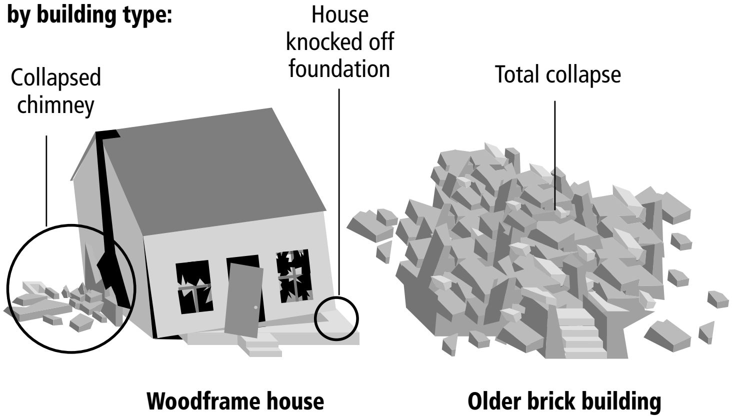


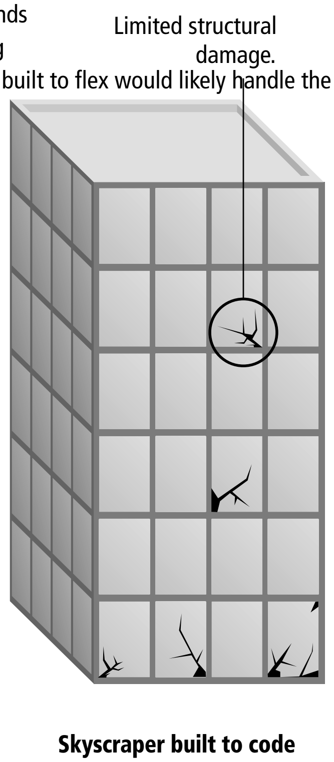
**Duration:** Roughly 20 to 60 seconds

**Intensity:** Violent ground shaking

**Damage:** Taller, newer structures built to flex would likely handle the shaking best. Brick or other unreinforced masonry buildings would do poorly, as would woodframe structures.

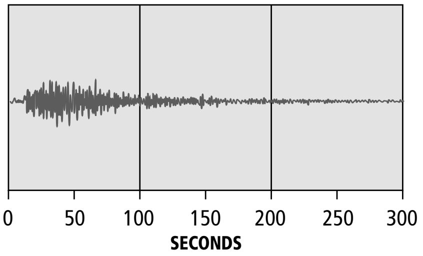
**How damage varies by building type:**





## M9 subduction earthquake

### DURATION, INTENSITY AND STRUCTURAL DAMAGE

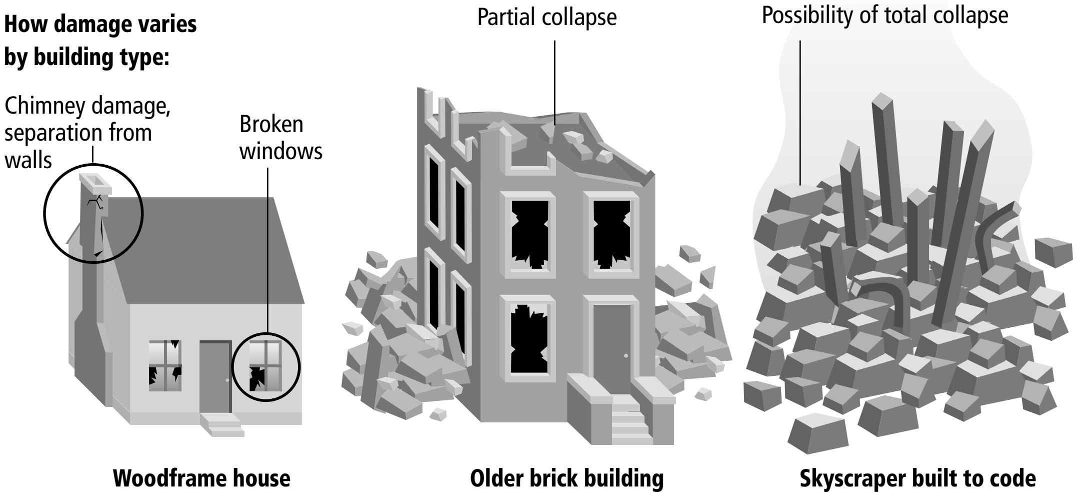


**Duration:** Roughly 1 to 5 minutes

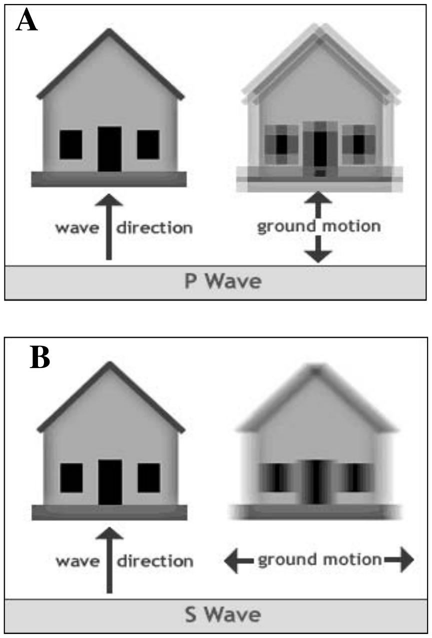
**Intensity:** Moderate ground shaking

**Damage:** This is the scenario scientists know least about. Some say the long duration of shaking could start modern skyscrapers and bridges swaying back and forth until they collapse because many structures have only been engineered to withstand shaking for seconds rather than minutes. Others think the damage might not be as severe because the shaking is not as violent as a shallow quake.

**How damage varies by building type:**



©Used with kind permission from the *SEATTLE POST-INTELLIGENCER*



***Above***. *House Shake Motion.* ***A:*** *The P wave, or compressional wave (think sound wave), is a seismic body wave that shakes the ground back and forth in the same direction that the wave is moving. P waves travel fastest and are generally felt first. They usually cause very little damage.* ***B:*** *An S, secondary or shear, wave is a seismic body wave that shakes the ground back and forth perpendicular to the direction the wave is moving. Watch the animations on IRIS animations pages:* **Seismic Wave Behavior: Effect on Buildings**

***Below:*** **Resonance video lecture demonstration:**
*NOTE: Play Quicktime on the site for sound. YouTube link has no audio.*
*John Lahr demonstrates the simplest and most spontaneous way to demonstrate the concept of resonance and building height uses spaghetti and small weights (raisins or marshmallows. Two other more-effective (but more time consuming) video lectures are included on the videos page.*

## Tall and small stay up; medium fall: Mexico, 1985—10,000 die.

On September 19, 1985, a magnitude 8.1 earthquake occurred off the Pacific coast of Mexico. 350 km from the epicenter damage was concentrated in a 25 km$^2$ area of Mexico City. The underlying geology contributed to this unusual concentration of damage at a distance from the epicenter. An estimated 10,000 people were killed, and 50,000 were injured. In addition, 250,000 people lost their homes. The set of slides (link below), shows different types of damaged buildings and the major kinds of structural failure that occurred in this earthquake including collapse of top, middle and bottom floors and total building failure.

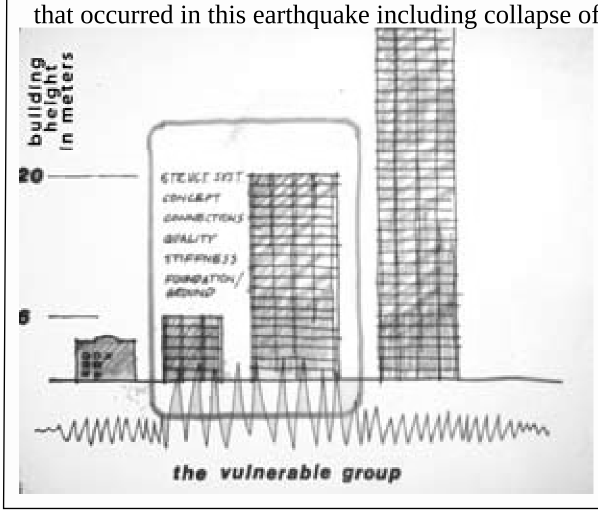


*Diagram credit: C. Arnold, Building Systems Development, Inc.*

Interestingly, the short and tall buildings remained standing. Medium-height buildings were the most vulnerable structures in the September 19 earthquake. Of the buildings that either collapsed or incurred serious damage, about 60% were in the 6-15 story range. The resonance frequency of such buildings coincided with the frequency range amplified most frequently in the subsoils.

To see slide show go to the NOAA website:
**Earthquake Damage in Mexico City**

Return to Page 1

# Activities

**1) Resonance Activities:** See "**Building Stability during Earthquakes**" on next page of this document for ideas on how to prepare and present a demonstration on resonance (video links on previous and next pages!):

A) **Spaghetti noodle** resonance
B) **Manilla file** BOSS Lite— Describe the impact of building resonance when assessing Earthquake Hazards
C) Block & Dowell **BOSS model** The activity is in the PDF file: FEMA's Seismic Sleuths (Unit 4, page 248)

D) The Exploratorium has a simple activity to show the resonance of buildings of different heights:
**http://www.exploratorium.edu/xref/phenomena/resonance.html**

**2) A shake table** can be used to test the resistance of structures to seismic shaking. It can also be used to demonstrate the sensitivity of structures of different heights to the frequency of the ground motion. Visit John Lahr's webpage:
**http://www.jclahr.com/science/earth_science/shake/index.html**

**3) Liquefaction**: **learn how soft sediment can affect how a building stands**
**www.exploratorium.edu/faultline/activezone/liquefaction.html**

## 4) INTERACTIVE Game: You have 25 min. to select retrofits to Stop a Disaster and save a town!!!

You can reduce human, physical, and financial catastrophe by making quick choices to plan and construct a safer environment, but you have limited funding. Expect good and bad advice along the way.

1) Go to **www.stopdisastersgame.org/en/home.html** and touch
**PLAY GAME > Launch game > Play game** (again)
2) **Select a Scenario**: Type: **Earthquake** / Select **SELECT DIFFICULTY LEVEL** (start "EASY" to learn)
3) Roll over each buildings to decide to get Info, Demolish, or provide Upgrades (each has a cost)

*WARNING: 25 minutes goes by quickly. Fix big older buildings first.*

## 5) INTERACTIVE Design a bridge; add structural elements; then set off an earthquake!!

Fun interactive program allows you to design the Bay Bridge...and then destroy it with an earthquake. Select bridge types, seismic safety features and earthquake type:**http://eduweb.com/portfolio/bridgetoclassroom/engineeringfor.html**

## 6) HOW BIG WAS IT? How do you get across the idea of magnitude? M5 vs M7?

**See "Pasta Quake" on page 6 of this document.**

# Building Stability during Earthquakes**

The three highly effective activities address earthquake resonance on buildings.
We offer different styles and levels of the same basic processes using a variety of materials.

**Time:** 5-30 Minutes

**Target:** Grade Level: 6-12

**Content Objective:** Students will predict how a structure will react to vibrations (oscillations) of different frequencies, and describe the phenomenon of resonance.

## Introduction

*Why do buildings of different heights respond differently in an earthquake?* These activities show that how seismic waves travel through the layers of the Earth can effect how a building might wobble. Aside from architectural constraints, i.e., how well built the structure is, the particular resonance of an earthquake can knock down a small building and spare the skyscraper. The resonance is the oscillation (up-and-down or back-and-forth motion) caused by a seismic wave. During an earthquake, buildings oscillate. If the frequency of this oscillation is close to the natural frequency of the building, resonance may cause severe damage. These models allow students to observe the phenomenon of resonance.

### Teacher Preparation—Choice of Models

***First,*** decide which oscillation model fits your class time, as well as preparation time. FEMA's Seismic Sleuth's BOSS model has much background material.With all models, practice before using in class!!

1) The spaghetti-and-marshmallow (or raisin) model is the quickest to assemble and is described in the movie, Modeling Resonance using Spaghetti.
2) The **BossLite model** (Movie-Manilla Folder) has the advantage of looking more like buildings; you could even draw windows on them. Because of the different weight of manilla folders, we found we had to experiment with doubling up the files as they were too floppy.
3) The **BOSS model** (Movie Boss Model) is the most elegant, and will be a permanent tool for the classroom. But it does take some assembly time and must be stored. The activity is in the PDF file: FEMA's Seismic Sleuths (Unit 4, page 248)

***Second***, find out what students already know about the concepts of amplitude, frequency, and resonance. If they are not familiar with these terms, introduce them by building on what students already know from other areas. They may know, for example, that resonance and frequency are used in describing the tone of musical instruments and the quality of sound produced by different recording techniques and players. The phenomenon of resonance also accounts for laser light and for the color of the sky.

### Materials:

Watch the 3 videos on resonance to determine how elaborate an activity you want.
**Video clips of the Resonance Demonstrations** introduce the concept of resonance in these three demonstrations:

**Modeling Resonance using Spaghetti Noodles**
**Modeling Resonance using Manilla Folder**
**Modeling Resonance using BOSS Model**

---

***Third,*** review the terms and concepts introduced in this lesson. Explain that seismic waves caused by earthquakes produce oscillations, or vibrations, in materials with many different frequencies. Every object has a natural rate of vibration that scientists call its natural frequency. The natural frequency of a building depends on its physical characteristics, including the design and the building material. Resonance is a buildup of amplitude in a physical system that occurs when the frequency of an applied oscillatory force is close to the natural frequency of the system. In the case of an earthquake, the ground shaking may be at the same frequency as the natural frequency of a building. Each vibration in the ground may come at or dangerously close to the natural frequency of the structure.

***Fourth***, ask the class to hypothesize what would happen when buildings of two different heights, standing next to each other, resonate from an earthquake. (Remember to practice a lot before demonstrating. The BOSS model, though most time consuming to construct, works best!) Students invariably select the tallest building. Wiggle the model so that the shorter building vibrates the greatest. If you have some images of this effect from actual earthquakes, show them now. The Mexico City quake described on page 27 is a good example of mid-size buildings falling preferentially.

***Fifth***, entice students to further investigation by leaving them with the question: "**How could you add structural elements to reduce resonance in a building**?" Adding sheer structure keeps things from falling. Watch the video **Building Strength Demo** on the IRIS "Videos" page.

Activity modified from activities from IRIS, FEMA, and John Lahr

# Haiti devastation exposes shoddy construction

By Ayesha Bhatty
BBC News, London

Experts say it is no surprise that shoddy construction contributed to the level of destruction in Haiti following Tuesday's earthquake. But the scale of the disaster has shed new light on the problem in the impoverished Caribbean nation. Tens of thousands are feared dead after being crushed by buildings that collapsed. Scores more remain trapped under the rubble.

"It's sub-standard construction," says London-based architect John McAslan, who has been working on a project linked to the Clinton Global Initiative in the country.

"There aren't any building codes as we would recognise them," he added. Mr McAslan says most buildings are made of masonry - bricks or construction blocks - which tend to perform badly in an earthquake.

> *"...the loss of life from earthquakes is typically 10 times higher in developing countries than the West and the damage can be up to 100 times worse."*

Touch link and go to bottom of page to watch & listen to:
"Animated building collapse"

## Cheap concrete

There are also significant problems with the quality of building materials used, says Peter Haas, head of the Appropriate Infrastructure Development Group, a US-based non-profit group that has been working in Haiti since 2006.

"People are skimping on cement to try to cut costs, putting a lot of water in, building too thin, and you end up with a structure that's innately weaker," said Mr Haas, who was on his way to Haiti to help assess the safety of damaged buildings.

"Concrete blocks are being made in people's backyards and dried out in the sun," he said.

Mr Haas said there were also "serious problems" with the enforcement of building codes in Haiti. He said the government did not function at all in several parts of the country, and many communities lacked basic services such as electricity, sanitation services or access to clean water.

"So the problem of code enforcement is low down on the list," he said.

## Poor record

Even before the quake, Haiti's building safety record was poor. Almost 100 people - mostly children - died when two schools collapsed within days of each other in November 2008. At the time, Haitian authorities blamed poor construction for the accidents. Roger Musson, head of seismic hazard at the British Geological Survey, said he was "not at all" surprised at the level of destruction in Haiti. He said Haiti, the poorest country in the western hemisphere, was not used to dealing with earthquakes of this magnitude. Tuesday's quake was the worst in two centuries. The country is more used to dealing with hurricanes, which have been getting more frequent in recent years, according to Mr Musson.

"Most buildings are like a house of cards," he said. "They can stand up to the forces of gravity, but if you have a sideways movement, it all comes tumbling down."

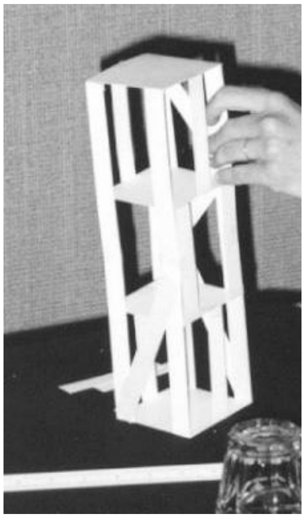
Ironically, people living in the shanty towns might have had a better chance of survival than those trapped under concrete buildings, many of which "pancaked". "A simple shack's collapse is likely to cause less damage to human safety than a multi-floor building that collapses," Mr McAslan said.

## Aftershocks

Mr McAslan says it is more complex and expensive to earthquake-proof a building than equip it for hurricane damage. "The priorities have inevitably been elsewhere, but I'm absolutely certain that the attention of the government will be to build back better."

He said the main task for the authorities now was to save as many lives as possible, then to stabilise damaged buildings so they could withstand any aftershocks, and finally, to assess how to create buildings that could reasonably withstand another earthquake. According to Mr McAslan, the extent of deforestation in Haiti also contributed to devastation. He said that on the hillsides of Petionville, a suburb east of Port-au-Prince, buildings simply "collapsed and collapsed and collapsed" on to each other as there was no forest to protect them.

According to the US Geological Survey, the loss of life from earthquakes is typically 10 times higher in developing countries than the West and the damage can be up to 100 times worse.



# Earthquake Shaking – Building Contest and Shake Table Testing Activity©

**(Posterboard Buildings,**
**May, 1999; revised, March 2003, October 2003)**

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**Objectives:** Explore earthquake hazards and damage to buildings by constructing model buildings and subjecting the buildings to ground vibration (shaking similar to earthquake vibrations) on a small shake table. The buildings are constructed by of two- or three-person teams of students or workshop participants. After construction, the buildings are tested by subjecting them to earthquake shaking to see which designs and constructions are successful. Comparison of the results of the building contest with photographs of earthquake damage is used to reinforce the concepts of building design and earthquake risk.

**Materials:**

- Posterboard (lightweight posterboard; note: there is a difference in quality and therefore strength of lightweight pasteboard; the best posterboard has one smooth, almost glossy side and on dull side; lightweight posterboard can be purchased at most bookstores, convenience stores, Wal-Mart and K-Mart.)

    4 – 8 x 8 cm squares (floors)
    12 – 1½ x 10 cm strips (uprights)*
    12 – 1½ x 15 cm strips (reinforcing)*
    1 – 30 x 8 cm (cut and use as you wish)
- Scotch Tape (2 cm or 3/4” wide) 100 cm length (Plan accordingly!)
- Scissors
- 30 cm ruler

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*The widths of these strips can be varied from about 1 cm to 2 cm. It will be more difficult to design and build a “successful” building with the thinner strips. A reasonable choice for most applications is 2 cm strips for uprights and 1½ cm strips for reinforcing. You can also use the 30 x 8 cm piece of poster board for reinforcing. Cut as you wish.

**Rules:**

- Building must be:
  - At least 30 cm high
  - at least 3 stories
  - no central post or uprights (so that weights can be placed on floors)
- Materials are limited (realistic)
- Complete construction in limited time (realistic)

**Design:**

- Note importance of shear or diagonal support. This concept can be illustrated (and explained) using the shear wall model from *Seismic Sleuths* (FEMA/AGU, 1994; Figure 1). One can also build model walls using short strips (1½ x 10 cm and 1½ x 14.4 cm) of 1/16" thick mounting board, or other similar materials such as popsicle sticks, and magnets or mounting putty for joints. Without diagonal bracing, the model wall is relatively strong for a static, vertical load. However, a horizontal load or shaking causes the wall to collapse. With the diagonal bracing (shear-support) installed, the wall is much stronger and more resistant to shaking.

*Figure 1. Experimenting with the Shear Wall (Seismic Sleuths activity).*

- Simple, rectangular building designs are effective (Figure 2). Many design options, particularly for the bracing, are possible.

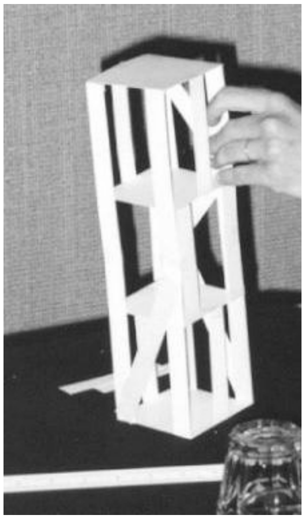


*Figure 2. A partially completed lightweight posterboard model building.*

**Testing:**

- Buildings are tested on the horizontal motion shake table (Figure 3). Tape the base of the building to the base plate of the shake table. We choose the direction to orient the building.

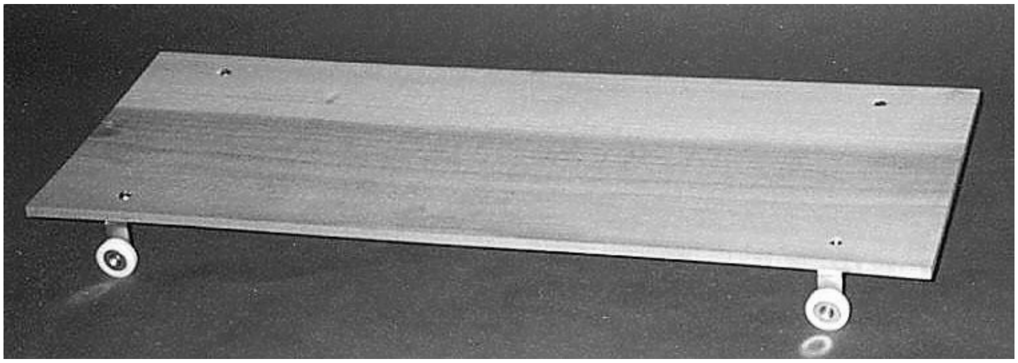


*Figure 3. A simple, horizontal motion shake table. Wheels are nylon cabinet or drawer wheels and are attached to the board with "L" brackets, machine screws and nuts.*

- Add masses to the floors and roof of the building (Figure 4). Masses should be about 30 to 80 g each. Begin testing with small masses. Steel washers of 3-4 sizes make convenient and effective masses. Tape washers to floors and roof or use small plastic spring clips available at hardware stores or in hardware departments of Wal-Mart and K-Mart.

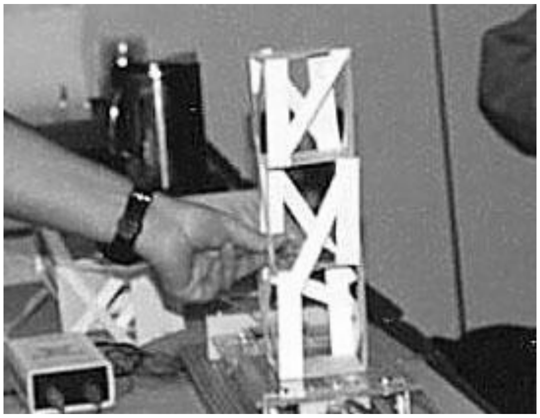


*Figure 4. A model building on a shake table. Weights (steel washers) are attached to each floor and the roof. Small (5-g) horizontal accelerometers are attached to the shake table and to the top of the building. The results of shake table testing (acceleration versus time of the shake table and the top of the building as the shake table is moved back and forth) can be monitored on the computer screen or projected using an LCD projector for everyone to see.*

- Shake building at three frequencies – low, medium and high – and at three amplitudes – low, medium and high. An accelerometer on the base plate can be used to quantify the shaking and make comparisons between the testing of different buildings more consistent. A second accelerometer can be attached to the top of the building to observe amplification and resonance effects. Small, relatively inexpensive accelerometers, an analog to digital interface for the accelerometers (Serial Box Interface or LabPro), and software (LoggerPro) for the interface are available at Vernier Software (www.vernier.com) or other vendors of “probeware”. High School or College physics departments often have Vernier or similar equipment so you may only need to obtain the accelerometers.

- In our experience, using the instructions and materials described here, it will usually be possible for most buildings to survive the shaking using small masses (30-50 g). However, few buildings with these materials will withstand strong (about 1 *g*, 1 *g* is the acceleration of gravity which is 980 $cm/s^2$ or 9.8 $m/s^2$), high frequency (about 10 Hz), shaking with larger masses (50-80 g). Interesting resonance and amplification effects will be visible for some frequencies and amplitudes of shaking.

- If your shake table is large enough (a convenient size is about 16 x 50 cm), you can attach and test two or three buildings at the same time which provides an interesting comparison of building responses.

- After the initial testing, it is possible to illustrate specific design issue/problems with model buildings that were successful. For example, you can create the "soft first story" problem by reducing the shear support in the first story of the building. Sometimes buildings are damaged by a mainshock earthquake and then further damaged or destroyed in an aftershock. Also, poor quality construction or mistakes made in construction can result in specific weak elements of a building. These situations can be simulated in a model building by weakening an upright or a joint by cutting or partially cutting the posterboard material or tape. Other building design and construction variations, such as very rigid or very flexible buildings, can be specifically built and tested. Comparing the responses and failure levels of these structures with the original designs that were successful is an excellent method of reinforcing the principles of effective building design and earthquake hazards related to structures.

- If time permits, students can construct a second set of buildings that benefit from the lessons learned in the first building contest and shake table testing.

- An excellent videotape on earthquakes that includes a segment on building design and shake table testing of a model building (using Legos) to show the importance of shear support is "Seismic Sleuths," Discovery Channel (www.discovery.com).

To view corresponding photographs of earthquake damage to buildings and other structures (for comparison to the lessons learned in shake table testing of the model buildings) and other information on earthquake hazards see:

1. *•EQ Hazard Info-Part 1*
*•EQ Hazard Info-Part 2*
*•EQ Photos-Part 1*
*•EQ Photos-Part 2*
at: http://www.eas.purdue.edu/~braile/indexlinks/educ.htm (use Quick Links), and/or:

2. A Power Point presentation (eqdamage.ppt) with some of the earthquake damage photographs (Figure 5) contained in the above online pages (available at: www.eas.purdue.edu/~braile, click on “Workshops” in the Quick Links).

Also note the significant building failures and risk represented by falling objects (on the exterior or within buildings) and poor foundations and liquefaction.

*Figure 5. "Soft" or weak first story failure of a four-story building in San Francisco damaged by the October, 1989 Loma Prieta earthquake. In this case the weak story is caused by reduced shear wall strength and lack of diagonal bracing related to constructing parking garages (note garage doors) in the first story of the building.*

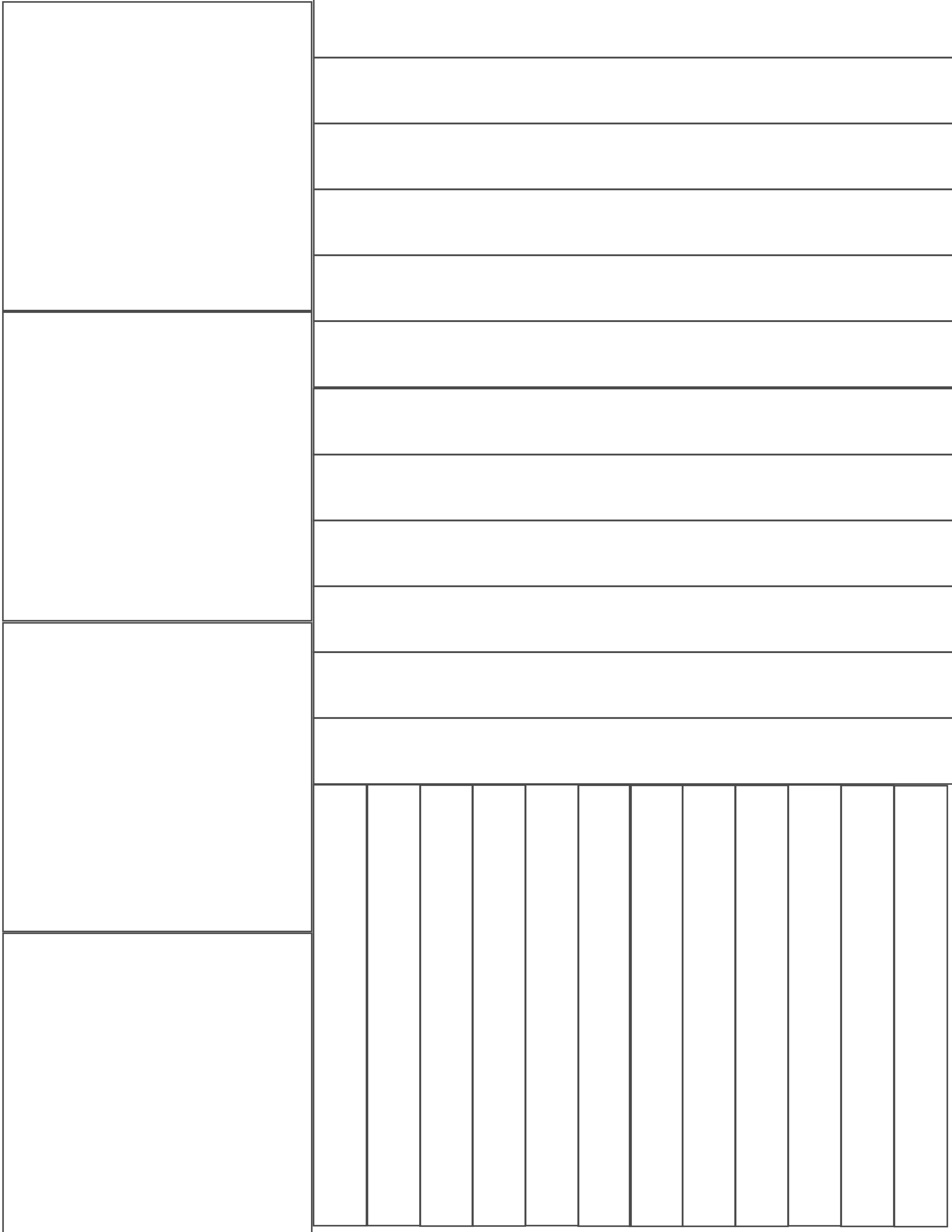
**References:**

FEMA/AGU, *Seismic Sleuths - Earthquakes - A Teachers Package on Earthquakes for Grades 7-12*, American Geophysical Union, Washington, D.C., 367 pp., 1994. (FEMA 253, for free copy, write on school letterhead to: FEMA, PO Box 70274, Washington, DC 20024).

Levy, Matthys and Mario Salvadori, Why Buildings Fall Down, W.W. Norton & Co., New York, 334 pp., 1992.

Levy, Matthys and Mario Salvadori, Why the Earth Quakes, W.W. Norton & Co., New York, 215 pp., 1995.

Salvadori, Mario, Why Buildings Stand Up, W.W. Norton & Co., New York, 323 pp., 1980.



## Earthquake Education Workshops

September 2014
Charlotte, Candler, and Winston-Salem

# *“Earthquake Preparedness – Lessons to Learn from the M = 5.8 Mineral, Virginia Earthquake of August 23, 2011”*

presented by

**Dr. Kenneth B. Taylor**

State Geologist of North Carolina
N.C. Geological Survey
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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.

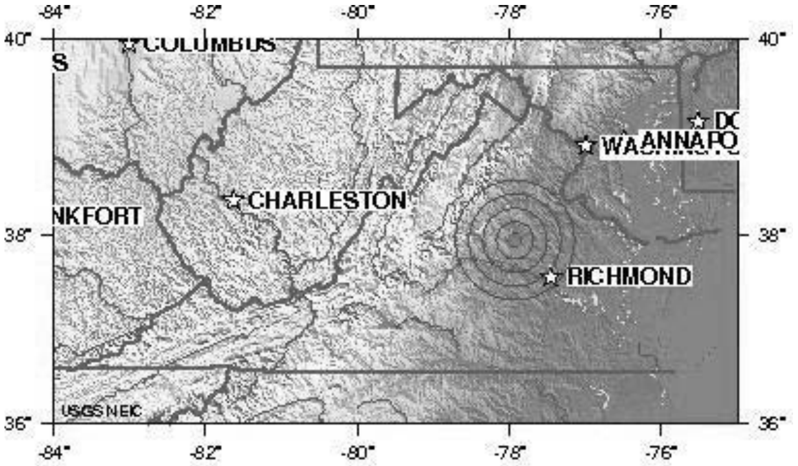


*Image courtesy of the US Geological Survey*

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*)

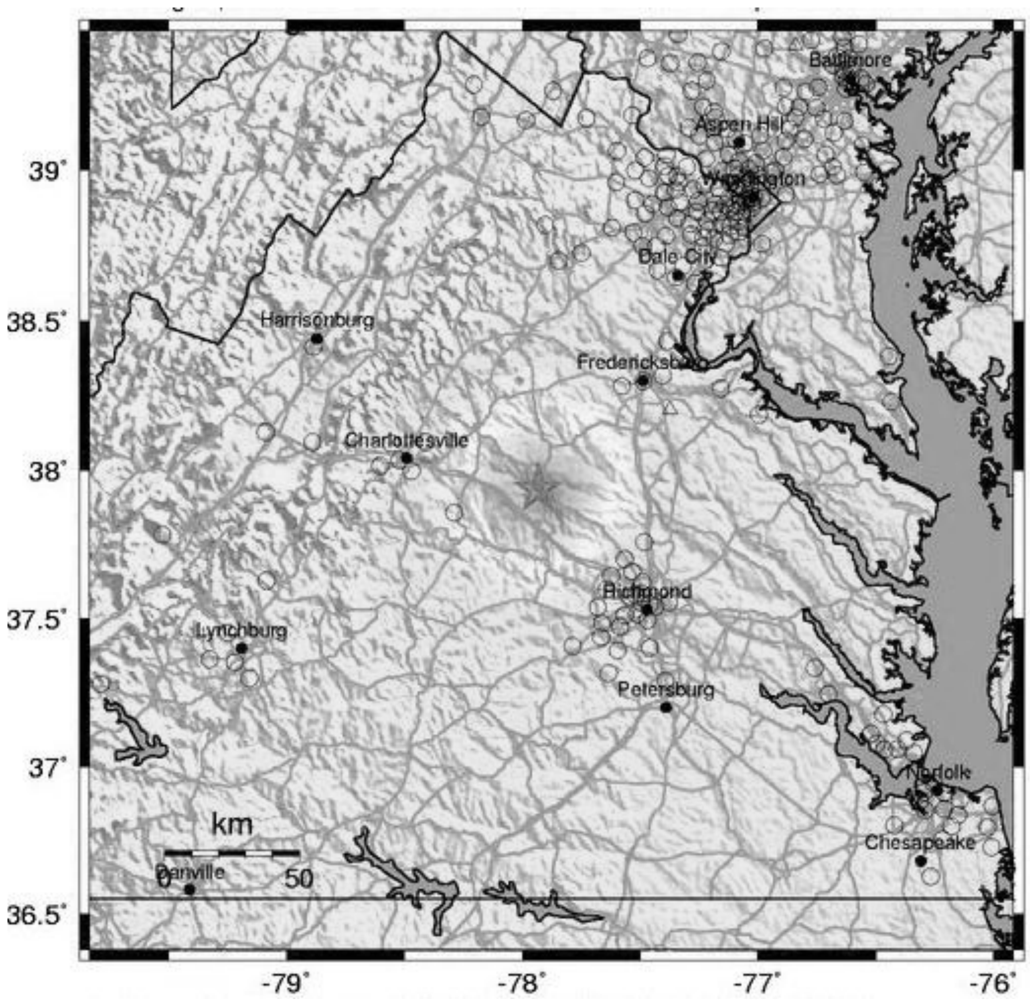
# Magnitude 5.8 VIRGINIA

## 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).

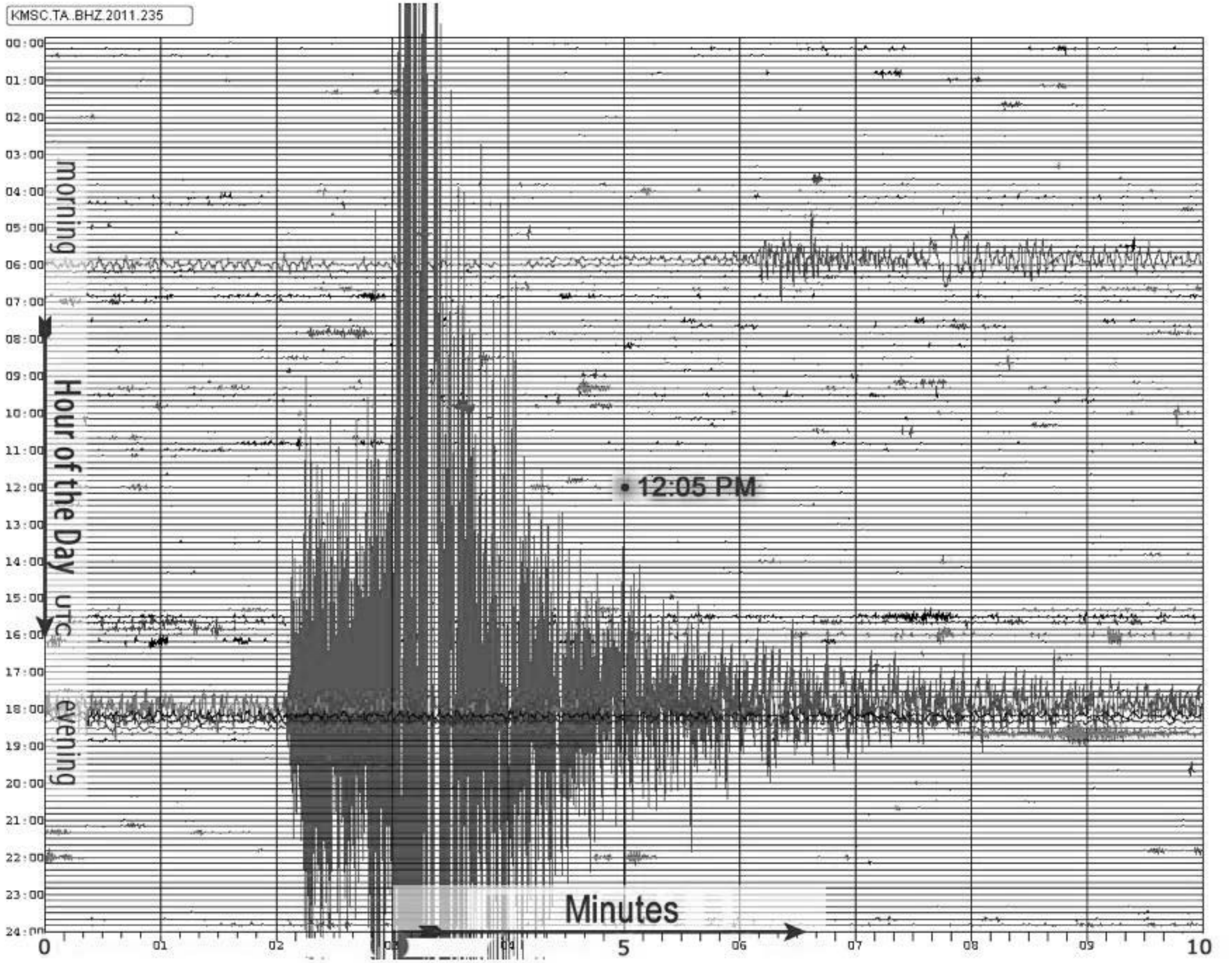
| Modified Mercalli Intensity | Perceived Shaking |
|---|---|
| X | Extreme |
| IX | Violent |
| VIII | Severe |
| VII | Very Strong |
| VI | Strong |
| V | Moderate |
| IV | Light |
| II-III | Weak |
| I | Not Felt |

Image courtesy of the US Geological Survey

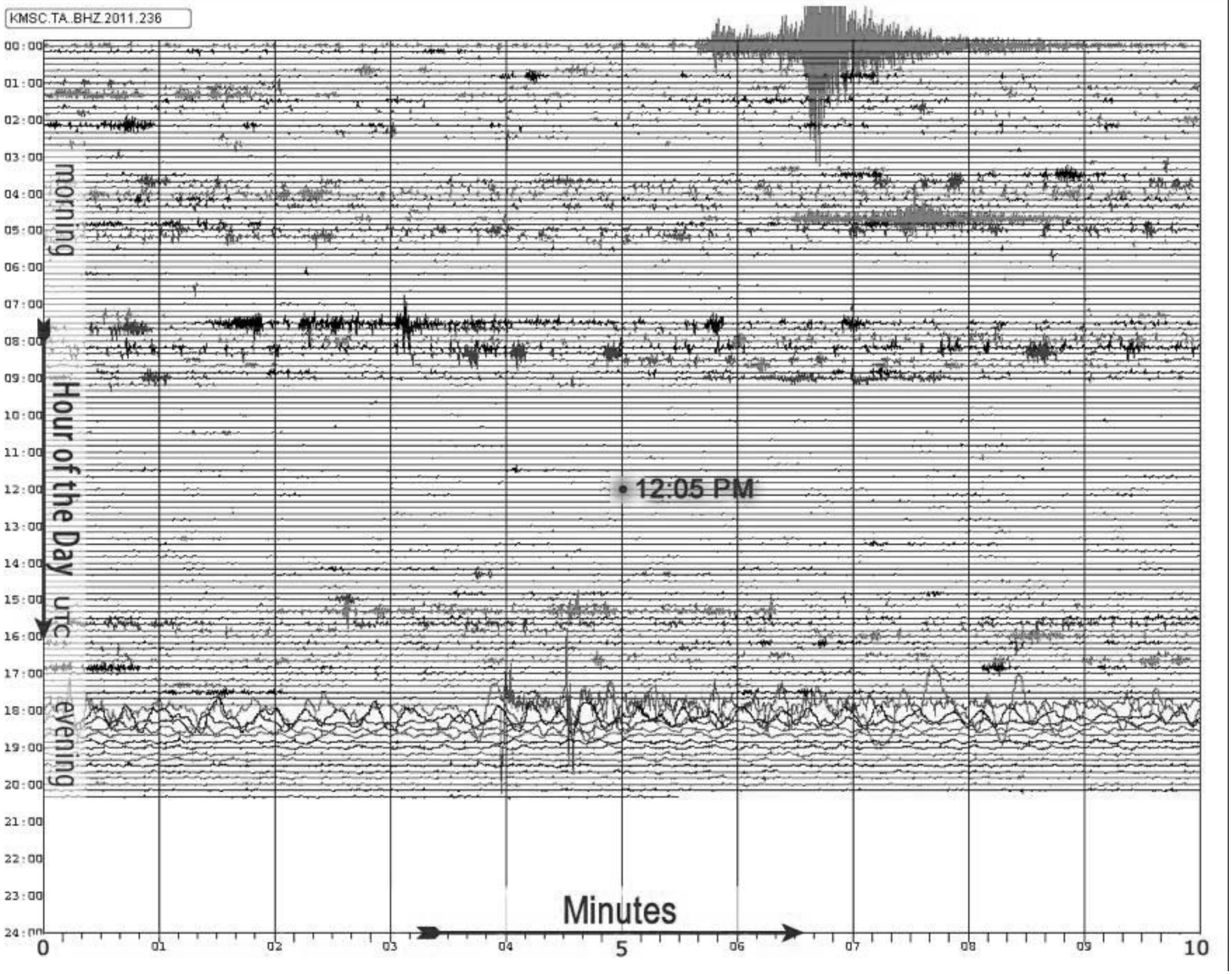


*USGS Estimated shaking Intensity from M 5.8 Earthquake*

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



# 08/24/2011 Seismic Activity at Station KMSC - Kings Mountain, Blacksburg, SC



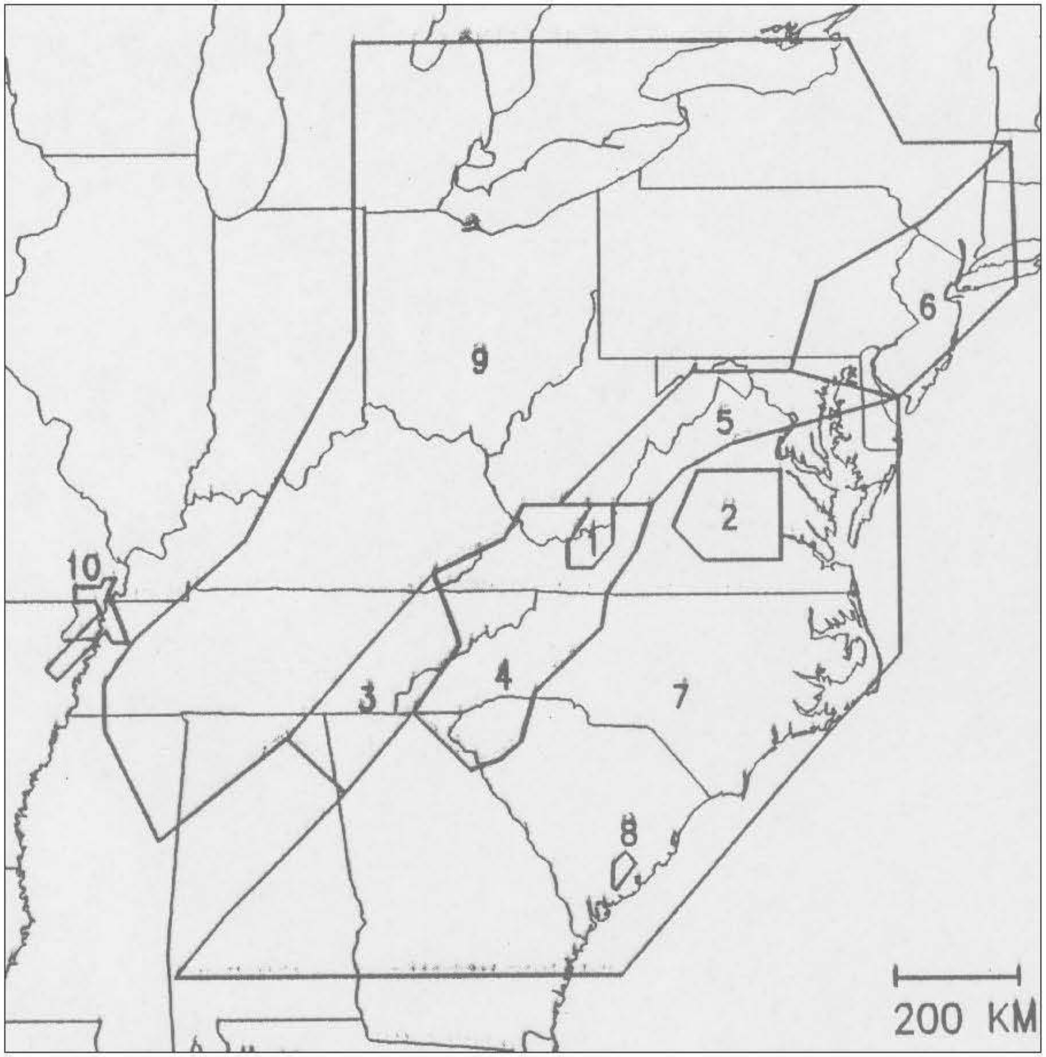
# Impacts and Damages

- 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]

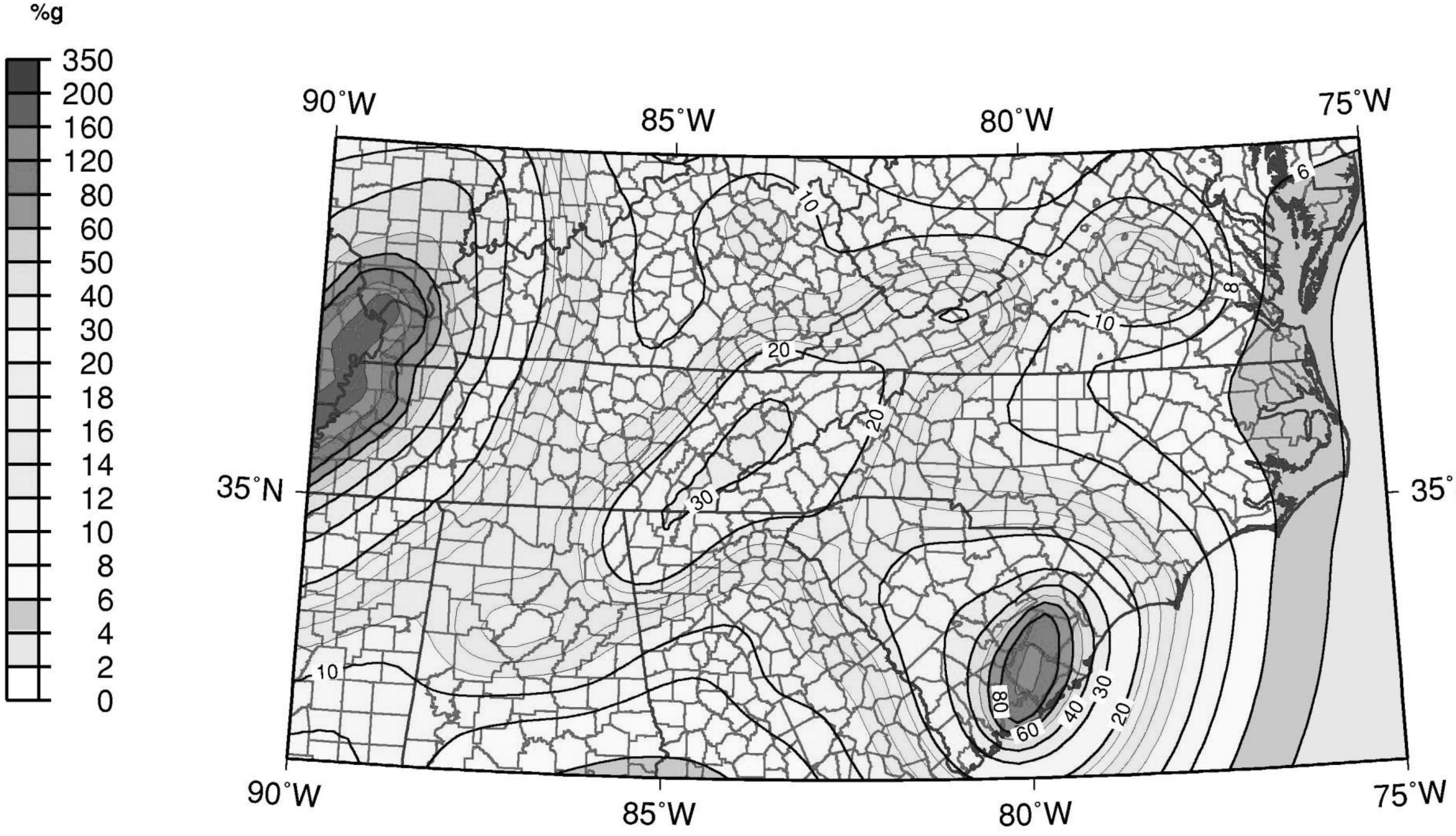
# Challenges in planning for earthquakes

- 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].*

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)



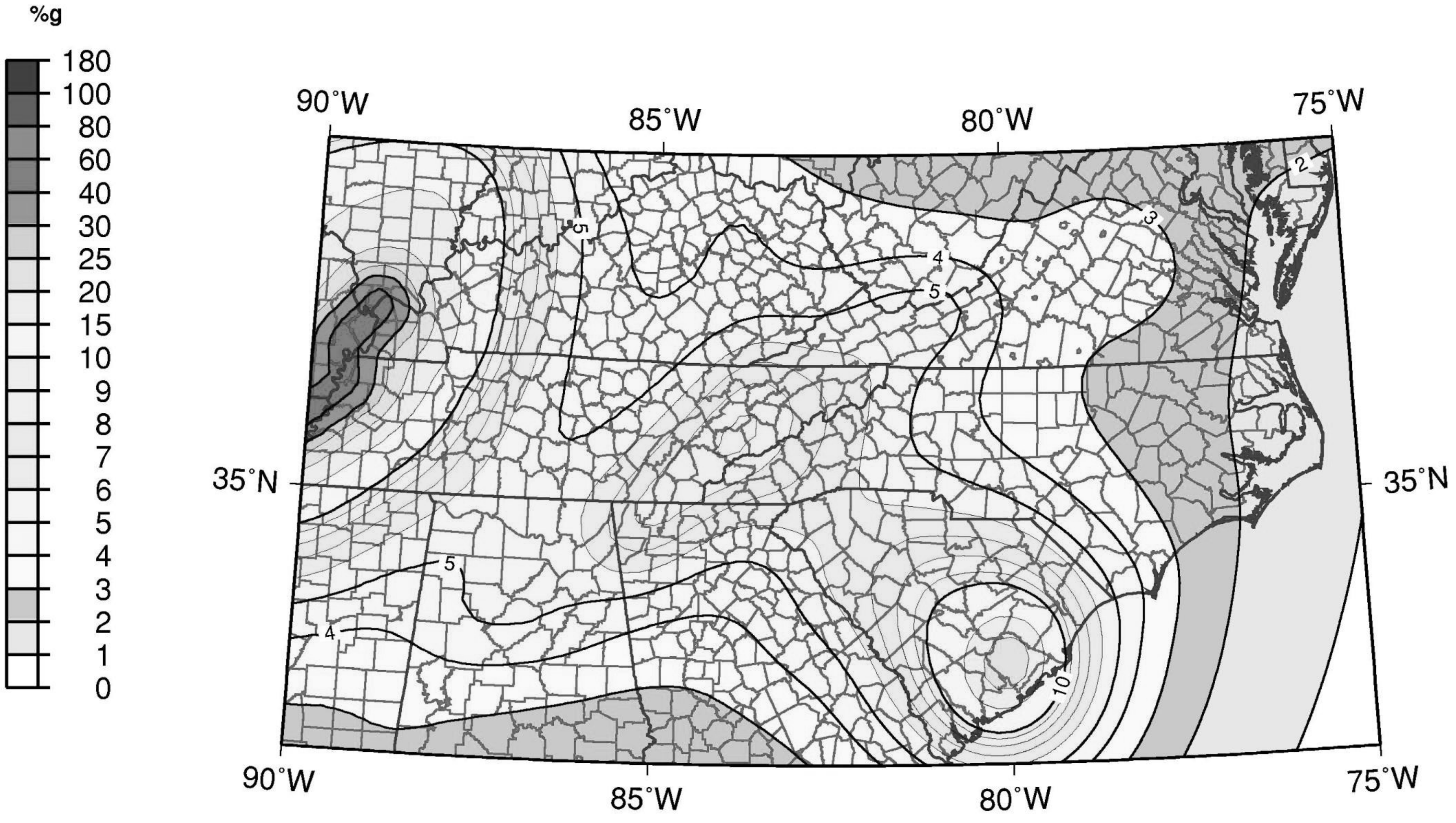
Earthquake source zones:
1 - Giles County, Virginia
2 - central Virginia
3 - eastern Tennessee
4 - southern Appalachians
5 - northern Virginia, Maryland
6 - central Appalachians
7 - Piedmont-Coastal Plain
8 - Charleston, South Carolina
9 - Appalachian foreland
10 - New Madrid



Peak Acceleration (%g) with 2% Probability of Exceedance in 50 Years
site: NEHRP B-C boundary

U.S. Geological Survey
National Seismic Hazard Mapping Project

Albers Conic Equal-Area Projection
Standard Parallels: 29.5 and 45.5 degrees



**Peak Acceleration (%g) with 10% Probability of Exceedance in 50 Years**
**site: NEHRP B-C boundary**

**U.S. Geological Survey**
**National Seismic Hazard Mapping Project**

**Albers Conic Equal-Area Projection**
**Standard Parallels: 29.5 and 45.5 degrees**

# What are the lessons to learn from the event?

A)  NC Earthquake Plan – written and exercised twice (tabletop and functional) addresses:

- Intelligence (where to get information)
- Impact estimation using modeling
- ATC-20 = Procedures for the Post Earthquake Safety Evaluation of Buildings

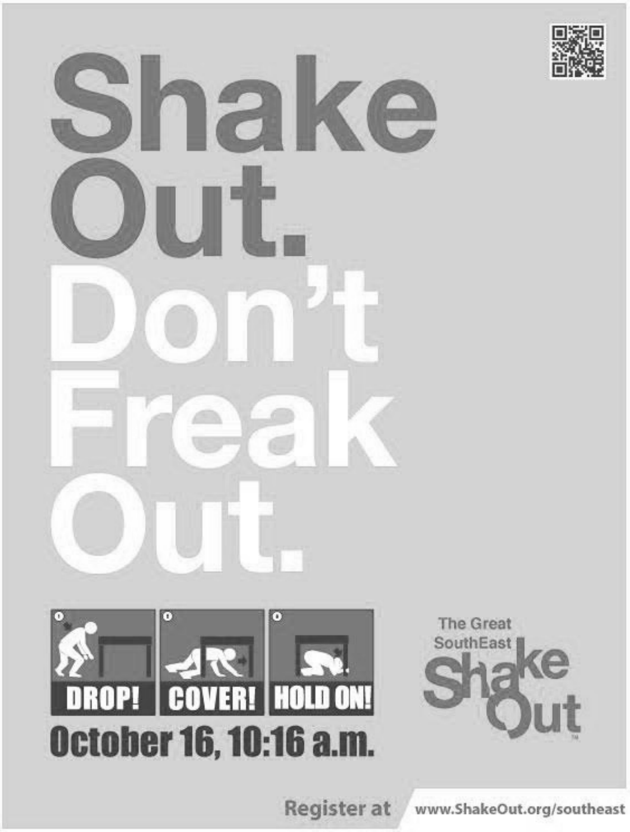
B) State disaster declaration option.  [Nearly two months and two FEMA turndowns.  Event impact “not severe” enough.]

C)  We rely on electronic communications and control systems that can be easily disrupted.

Readync.org and the *ReadyNC* mobile app is an all-in-one tool to help people get ready for everything from traffic jams to hurricanes and ice storms. The app gives information on real-time traffic and weather conditions, river levels, evacuations and power outages. It works both for iPhone and Android phones. Download it today! For people living in or visiting North Carolina, this is **an all-in-one FREE tool for emergency preparedness.**

- Current weather conditions
- Real-time traffic conditions where you are, by route or region>
- Where to report nearby power outages
- Open shelters near you (including ones which accept pets)
- Counties being evacuated
- How to prepare for and be safe during typical hazards that impact NC
- How to create an emergency plan and kit
- Real-time stream and river flooding information
- Who to call for help when disasters strike

Created by the N.C. Department of Public Safety and North Carolina Emergency Management.



The ground starts shaking – it’s an earthquake! What do you do?  Drop, Cover, and Hold On!  If you’ve never heard this before, visit

www.ShakeOut.org/SouthEast/register to practice how to be quake-safe with the rest of Southeast. The life you save may be your own.

Free registration at www.ShakeOut.org/SouthEast/register will pledge an individual’s or group’s participation in this important preparedness event. Participants will receive information on how to prepare an earthquake and what actions to take during and after the shaking.

Why Should You Participate? www.ShakeOut.org/SouthEast

While earthquake hazard varies from region to region most of the Southeast is prone to earthquakes. You could be anywhere when an earthquake strikes: at home, at work, at school or even on vacation.

The ShakeOut Drill is scheduled for 10:16 a.m. on October 16, 2014. This means that wherever you are at that moment—at home, at work, at school, anywhere—you should *Drop, Cover, and Hold On* as if there were a major earthquake occurring at that very moment, and stay in this position for at least 60 seconds.

The Great SouthEast ShakeOut is a regional opportunity to practice how to be safer during big earthquakes: "Drop, Cover and Hold On." The ShakeOut has also been organized to encourage you, your community, your school, or your organization to review and update emergency preparedness plans and supplies, and to secure your space in order to prevent damage and injuries.

# Essential Earthquake and Seismology Websites Earthquakes in NC workshop

Tim Martin tmartin@greensboroday.org

**IRIS Incorporated Research Institutions for Seismology** http://www.iris.edu/hq/

**IRIS Earthquake Browser –** Interactive global map of earthquake data http://www.iris.edu/ieb/

**Teachable Moments** - Within 24 hours of a major earthquake, downloadable presentation with pictures, history and information about the earthquake http://www.iris.edu/hq/retm

**JAmaSeis –** View and analyze seismograms in real time http://www.iris.edu/hq/programs/education_and_outreach/software/jamaseis

**REV Rapid Earthquake Viewer** - Visual display of recent quakes http://rev.seis.sc.edu/earthquakes.html

**IRIS Education and Public Outreach Page** – links to videos, animations and lesson plans for many earthquake related concepts. http://www.iris.edu/hq/programs/education_and_outreach

**USGS United States Geological Survey Hazards Program -** Info for real time data, historical info, hazards, report an earthquake, shake maps, and more: http://earthquake.usgs.gov/

**Real Time Seismograms from California -** http://earthquake.usgs.gov/monitoring/helicorders/nca/

**Virtual Earthquake** – Become a "virtual seismologist" excellent one or two day class lesson about earthquakes and seismology. Locate earthquake epicenters and measure earthquake magnitude.

**New version** http://www.sciencecourseware.com/eec/Earthquake/ **(Requires updated JAVA)**

**Older version** http://www.sciencecourseware.com/virtualearthquake/

**QCN Quake Catcher Network –** Monitor earthquakes on your computer http://qcn.stanford.edu/

(As a teacher you may purchase 3 seismometers for use in the classroom for $5 each)

**Northern California Earthquake Data Center - ANSS Advanced National Seismic System** – Download large data files for GIS mapping. http://www.quake.geo.berkeley.edu/anss/catalog-search.html

*The Earthquakes in North Carolina educator training sessions are made possible through a federally funded grant administered by the N.C. Division of Emergency Management.*