Steve

Modeling Inquiry Learning
Earthquakes by Steve Mattox

Engage: make connection with past and future activities.

Explore: common, concrete experiences upon which students continue to build concepts, processes, and skills.

1. breaking materials (elastic rebound theory) people jump

2. energy in waves (P and S waves in humans and Slinky, relative speed)

3. locating earthquakes:
Virtual earthquake at http://www.sciencecourseware.com/VirtualEarthquake/

4. Effects of Earthquakes: Intensity
Effects of Michigan's Largest earthquake.

5. Effects of Earthquakes
The Story of an Eyewitness, Jack London and the 1906 San Francisco Earthquake at http://sunsite.berkeley.edu/London/Writings/Journalism/sfearthquake.html
also: http://www.sfmuseum.org/1906/ew.html

6. Magnitude
Virtual earthquake at http://www.sciencecourseware.com/VirtualEarthquake/

7. Distribution of Earthquakes
Earthquakes Through Time and *Eruptions Through Time*
http://www.volcano.si.edu/gvp/products/eqerupt.cfm

8. Structure of the Earth
Earthquakes Through Time and *Eruptions Through Time*
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Explain: teacher directs students' attention to specific aspects of topic.

Apply: students asked to apply their understanding to new situations.
1. Earthquake Review: waves and locating earthquakes.
2. Intensity of an East Coast earthquake.
3. Distribution of earthquakes.

Inquire further: open-ended questions.
1. Who was Inge Lehmann and what was her contribution to understanding the Earth? See http://timeline.aps.org/serlet/Event?evtId=56

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4. For careers in seismology see:
What is a seismologist? **http://www.seismo.nrcan.gc.ca/educ/seismolog_e.php**
Maya Tolstoy at
http://www.womenoceanographers.org/doc/MTolstoy/Mayaintro.htm
Seismologist at
http://jobprofiles.monster.com/Content/job_content/JC_Science/JSC_ScienceGeneral/JOB_Sesimologist/jobzilla_html?jobprofiles=1

Geology Labs On-Line | Virtual Earthquake

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.

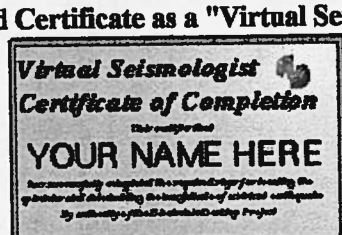
NEW: A completely revised version of Virtual Earthquake can be found HERE. This new applet-based version is more inquiry-based than the original version and contains tools so instructors can assess student learning. Currently it runs only under IE on PCs.

(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.

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.

Click on the Execute button below to start the *Virtual Earthquake* application.

177

THE STORY OF AN EYEWITNESS
By Jack London, Collier's special Correspondent
(First published in Collier's, May 5, 1906)

THE earthquake shook down in San Francisco hundreds of thousands of dollars worth of walls and chimneys. But the conflagration that followed burned up hundreds of millions of dollars' worth of property. There is no estimating within hundreds of millions the actual damage wrought. Not in history has a modern imperial city been so completely destroyed. San Francisco is gone. Nothing remains of it but memories and a fringe of dwelling-houses on its outskirts. Its industrial section is wiped out. Its business section is wiped out. Its social and residential section is wiped out. The factories and warehouses, the great stores and newspaper buildings, the hotels and the palaces of the nabobs, are all gone. Remains only the fringe of dwelling houses on the outskirts of what was once San Francisco.

Within an hour after the earthquake shock the smoke of San Francisco's burning was a lurid tower visible a hundred miles away. And for three days and nights this lurid tower swayed in the sky, reddening the sun, darkening the day, and filling the land with smoke.

On Wednesday morning at a quarter past five came the earthquake. A minute later the flames were leaping upward In a dozen different quarters south of Market Street, in the working-class ghetto, and in the factories, fires started. There was no opposing the flames. There was no organization, no communication. All the cunning adjustments of a twentieth century city had been smashed by the earthquake. The streets were humped into ridges and depressions, and piled with the debris of fallen walls. The steel rails were twisted into perpendicular and horizontal angles. The telephone and telegraph systems were disrupted. And the great water-mains had burst. All the shrewd contrivances and safeguards of man had been thrown out of gear by thirty seconds' twitching of the earth-crust.

The Fire Made its Own Draft

By Wednesday afternoon, inside of twelve hours, half the heart of the city was gone. At that time I watched the vast conflagration from out on the bay. It was dead calm. Not a flicker of wind stirred. Yet from every side wind was pouring in upon the city. East, west, north, and south, strong winds were blowing upon the doomed city. The heated air rising made an enormous suck. Thus did the fire of itself build its own colossal chimney through the atmosphere. Day and night this dead calm continued, and yet, near to the flames, the wind was often half a gale, so mighty was the suck.

Wednesday night saw the destruction of the very heart of the city. Dynamite was lavishly used, and many of San Francisco proudest structures were crumbled by man himself into ruins, but there was no withstanding the onrush of the flames. Time and again successful stands were made by the fire-fighters, and every time the flames flanked around on either side or came up from the rear, and turned to defeat the hard-won victory.

An enumeration of the buildings destroyed would be a directory of San Francisco. An enumeration of the buildings undestroyed would be a line and several addresses. An enumeration of the deeds of heroism would stock a library and bankrupt the Carnegie medal fund. An enumeration of the dead-will never be made. All vestiges of them were destroyed by the flames. The number of the victims of the earthquake will never be known. South of Market Street, where the loss of life was particularly heavy, was the first to catch fire.

from: http://sunsite.berkeley.edu/London/Writings/Journalism/sfearthquake.html

Table 17.3 The modified Mercalli intensity scale.

Intensity	Effects
I	Not felt. Marginal and long-period effects of large earthquakes.
II	Felt by persons at rest, on upper floors, or favorably placed.
III	Felt indoors. Hanging objects swing. Vibration like passing of light trucks. Duration estimated. May not be recognized as an earthquake.
IV	Hanging objects swing. Vibration like passing of heavy trucks, or sensation of a jolt like a heavy ball striking the walls. Standing motor cars rock. Windows, dishes, doors rattle. Glasses clink. Crockery clashes. In the upper range of IV, wooden walls and frames creak.
V	Felt indoors; direction estimated. Sleepers wakened. Liquids disturbed, some spilled. Small unstable objects displaced or upset. Doors swing, close, open. Shutters, pictures move. Pendulum clocks disturbed.
VI	Felt by all. Many frightened and run outdoors. Persons walk unsteadily Windows, dishes, glassware broken. Knickknacks, books, etc., off shelves. Pictures off walls. Furniture moved or overturned. Weak plaster and masonry D cracked. Small bells ring (church, school). Trees, bushes shaken (visibly, or heard to rustle).
VII	Difficult to stand. Noticed by drivers of motor cars. Hanging objects quiver. Furniture broken. Damage to masonry D, including cracks. Weak chimneys broken at roof line. Fall of plaster, loose bricks, stones, tiles, cornices (also unbraced parapets and architectural ornaments). Some cracks in masonry C. Waves in ponds; water turbid with mud. Small slides and caving in along sand or gravel banks. Large bells ring. Concrete irrigation ditches damaged.
VIII	Steering of motor cars affected. Damage to masonry C; partial collapse. Some damage to masonry B; none to masonry A. Fall of stucco and some masonry walls. Twisting, fall of chimneys, factory stacks, monuments, towers, elevated tanks. Frame houses moved on foundations if not bolted down; loose panel walls thrown out. Decayed piling broken off. Branches broken from trees. Changes in flow or temperatures of springs and wells. Cracks in wet ground and on steep slopes.
IX	General panic. Masonry D destroyed; masonry C heavily damaged, sometimes with complete collapse; masonry B seriously damaged (General damage to foundations). Frame structures, if not bolted, shift off foundations. Frame racked. Serious damage to reservoirs. Underground pipes broken. Conspicuous cracks in ground. In alluviated areas sand and mud ejected, earthquake fountains, sand craters.
X	Most masonry and frame structures destroyed with their foundations. Some well-built wooden structures and bridges destroyed. Serious damage to dams, dikes, embankments. Large landslides. Water thrown on banks of canals, rivers, lakes, etc. Sand and mud shifted horizontally on beaches and flat land. Rails bent slightly.
XI	Rails bent greatly. Underground pipelines completely out of service.
XII.	Damage near total. Large rock masses displaced. Lines of sight and level distorted. Objects thrown into the air.

From Wyss and Koyanagi (1992).

Excerpt from: *Quake Replay in the Great Basin*; Natural History magazine; June 1986; p. 29

Authors: Ross S. Stein and Robert C. Bucknam, U.S. Geological Survey

Experiences of: Two groups of elk hunters at epicenter--Don Hendrickson and John Turner, Lawanna and William Knox

Location at time of earthquake: Near north end of Lost River fault, in Custer County, Idaho

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Elk hunters Don Hendrickson and John Turner were driving their Ford Bronco down a dirt road in Arentson Gulch, at the northern end of the Lost River fault in Idaho, when Don suddenly felt light-headed. "I lost my equilibrium. I felt like I was going to pass out. I was ready to tell John at that time, 'There's something wrong with me,' and right after that the Bronco just started shaking like crazy. It was off the ground completely, just rocking like this, and right soon after that, the bank dropped and I was hanging on to the steering wheel." The fault cut the ground sixty feet in front of them and dropped the side bearing the Bronco three feet. "I looked over to John and he was flying in the passenger seat. He was between the two seats, trying to get up. And he said, 'What's going on?' I wasn't about to answer, because I didn't know." Later, Don recalled, "That's when the quake went into its greatest violence, and that's when the noise came in. And it was deafening, a deafening rumble." The noise may have been the sound of rock grinding along the fault face or of landslides and boulders tumbling down the steep mountain front.

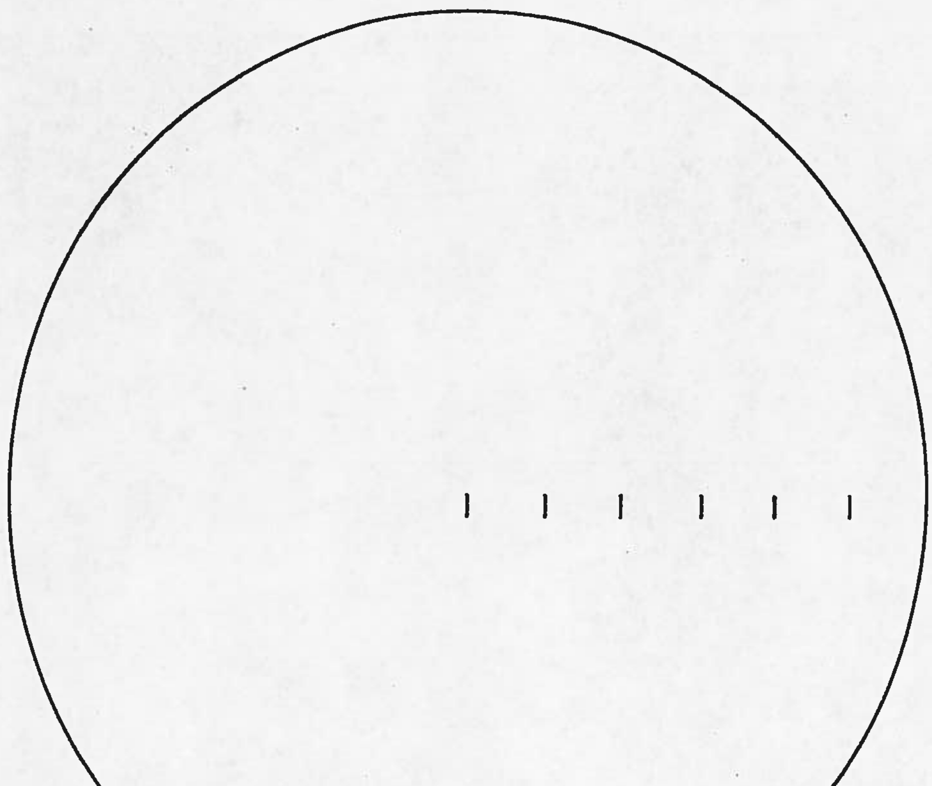
A half mile to the north of the bucking Bronco, William Knox was driving elk over a ridge while his wife, Lawana, waited below for a clear shot. When the shaking started, William felt sick and instantly went down on one knee. As the motion intensified, he lay on his stomach and was rolled back and forth by the ground motion. The shaking "might have been a half minute but it felt like a lifetime," said Lawana, who suffered whiplash from the quake's strong motion. When the shaking subsided, she watched the rupture cut across the mile-wide hillside, "just as though one took a paintbrush and painted a line along the hill." In a second it raised one side of the hill and dropped the other side three feet. Eyewitness accounts of the fault rupture--as opposed to the shaking--are rare; these observations help clarify the speed and character of the rupture.

Earthquake Distribution Name:

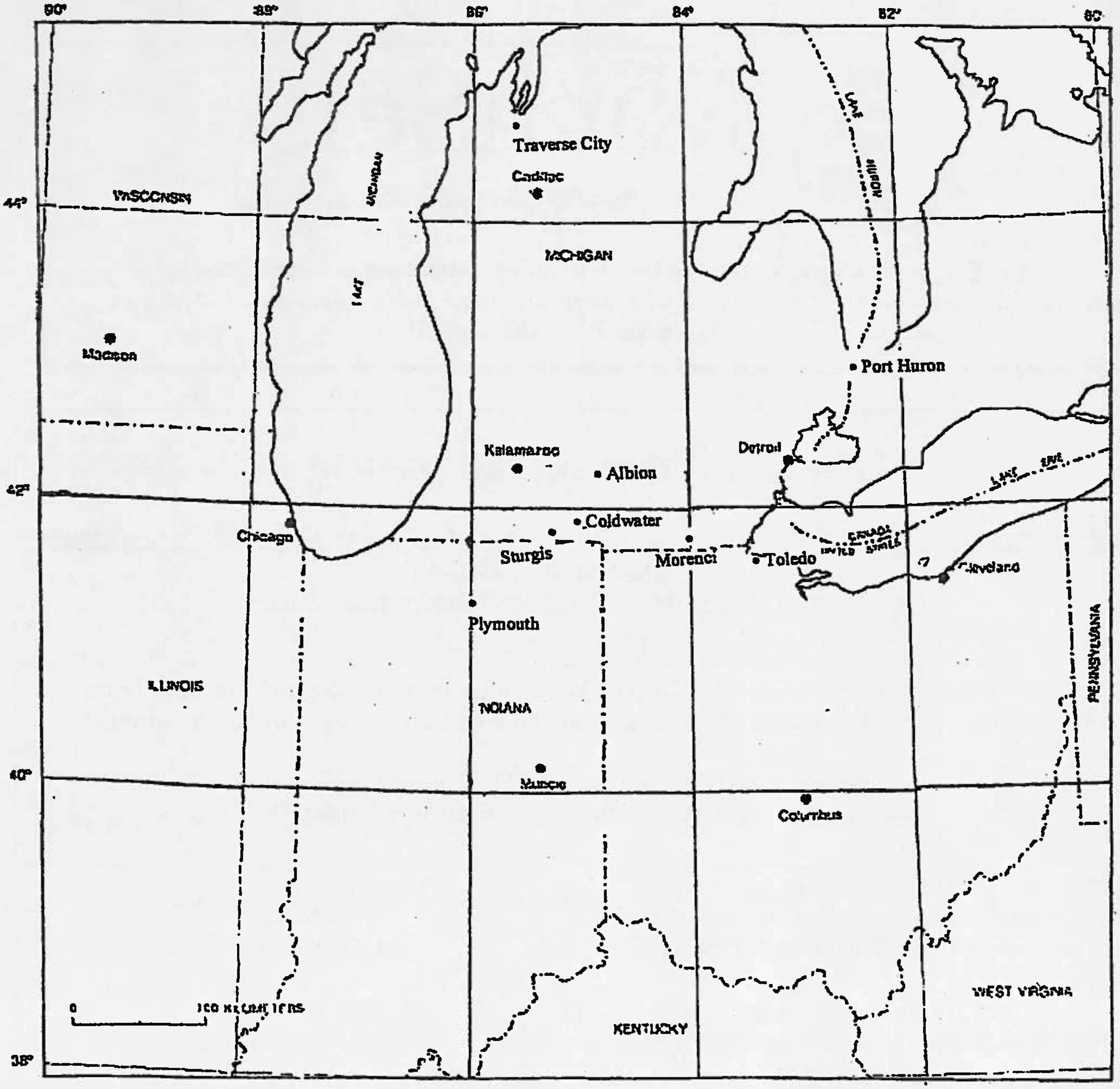
1. On the world map below place 10 "e"s where earthquakes commonly occur.
2. On the world map below place:
   - an "s" where shallow earthquakes commonly occur,
   - an "i" where shallow earthquakes commonly occur, and
   - an "d" where shallow earthquakes commonly occur.

3. Write a sentence or two that describes the global distribution of earthquakes.

What's Inside the Earth?
The circle below represents a cross-section of the Earth. Draw, to the best of your ability, the structures or layers that scientists think are inside the Earth. Are your structures or layers solid, liquid, or gas?
What are they made of?
Label each layer.



1 cm = about 1,000 km


90°
88°
86°
84°
82°
80°
44°
42°
40°
38°
WISCONSIN
Madison
Traverse City
Cadillac
MICHIGAN
LAKE MICHIGAN
LAKE HURON
Port Huron
Kalamazoo
Albion
Detroit
LAKE ERIE
Chicago
Coldwater
Sturgis
Morenci
Toledo
CANADA
UNITED STATES
Cleveland
Plymouth
ILLINOIS
INDIANA
PENNSYLVANIA
Muncie
Columbus
0
100 KILOMETERS
KENTUCKY
WEST VIRGINIA

MichSeis

" MichSeis is the concept that a network of independent, yet cooperative, digital seismographic stations can be operated by schools and institutions throughout Michigan*." (*or anywhere else in the world!)

NEW Recent Earthquake Information NEW

Its the new SeismoGraf digital seismographic station, and it is Live on the Web! Connect to the AAMC seismograph web page
(Link to the Seismo-Cam view of this station is listed below)

eduPhase
eduPhase is now a sub-section of the EduQuakes column in Seismological Research Letters
Go to link in the below box to access eduPhase, a new phase is added every two months

The long-awaited software upgrades are here!
Go to SeismoGraf link in the below-right box for details

Any Earthquakes today?
A real-time list of earthquakes with maps showing their epicentral locations compiled by NEIC

Where are the most recent earthquakes?
"Seismic Monitor" Map of recent earthquakes compiled by IRIS

Seismo-Cam: What is the ground doing now in Ann Arbor?

NEW Data: Seismograms for EQ location and magnitude of Regional Events NEW

EduPhase: NEW
EduPhase main page

Special Project:
"Hurricane Season!"

QuakeView
A quick look at earthquakes and seismograms from around the world

Special Earthquake Report: NEW
Sept 25, 1998 Ohio-Penn (M=5.2)

Its here! NEW
The new "SeismoGraf" stations are here! Click to go to hardware/software desciption & tech info. (Jan '99)

MichSeis Resources

March 14, 16, 18 Week 10 Earthquakes and the Interior of the Earth

Before we start:

Read: Chapter 11 and 12

About 12 pages in course pack on earthquakes

Engage: 1. Motion and frequency (which of these will sway the most?) from *Seismic Sleuths*

2. What happened to these structures?

Explore:

1. Compare a breaking stick to the rupture of rock. (elastic rebound theory)
2. Students jump on floor. (energy travels in waves; more energy, higher amplitude)
3. Human and slinky waves. (P-waves and s-waves, relative velocities)
4. Locating earthquakes and magnitude:

Virtual earthquake at http://www.sciencecourseware.com/VirtualEarthquake/

5. Effects of Earthquakes: Intensity

Effects of Michigan's Largest earthquake. Contour intensity data.

6. Effects of Earthquakes

The Story of an Eyewitness, Jack London and the 1906 San Francisco Earthquake at http://sunsite.berkeley.edu/London/Writings/Journalism/sfearthquake.html

also: http://www.sfmuseum.org/1906/ew.html

7. Distribution of Earthquakes

Interpret *This Dynamic Planet* map by U.S. Geological Survey

See http://pubs.usgs.gov/pdf/planet.html

8. Distribution of Earthquakes

Earthquakes Through Time and *Eruptions Through Time*

http://www.volcano.si.edu/gvp/products/eqerupt.cfm

9. Structure of the Earth

Earthquakes Through Time and *Eruptions Through Time*

http://www.volcano.si.edu/gvp/products/eqerupt.cfm

Explain:

Epicenter, focus, and fault

Elastic rebound theory

Mercalli Intensity scale

Apply:

Inquire Further:

Should I spend extra money to make my house safer against earthquakes?

1. Earthquake Review: waves and locating earthquakes.
2. Intensity of an East Coast earthquake.
3. Distribution of earthquakes.

Resources:

Earthquakes by Ellen Prager (6)

Tremor Troops Eathquakes by FEMA and NSTA (FEMA- 159/August 1992)

Seismology Resources for Teachers By The Seismological Society Of America at

http://www.eas.purdue.edu/%7Ebraile/edumod/seisres/seisresweb.htm

2. Does the Moon have moonquakes? What data do you need and how would you get it? Has this study been done? What are the results and what is their significance?

3. Some people report unusual behavior in pets just prior to an earthquake. Design an experiment to show that animals are reliable (or unreliable) in predicting earthquakes.

4. For careers in seismology see:
What is a seismologist? **http://www.seismo.nrcan.gc.ca/educ/seismolog_e.php**
Maya Tolstoy at
http://www.womenoceanographers.org/doc/MTolstoy/Mayaintro.htm
Seismologist at
http://jobprofiles.monster.com/Content/job_content/JC_Science/JSC_ScienceGeneral/JOB_Sesimologist/jobzilla_html?jobprofiles=1

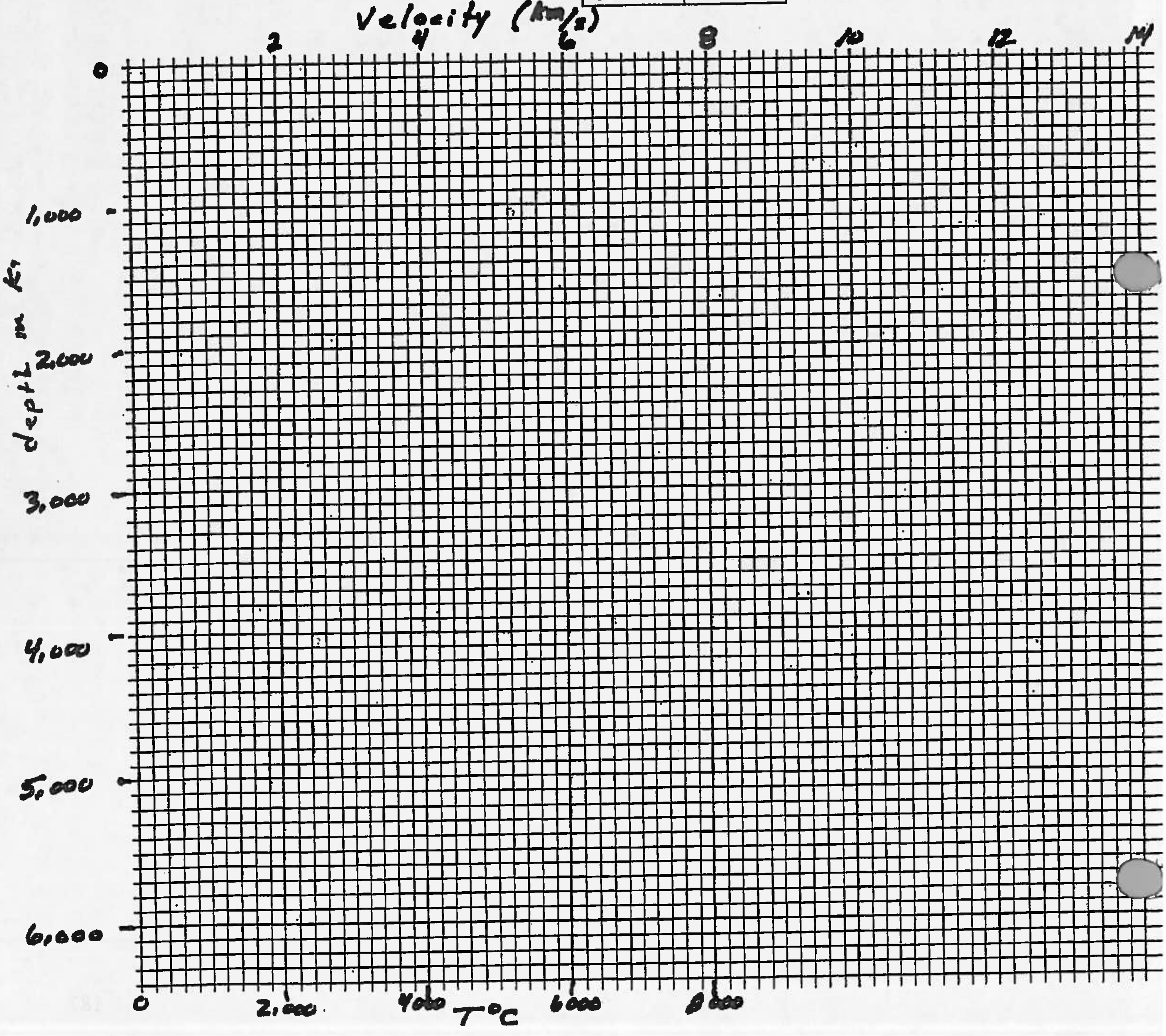
Earth's Interior

Geologists use two types of data to identify layers within the earth. Temperature data helps locate major changes in composition. Earthquake data is useful in describing the physical character and state of the Earth's internal layers. Temperatures are in degrees Celsius and wave velocities are in km/s. Plot the data on the graph below. Speculate on the location and state of earth's compositional and chemical layers.

Depth	Temperature
0	0
150	1500
2800	2700
3000	4500
6386	6600

Depth	S-wave
0	4
200	4.75
325	4.4
660	6.5
3000	7.2

Depth	P-wave
0	7
200	8.5
325	8.25
2,900	13.5
3,000	8.1
5,200	11.25
6386	11.25



GLOBAL DISTRIBUTION OF EARTHQUAKES Name:

Use the "This Dynamic Planet" map to answer the following questions.

1. In general, how would you describe the pattern(s) defined by earthquakes around the earth?

2. Give the location of three earthquake zones in the ocean basins that are defined by narrow bands of shallow earthquakes:

a.

b.

c.

3. Regarding the area in question 2, what physiographic feature(s) are associated with these earthquakes?

4. List one earthquake zone on a the continent that is defined by a narrow band of shallow earthquakes:

5. In what area(s) do shallow earthquakes define a very broad, somewhat diffuse pattern?

a.

b.

6. Regarding the area in question 5, what physiographic features are associated with these earthquakes?

7. List three earthquake zones in along the edges of continents that are defined by bands of earthquakes that progress from shallow to intermediate to deep depths:

a.

b.

c.

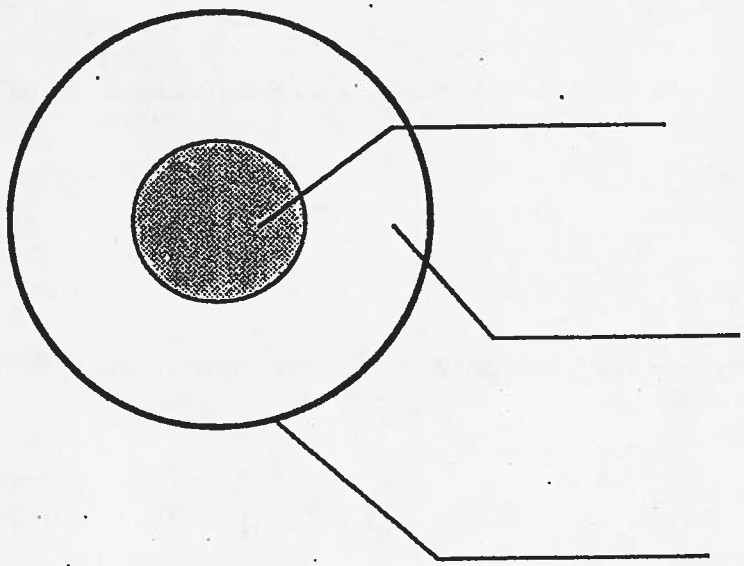
8. Do the zones in question 7 vary in width? Which of the three is widest ?

9. What physiographic features are the earthquakes in question 6 associated with?

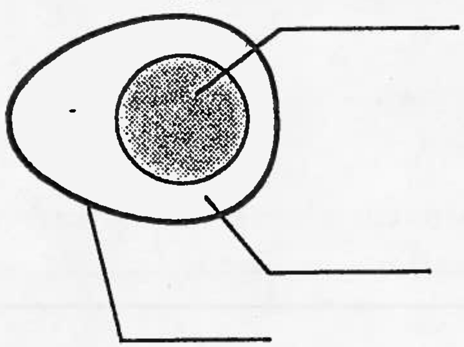
10. Are there any patterns to the distribution of earthquakes of low (4-5.4) and high (>7.0) magnitude?

Activity 1.1 Illustrating the Layers of the Earth

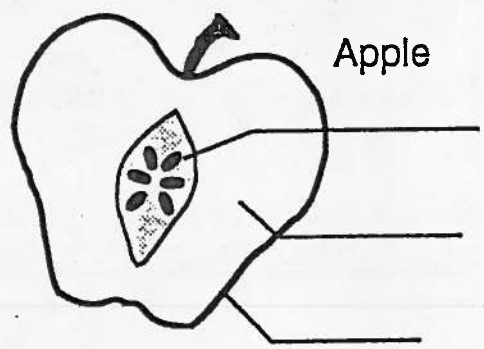
Earth



Egg



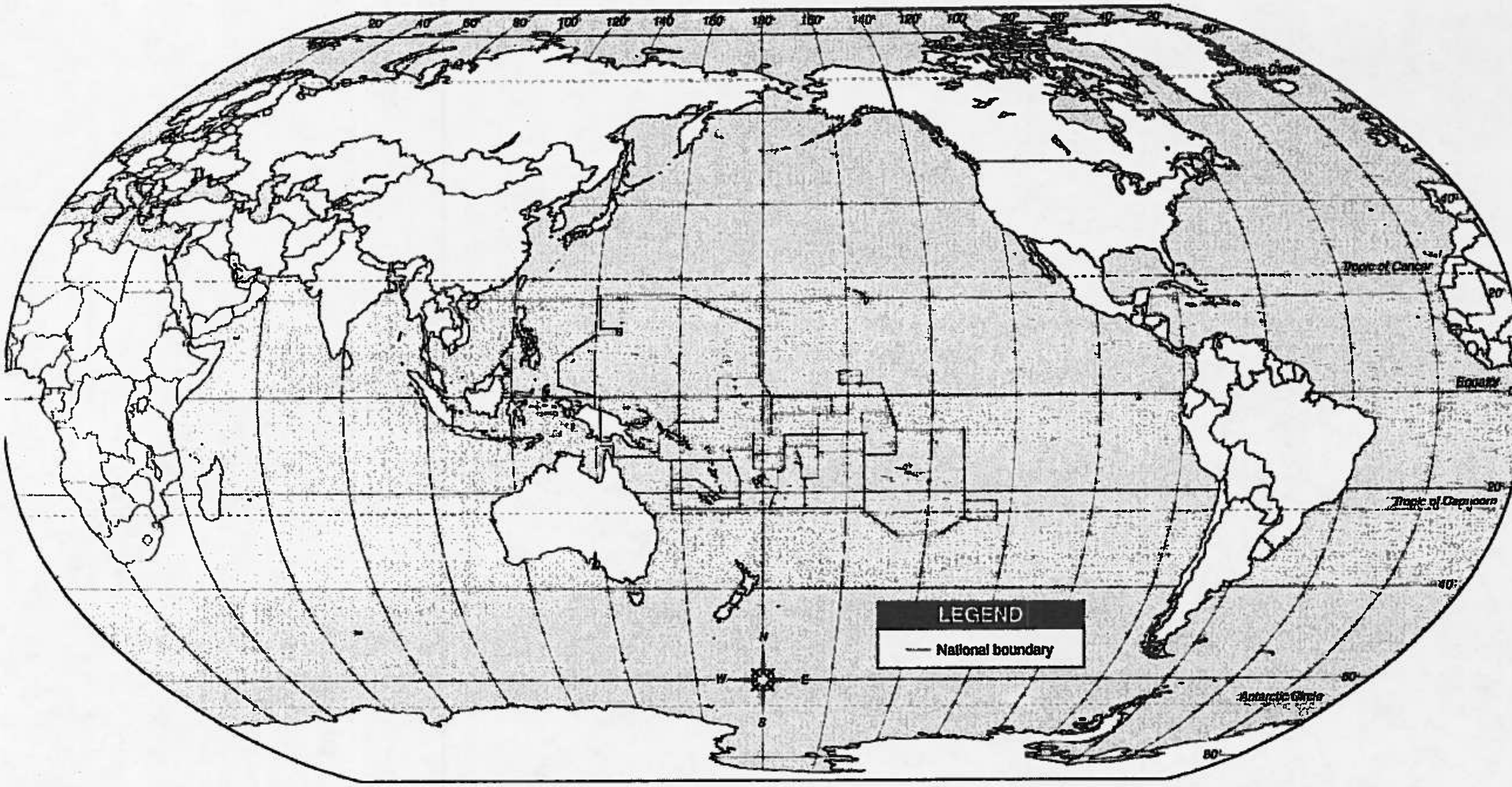
Apple



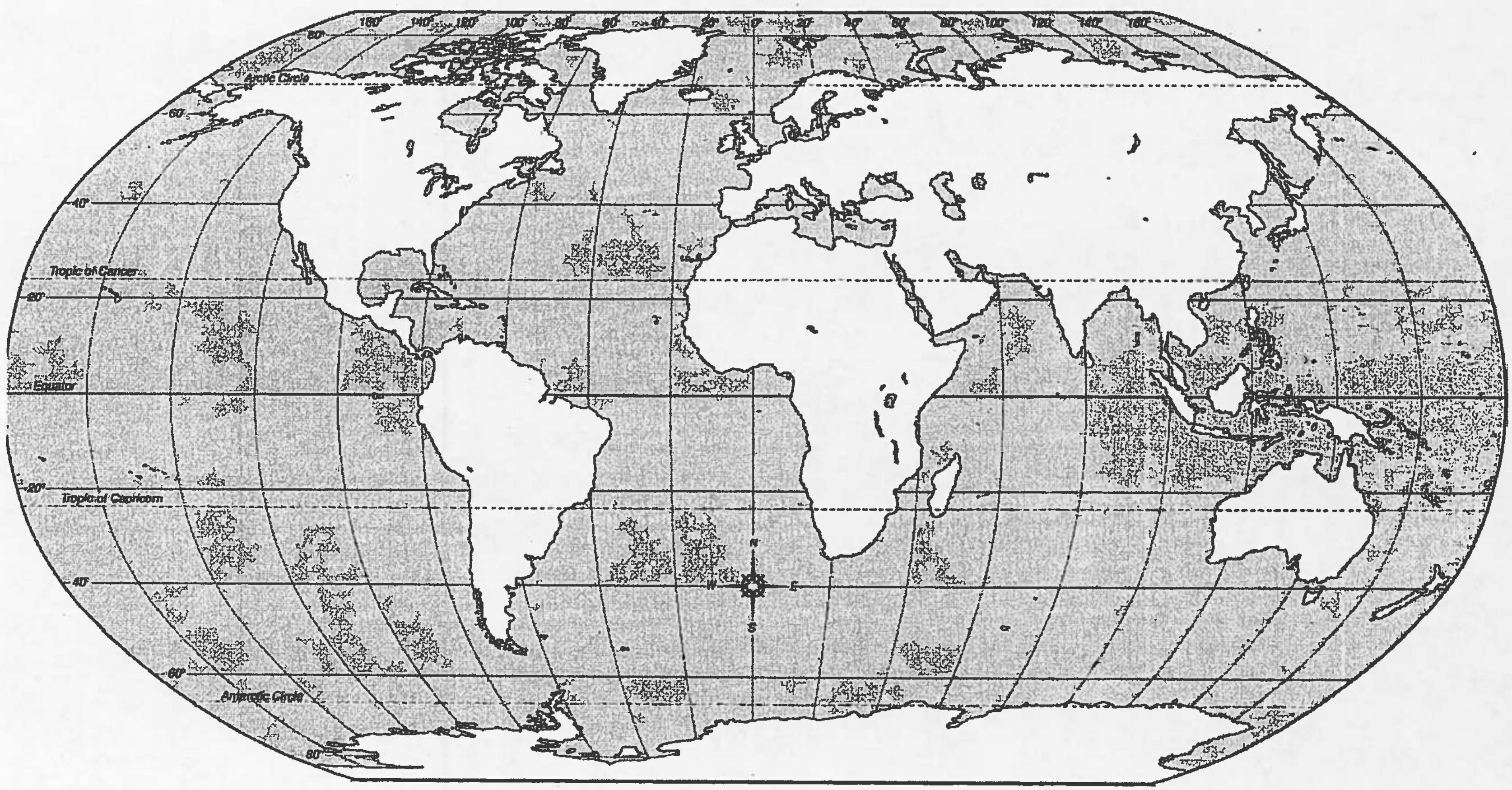
Directions:

Label the core, the mantle, and the crust of the apple, the egg, and the Earth.

World: Pacific View



World: Continents



1992].

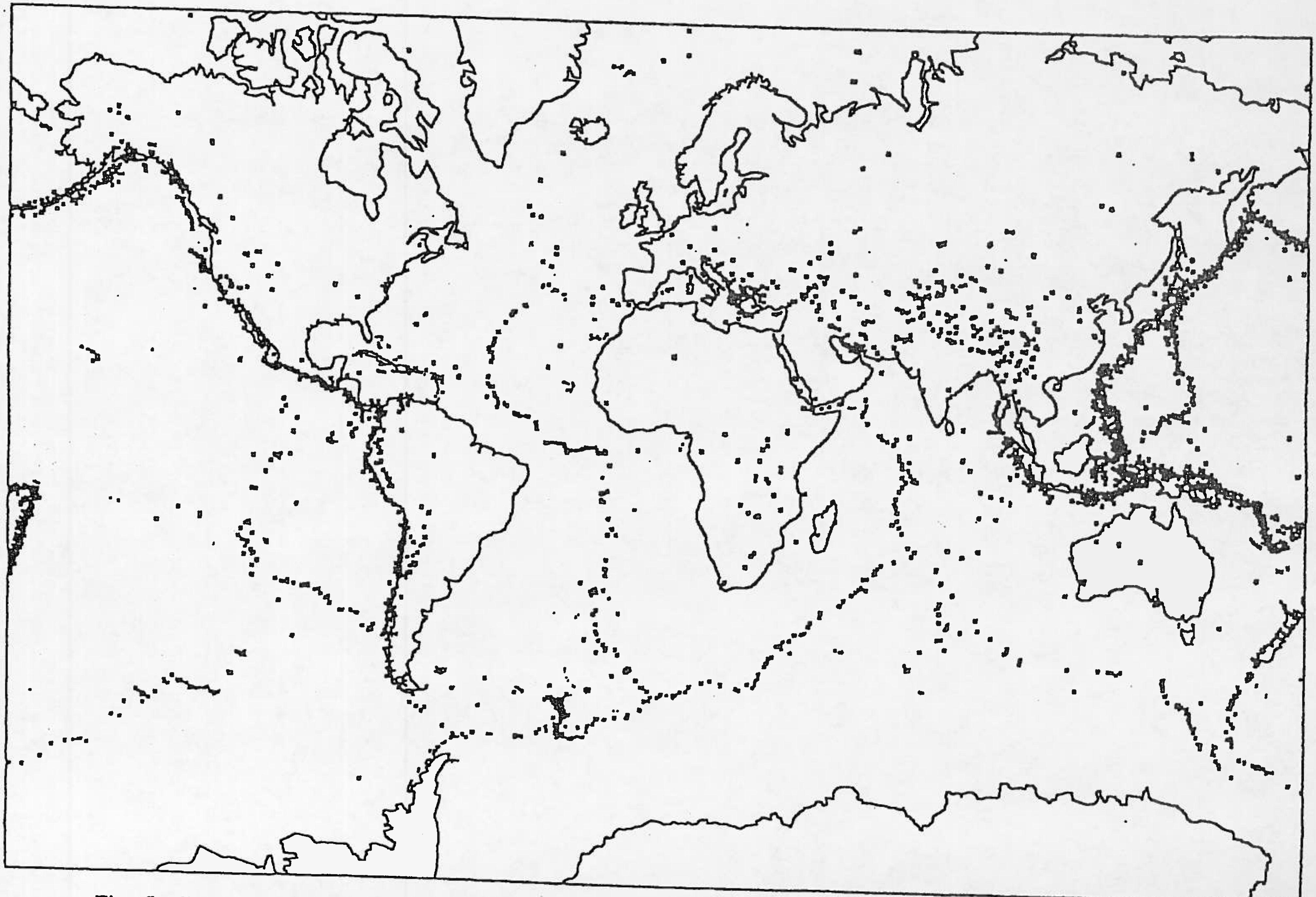


Fig. 5. Epicenter map of earthquakes shallower than 50 km and with magnitudes of at least 5.5 from 1963 to 1987 from the catalog of the National Earthquake Information Center.

Teaching through Trade Books

Remembering the 1906 San Francisco Earthquake

Stephen Mattox and Colleen Zeeff

April 18, 2006 marks the centennial of the great 1906 San Francisco earthquake. This event and its effects serve as a reminder for the need of geologic and geophysical research and investment in disaster preparedness (at all levels). It is also important that the public carry events in their consciousness of rare but devastating geologic events with recurrence intervals that exceed the short duration of human lifetimes.

This Month's Trade Books

Earthquakes
By Ellen Prager. 2002. National Geographic Society.
ISBN 0-792-28202-7. Grades K-5

Synopsis
This short, engaging book is excellent and complete. The key topics are all covered and jargon is kept to a minimum. The book is well written with accurate, useful analogies. It presents the key aspects of earthquakes: cause, distribution, effects, mitigation of effects, and safety. Use this book. It is a great start to any earthquake lesson and supports diversity by presenting a female scientist. It is probably the best earthquake book on the market.

...If You Lived at the Time of the Great San Francisco Earthquake
By Ellen Levine. 1987. Scholastic.
ISBN 0-590-45157-X. Grades 3-8

Synopsis
In this book, questions and answers provide a complete description of events before, during, and after the 1906 earthquake. All of the general aspects of earthquakes are well presented including magnitude, intensity, effects, response, and recovery.

Curricular Connections

For Grades K-3: Fault in Motion

Purpose: Students mimic the duration, displacement, and type of movement along the fault that produced the 1906 earthquake.

Materials: a rope at least 20 meters long

Procedure:
1. We pose two possibilities to introduce the activity. The teacher might show a photograph of the damaged caused by the 1906 earthquake (see Internet resources). Ask the students what

forces in nature might cause such destruction. Alternatively, focus the students' attention on pages 6, 9 and 17 of the book *...If you lived...* and ask how much does the Earth move during a large earthquake.

1. While reading *...If you lived...* aloud ask the students to note physical changes in the Earth or effects caused by the earthquake. Invite the class to contribute to a list on the board.

2. Next, introduce the process of movement on a fault. A fault is a crack in the Earth along which blocks of rock move past each other. Explain to the students that in this activity they will move just like the rocks did during the 1906 earthquake.

3. Divide your class into two equal size groups. Have each group form single file lines. Place each line of students parallel to the fault (represented by a long rope stretched in a straight line) with one line of students on each side of the fault. Have the students in each line stand shoulder to shoulder facing their classmates across the fault. Students need to place the palms of their hands outward, in front of them, touching their peers' palms across the fault.

4. The students shout "earthquake" and release their energy by moving. Each line of students represents a block of rock. Where their hands touch represents the fault. Where the two "blocks" slide past each other, they make an earthquake. The students need to make two motions simultaneously: jumping up and down and each line must move to its left (so the two lines are moving in opposite directions).

5. Ideally, the students should remain in motion for about 50 seconds (the duration of the earthquake), and move laterally until students that were once facing each other are now 6 m apart (the displacement of objects across the fault in 1906).

6. After participating in the activity, discuss the key points: blocks of rock slide past each other along faults, as the blocks move they release energy in the form of an earthquake, during great earthquakes the ground might shake many tens of seconds and move 10-20 m. During the 1906 earthquake, the 6 m of movement occurred along 470 km of the fault (not just the short length modeled by the students) (see maps in Internet resources). The earthquake had a magnitude of 8.3 (Bolt, 2005).

For Grades 4-6: Estimating Intensity
Purpose
Students will collect their own data and then assign an intensity to the 1906 earthquake.

Unlike magnitude, which is a measure of wave height made by an instrument, earthquake intensity is a measure of felt effects by anyone that experiences an earthquake. Intensity is commonly measured by reports made by people that felt the earthquake. Intensity can also be estimated after the earthquake by carefully examining photographs.

Materials
- Access to the internet or sets of printed photographs (see Internet resources).

- Printed copies of the intensity scale (see Internet resources).

Procedure

1. While reading "*...If You Lived...*" students need to describe the effects of the 1906 earthquake (fire, buildings knocked down, etc...).

2. Next, ask the students to review the intensity scale (see Internet resources).

3. Ask the students to assign a specific intensity value to individual drawings in the book.

4. Discuss the students' observations and assign a maximum intensity for the 1906 earthquake. Was there a range in the values? What might cause a single event to produce different intensities across an area (e.g. distance from epicenter, construction practices, types of geologic materials)? After the group discussion, review the intensity map for the 1906 earthquake (see Internet resources). Note: Maximum intensity, X-XII, occurred along the length of the fault. Intensity decreased with increasing distance away from the fault. Areas underlain by soft material, such as fill or sediment, shake more than areas that are constructed on bedrock.

Connecting the Standards

This article addresses the following *Natural Science Education Standards* (NRC 1996):

Content Standards
Grades K-4
Standard D: Earth and Space Science
- Changes in the earth and sky.

Standard F: Science in Personal and Social Perspectives
- Personal safety

Standard G: History and Nature of Science
- Science as a human endeavor.

Grades 5-8
Standard D: Earth and Space Science
- Structure of the Earth System

Standard F: Science in Personal and Social Perspectives
- Personal health
- Nature hazards

Standard G: History and Nature of Science
- History of science

Extension

The effects of the 1906 earthquake are well documented in historic photographs. Sources of photographs are available on the internet. The students can view these photos and, based on their observations, assign an intensity. Students must justify their estimate.

Many public and university libraries have access to the New York Times historical collection. Search this online database for April 1906 earthquake. Students can read the original news reports and assign an intensity or describe the effects of the earthquake.

Steve Mattox (mattoxs@gvsu.edu) trains pre-service teachers in earth science at Grand Valley State University in Allendale, Michigan.

Colleen Zeeff (zeeffc@student.gvsu.edu) is a pre-service teacher at Grand Valley State University.

Resources

Bolt, Bruce, 2005. Earthquakes (5th ed.), New York, Freeman Publishers, 390 p.

National Research Council (NRC). 1996. National Science education Standards. Washington, DC: National Academy Press. 262 p.

Internet

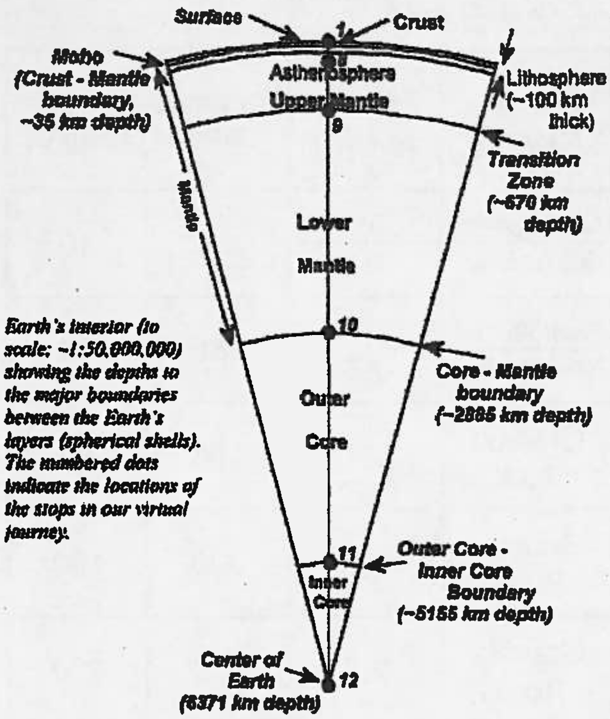
1906 San Francisco earthquake by the U.S. Geological Survey
http://quake.wr.usgs.gov/info/1906/

Museum of the City of San Francisco
http://www.sfmuseum.org/1906/06.html

Modified Mercalli Intensity Maps for the 1906 San Francisco Earthquake Plotted in ShakeMap Format by John Boatwright and Howard Bundock
http://pubs.usgs.gov/of/2005/1135

Modeled Shaking Intensity Map for the Entire Bay Area Scenario: 1906 San Francisco Earthquake
http://www.abag.ca.gov/cgi-bin/pickmapx.pl

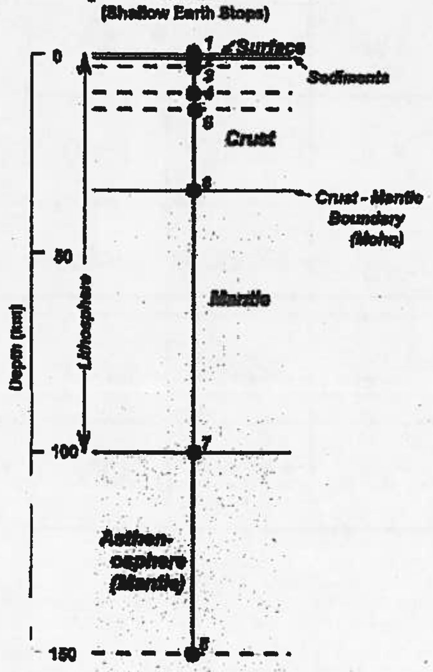
Journey to the Center of the Earth
(Deep Earth Stops)



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
(Shallow Earth Stops)



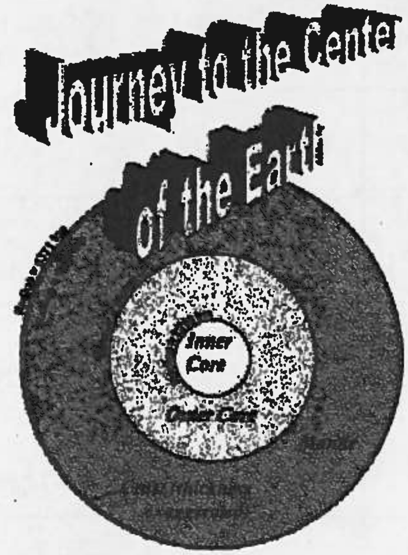
Shallow Earth structure showing the depths to boundaries in the upper 150 km of the Earth. The numbered dots indicate the locations of the first 8

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**

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!

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/cm³.**
12. **Center of the Earth (6371 km) – Temperature is ~4800° C, pressure is over 3.6 million times the pressure at the surface.**

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 Sediments	0.001 1.5	0.1	10
2	1	0.001 (1 mm)	0.01 (1 cm)	Top of "Basement"	Sed. Rocks Granitic Rk.	2.0 2.6	20	16
3	3.6	0.0036 (3.6 mm)	0.036 (3.6 cm)	Deepest Mine	Granitic Rock	2.7	100	50
4	10	0.01 (1 cm)	0.1 (10 cm)	Upper Crust	Granitic Rock	2.7	300	180
5	12	0.012 (1.2 cm)	0.12 (12 cm)	Deepest Drill Hole	Granitic Rock	2.7	360	200
6	35	0.035 (3.5 cm)	0.35 (35 cm)	Base of Crust ("Moho")	Mafic Rock Olivine-rich Rk.	3.0 3.3	1100	600
7	100	0.1 (10 cm)	1	Base of Lithosphere	Olivine-rich Rock	3.4	3200	1200
8	150	0.15 (15 cm)	1.5	Astheno-sphere	Olivine-rich Rock	3.35	4800	1300
9	670	0.67 (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 Liquid Iron	5.6 9.9	135800	3450
11	5155	5.155	51.55	Inner Core/Outer Core Bound.	Liquid Iron Solid Iron	12.2 12.8	329000	4700
12	6371	6.37	63.7	Center of Earth	Solid Iron	13.1	364000	4800