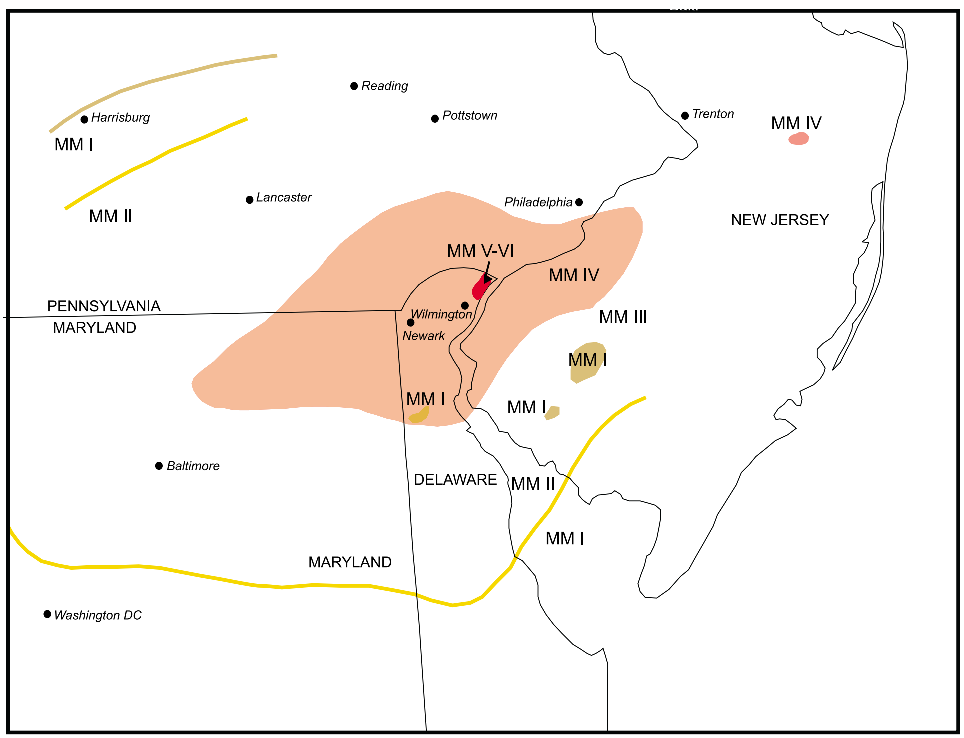
State of Delaware
DELAWARE GEOLOGICAL SURVEY
Robert R. Jordan, State Geologist

SPECIAL PUBLICATION NO. 23

EARTHQUAKE BASICS

by

Stefanie J. Baxter



University of Delaware
Newark, Delaware

2000

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EARTHQUAKE BASICS

Stefanie J. Baxter

INTRODUCTION

Every year approximately 3,000,000 earthquakes occur worldwide. Ninety eight percent of them are less than a magnitude 3. Fewer than 20 earthquakes occur each year, on average, that are considered major (magnitude 7.0 – 7.9) or great (magnitude 8 and greater). During the 1990s the United States experienced approximately 28,000 earthquakes; nine were considered major and occurred in either Alaska or California (Source: U.S. Geological Survey Internet web site: http://www.neic.cr.usgs.gov/general/handouts).

Earthquakes do not occur exclusively in the western United States. More than 3,500 earthquakes have occurred east of the Mississippi River* since 1568 (Source: U.S. Geological Survey National Earthquake Information Center Internet web site). Seven events with body wave magnitudes greater than 6.0 have occurred in the central and eastern United States since 1727 (Nishenko and Bollinger, 1990). Of the five largest of these, four occurred near New Madrid, Missouri, between 1811 and 1812, and one occurred in Charleston, South Carolina, in 1886. The largest event in Delaware occurred in 1871 and had an estimated magnitude 4.1.

In 1997, Delaware was reclassified from low seismic risk to medium seismic risk by the U.S. Geological Survey (USGS) and the Federal Emergency Management Agency (FEMA). The Delaware Geological Survey (DGS) currently operates a network of five seismic stations throughout Delaware. Sixty-nine earthquakes in Delaware have been documented or suspected since 1871. Refer to Baxter (2000) for more details about the DGS Seismic Network and for documentation of earthquakes.

This report provides a brief overview of the causes of earthquakes, how earthquakes are measured, and a glossary of earthquake terminology. Italicized words in the text are defined in the glossary.

EARTHQUAKE BASICS

What Causes Earthquakes?

Earthquakes occur naturally (i.e., tectonic and volcanic) and as a result of human activity (i.e., explosion, mine collapse, and reservoir-induced). Tectonic earthquakes are the most common (Bolt, 1993) and are explained by the theory of *plate tectonics*. The theory merges the ideas of continental drift and sea-floor spreading and states that the surface of the earth is divided into a number of relatively thin (100-150 km), rigid segments or plates that continuously move relative to each other over a semi-plastic layer (*asthenosphere*) beneath the earth's *crust*. The largest plates are outlined in Figure 1. These plates are not static–they diverge, converge, and slide past one another at their boundaries.

The earth's seismicity is concentrated primarily along these plate boundaries. More than 90 percent of the seismic energy released occurs where plate boundaries converge and where the Earth's crust is consumed along trenches. Approximately 5 percent of the world's seismic energy is released along the ocean-ridge system where plate boundaries diverge, forming new oceanic crust. The remaining seismic energy is released through intraplate earthquakes which occur within the interior of a plate (Bolt, 1993).

Although proximity to plate boundaries can explain many earthquakes in the western United States, there is no obvious reason as to why earthquakes occur in the northeastern United States since this region is not located near a plate boundary. The closest plate boundary to Delaware is located several thousand kilometers to the east at the Mid-Atlantic Ridge. Although far removed from a plate boundary, the mid-Atlantic region of the United States is being influenced by northwest-southeast oriented compressional *stresses* caused by present day plate movement (Zoback and Zoback, 1991). These stresses, over time, may be enough to reactivate preexisting ancient *faults* in northern Delaware that may have formed 150-200 million years ago during rifting of the supercontinent of Pangea followed by the opening of the Atlantic Ocean and the separation of Africa and North America in the Mesozoic Era (Benson, 1993).

Strain in the Earth's crust accumulates as plates shift and grind past one another. Strain cannot build indefinitely and is released when the strength of the crustal rocks is exceeded. This sudden release of elastic energy causes an earthquake. The elastic energy is released in the form of heat and elastic waves. The movement of these waves through the Earth's crust is felt during an earthquake.

*Area approximated by a rectangle with bounding coordinates of 30˚N to 45˚N and 70˚W to 90˚W

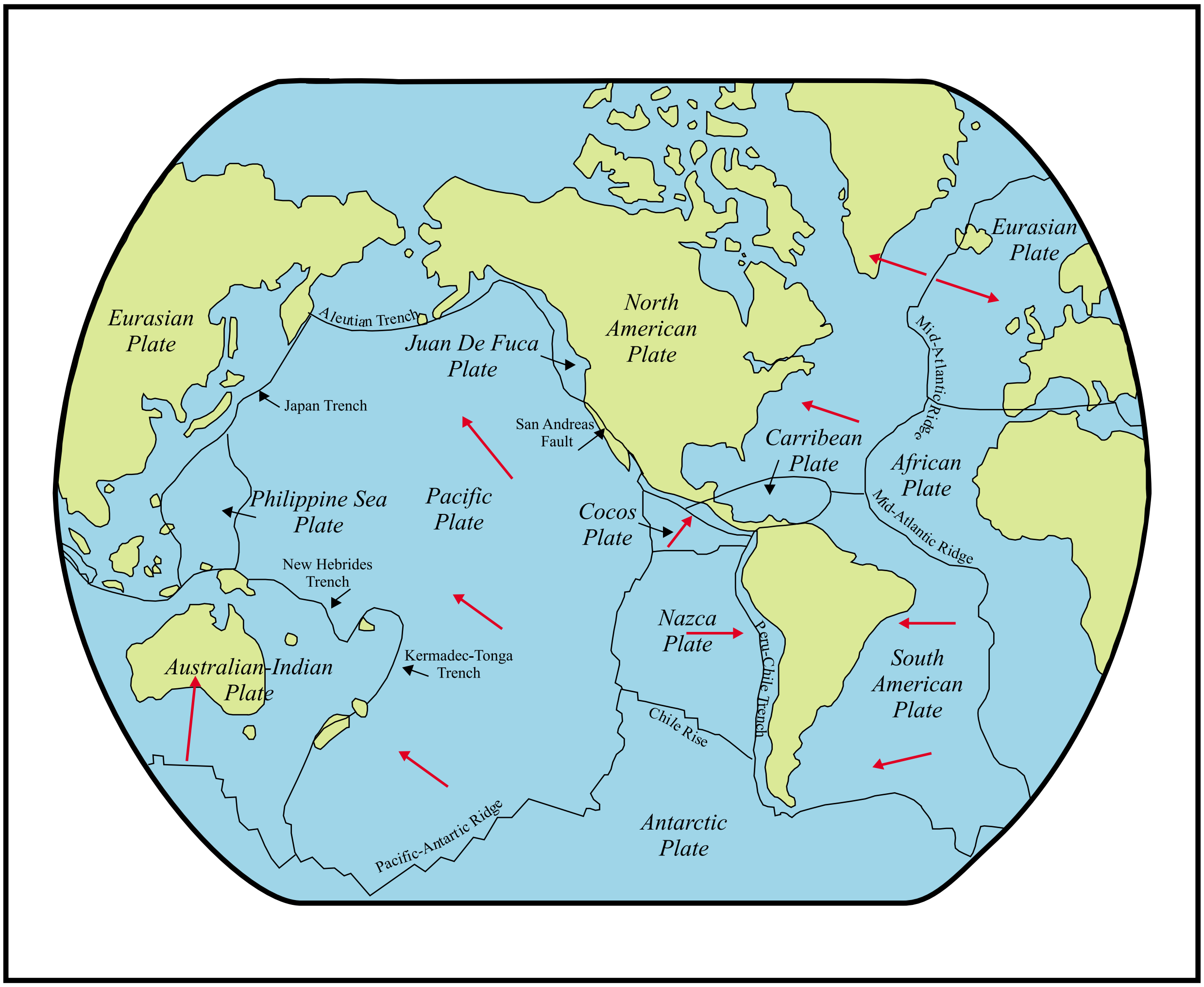

Figure 1. Major tectonic plates, midocean ridges, and trenches. Red arrows indicate direction of plate motion. Plate boundaries are approximated. (Modified from Wallace, R. E., ed., 1990.)

Seismic Waves

There are two basic types of seismic waves: *body waves* which travel through the body of the earth and *surface waves* which travel around the surface of the earth. Body waves can be characterized as either primary or secondary. The *primary* or *P wave* (Figure 2a) is the fastest (~5.5 km/sec in granite) (Bolt, 1993) of the body waves and is the first wave recorded on a *seismograph*. The P wave can travel through both solid and liquid material. P wave motion is similar to that of a sound wave in its push-pull (compression-dilation) motion. The *secondary* or *S wave* (Figure 2b) travels more slowly (~3.0 km/sec in granite) (Bolt, 1993) than the P wave. The S wave travels only through solid material and its movement is similar to light waves in that it moves perpendicular to the direction of motion as it propagates.

Surface waves travel more slowly than body waves (Bolt, 1993) and usually cause the most destruction in populated areas (Kulhanek, 1990). *Love* and *Rayleigh waves* (Figures 2c and 2d, respectively) are two types of surface waves. Generally speaking, Love waves travel faster than Rayleigh waves with horizontal shear motion perpendicular to the direction of propagation while the motion of a Rayleigh wave is in a vertical plane parallel to the direction of wave propagation (Kulhanek, 1990).

Ground motion that occurs during an earthquake is due to the arrival of the various seismic waves produced during movement along the *fault plane*. Sensitive instruments (*seismometers*) detect wave motions and the resulting signals are recorded on seismographs. The difference in the arrival times of the P and S waves can be used to determine the distance to the *epicenter*. If arrival times of the P and S waves are available from three stations, triangulation may be used to determine the epicenter and time the earthquake occurred.

When P and S waves radiate outward from the *focus*, they encounter boundaries between rock types which cause the waves to travel at different speeds. When a wave encounters a boundary it is converted into reflected and refracted P waves and S waves. Once these waves reach the Earth's surface, much of their energy is reflected back into the crust which results in upward and downward motions taking place concurrently. These simultaneous motions create an amplification of shaking near the earth's surface which may double the *amplitude* of waves approaching the surface (Bolt, 1993).

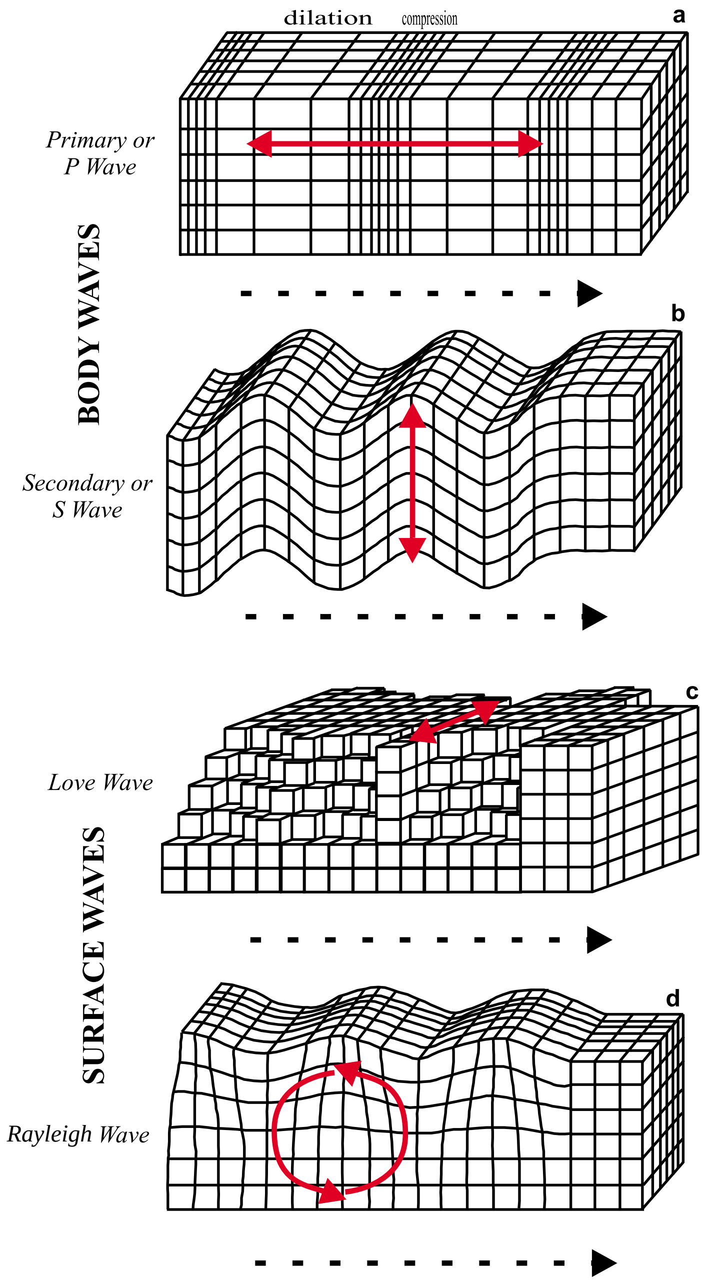

Figure 2. Ground motion near the surface of the earth produced by four types of earthquake waves. Black arrows indicate direction of wave travel. Red arrows indicate the direction rock particles move or vibrate. (Modified from Southeastern Missouri Earthquake Hazard Potential Display: Missouri Department of Natural Resources, Division of Geology and Land Survey.)

Faults

The Earth's crust breaks along surfaces known as faults which are weak areas in the crust along which opposite sides have been displaced relative to each other. Faults occur when stresses within the Earth build to a point that the elastic properties of the rock are exceeded causing irreversible strain or fracturing of the rock. Fault lengths may range from a few centimeters to hundreds of kilometers. Displacement along a fault also may vary from centimeters to kilometers, and movement along a fault may occur as continuous creep or as a series of abrupt jumps.

There are three primary types of fault motion (1) *normal*, (2) *reverse*, and (3) *strike slip*. A normal (or gravity) fault (Figure 3a) is one in which the rocks above the fault plane *(hanging wall*) move downward relative to the opposite side of the fault (*footwall*) and is produced in regions of tensional stress where the crust is being pulled apart. The angle of dip is generally 45° to 90°. Normal faulting occurs along the mid ocean ridge system as well as in areas such as eastern Africa where continental rifting is taking place.

A reverse fault (Figure 3b) is one in which the hanging wall moves upward relative to the footwall and is produced in areas of compression where the crust is converging. The angle of dip is generally 45° or more. *Thrust faults* are a particular type of low angle (30° or less) reverse fault in which the hanging wall is displaced upward and laterally over the footwall. Reverse faulting occurs in *subduction zones* and in regions where plates are colliding.

A strike-slip fault (Figure 3c) is one in which the movement is predominantly horizontal and approximately parallel to the strike of the fault. Strike-slip faults can be classified as *right lateral* or *left lateral* depending if the fault block opposite the viewer moved right or left, respectively. The San Andreas fault in California and the north Anatolian fault in Turkey are examples of predominantly strike-slip faults.

Faults are not always visible at the Earth's surface and the existence of a fault does not necessarily imply that the fault is active and earthquakes are occurring along it today. In the eastern United States there are no active faults which have surficial expression similar to the San Andreas. Indirect evidence such as major shifts in the direction of streams and linear features seen on satellite imagery may be used to infer their existence. No known faults have been associated with earthquakes in Delaware.

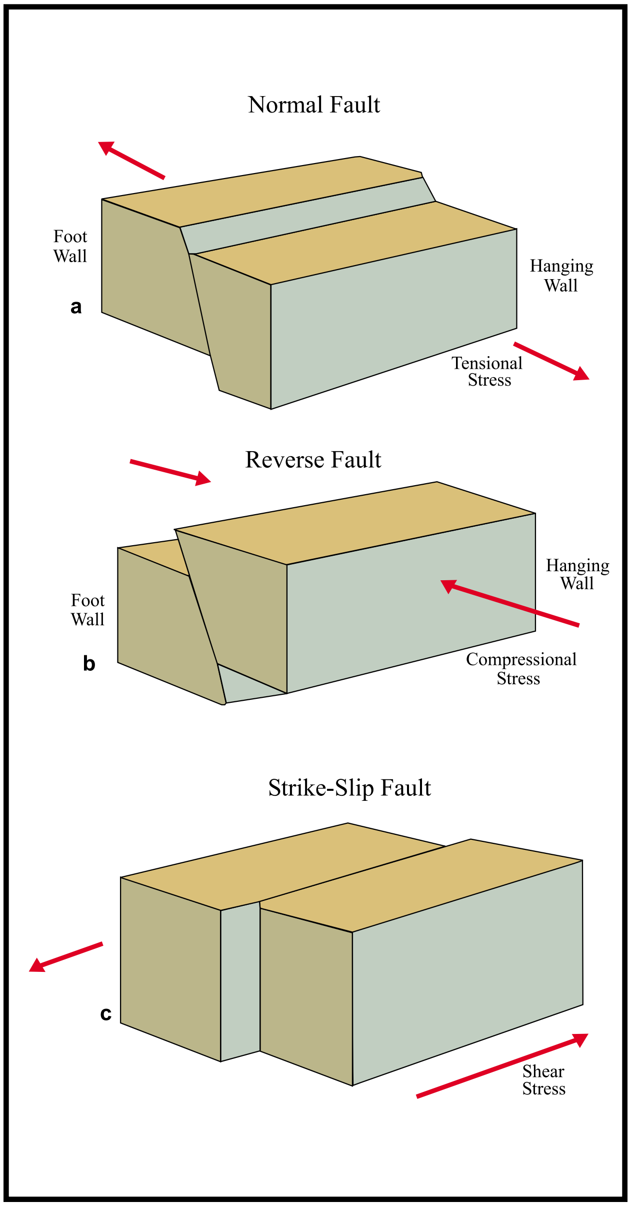

Figure 3. Three primary types of fault motion. Arrows indicate stresses that cause fault motion.

Measuring Earthquakes - Magnitude and Intensity

The size of an earthquake is described in terms of *magnitude*, which is a measure of the amplitude of a seismic wave and is related to the amount of energy released during an earthquake. In the 1930s Charles Richter developed a magnitude scale (*Richter scale*) which was an objective way of discriminating between large and small shocks using the seismic wave amplitude recorded by seismographs (Richter, 1958). The Richter scale was originally set up for local (California) earthquakes that occurred within 100 kilometers (62 miles) of a standardized seismometer. The scale is logarithmic meaning that an increase in magnitude of 1 represents a tenfold amplification of ground motion. For example, the amplitude of the seismic wave associated with a magnitude 6 is 100 times larger than that of a magnitude 4. However, this does not mean that a magnitude 6 is 100 times stronger than a magnitude 4. The amount of energy released or the strength of an earthquake increases by a factor of approximately 32 for every tenfold increase in amplitude; therefore, a magnitude 6 releases approximately 1000 times more energy than a magnitude 4 (32×32). Since the Richter scale is logarithmic, it is possible for an event to be so small that it has a negative magnitude (Richter, 1958). The largest event recorded in the United States was a magnitude 9.2 at Prince William Sound, Alaska, in 1964 (Table 1). The 15 largest earthquakes in the United States are all considered major or great (magnitude 7 and above) ranging in magnitude from 7.8 to 9.2 (Table 1). Although it is commonly believed that the largest event in the contiguous United States occurred in California, it actually occurred near New Madrid, Missouri, in 1812 (Table 2).

An alternative method of determining magnitude is to measure the length (duration) of the seismic signal as opposed to the amplitude of the seismic wave. At the DGS, the duration of the signal is measured from the beginning of the signal until it fades to a level considered "background noise." The duration (each millimeter on the *seismogram* is equivalent to one second) is then compared to a graph developed for the seismic station (NED) located near Newark, Delaware (Figure 4). Values from this graph generally agree with published magnitudes within 0.1 magnitude units (Woodruff, 1984).

Richter's magnitude scale as developed in the 1930s is referred to in the western United States as M_L (L standing for local). Several magnitude scales exist, each developed as extensions of the original Richter magnitude scale, that are equally as valid as the Richter scale. These include M_n (local and regional for the eastern United States), M_S (surface wave magnitude), m_b (body wave magnitude), and M_W (moment magnitude). M_L, M_n, M_S, and m_b are based on instrumental recordings of an earthquake and take into account such factors as ground amplitude, *period*, and the distance from a station to epicenter. M_W is not based on instrumental recordings but rather on a fault's rupture surface and the movement along a fault. Each method will result in a slightly different magnitude for any given event.

LOCATION	***YEAR***	***MAGNITUDE***
Prince William Sound, Alaska	*1964*	*9.2*
Andreanof Islands, Alaska	*1957*	*8.8*
Rat Islands, Alaska	*1965*	*8.7*
East of Shumagin Islands, Alaska	*1938*	*8.3*
Lituya Bay, Alaska	*1958*	*8.3*
Yakutat Bay, Alaska	*1899*	*8.2*
Near Cape Yakatage, Alaska	*1899*	*8.2*
Andreanof Islands, Alaska	*1986*	*8.0*
New Madrid, Missouri	*1812*	*7.9*
Fort Tejon, California	*1857*	*7.9*
Ka'u District, Hawaii	*1868*	*7.9*
Kodiak Island, Alaska	*1900*	*7.9*
Gulf of Alaska, Alaska	*1987*	*7.9*
Owens Valley, California	*1872*	*7.8*
Imperial Valley, California	*1892*	*7.8*

Table 1. The 15 largest earthquakes in the United States.

From U.S. Geological Survey web site http://wwwneic.cr.usgs.gov/neis/eqlists.

LOCATION	***YEAR***	***MAGNITUDE***
New Madrid, Missouri	*1812*	*7.9*
Fort Tejon, California	*1857*	*7.9*
Owens Valley, California	*1872*	*7.8*
Imperial Valley, California	*1892*	*7.8*
New Madrid, Missouri	*1811*	*7.7*
San Francisco, California	*1906*	*7.7*
Pleasant Valley, Nevada	*1915*	*7.7*
New Madrid, Missouri	*1812*	*7.6*
Landers, California	*1992*	*7.6*
Kern County, California	*1952*	*7.5*
West of Lompoc, California	*1927*	*7.3*
Dixie Valley, Nevada	*1954*	*7.3*
Hebgen Lake, Montana	*1959*	*7.3*
Borah Peak, Idaho	*1983*	*7.3*
West of Eureka, California	*1922*	*7.3*

Table 2. The 15 largest earthquakes in the contiguous United States.

From U.S. Geological Survey web site http://wwwneic.cr.usgs.gov/neis/eqlists.

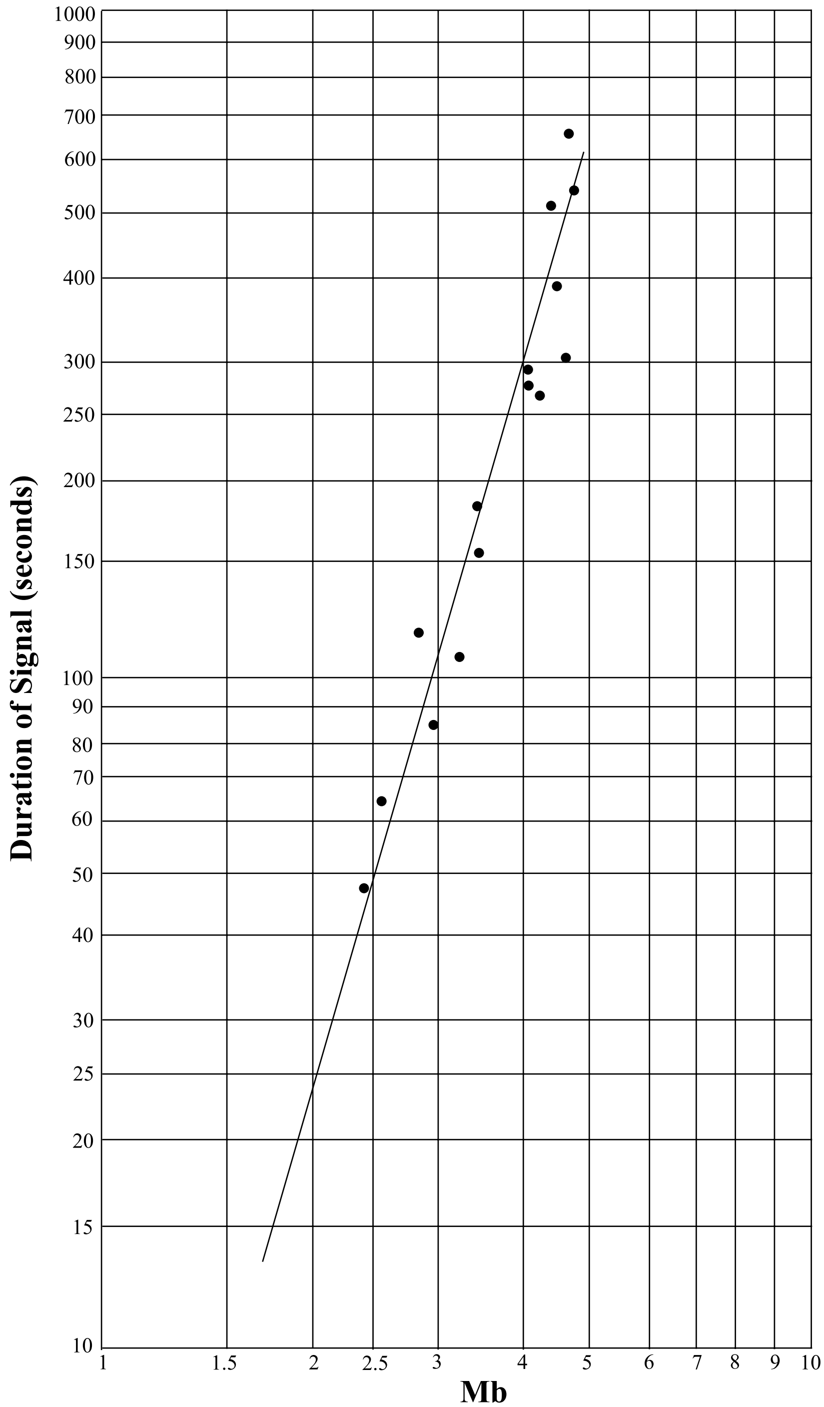

Figure 4. Duration Magnitude for Delaware Geological Survey seismic station (NED) located near Newark, Delaware. See text and Woodruff (1984) for explanation.

Earthquakes were described in terms of *intensity* prior to the development of the Richter scale. Intensity is a semi-quantitative expression used to describe the effects of ground movement and is a function of many variables including the magnitude and depth of an earthquake, distance from the earthquake, local geologic conditions, and local construction practices. In 1902 Giuseppi Mercalli developed a twelve-grade scale ranging from I (recorded by sensitive instruments only) to XII (complete devastation) to quantify felt reports and effects on building and landscapes. The Mercalli scale was subsequently modified in 1931 by American seismologists H. O. Wood and Frank Neumann (Richter, 1958) and was known as the *Modified Mercalli Intensity scale* (MMI scale). The MMI scale is the intensity scale currently used in the United States. Although there is a rough correlation between the Richter scale and the MMI scale (Table 3), the effects of an earthquake will depend on the conditions mentioned above.

Soon after the earthquake that occurred in northern Delaware in February 1973, intensity or "felt" report forms were distributed to the public. Returned forms were assigned intensity values that were then plotted on topographic maps and contoured (Woodruff et al., 1973). The contoured map provided scientists with an indication of where the effects of the earthquake were most strongly felt (Figure 5). The public is encouraged to complete felt reports following earthquakes in Delaware and nearby areas. DGS felt reports are contained on line at http://www.udel.edu/dgs/qkform.html.

Magnitude	*Intensity*	*Description*	*TNT Equivalent (approximate)*	*Descriptor*	*Frequency per Year*
1.0 to 1.9	***I***	*Felt by very few people; barely noticeable*	*1 lb*	*Very Minor*	*~8,000 per day*
2.0 to 2.9	***II***	*Felt by a few people; especially on upper floors*	*Up to 100 lbs*	*Very Minor*	*~1,000 per day*
3.0 to 3.9	***III***	*Noticeable indoors, especially on upper floors, but may not be recognized as an earthquake*	*Up to1 ton*	*Minor*	*49,000*
4.0 to 4.9	***IV-V***	***IV.*** *Felt indoors by many; outdoors be 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.*	*6 to 100 tons*	*Light*	*6,200*
5.0 to 5.9	***VI-VII***	***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.*	*199 to 4,455 tons*	*Moderate*	*800*
6.0 to 6.9	***VII-IX***	***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.*	*6,300 to <199,000 tons*	*Strong*	*120*
7.0 to 7.9	***X-XI***	***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.*	*199,999 to < 6,193,000 tons*	*Major*	*18*
8.0 +	***XII***	***XII.*** *Damage total. Lines of sight and level are distorted. Obiects thrown into the air.*	*6,193,000+ tons*	*Great*	*1*

Table 3. Comparison of magnitude, intensity, and energy equivalent for earthquakes.
(Modified from U.S. Geological Survey Internet web site http://wwwneic.cr.usgs.gov/neis/eqlists.)

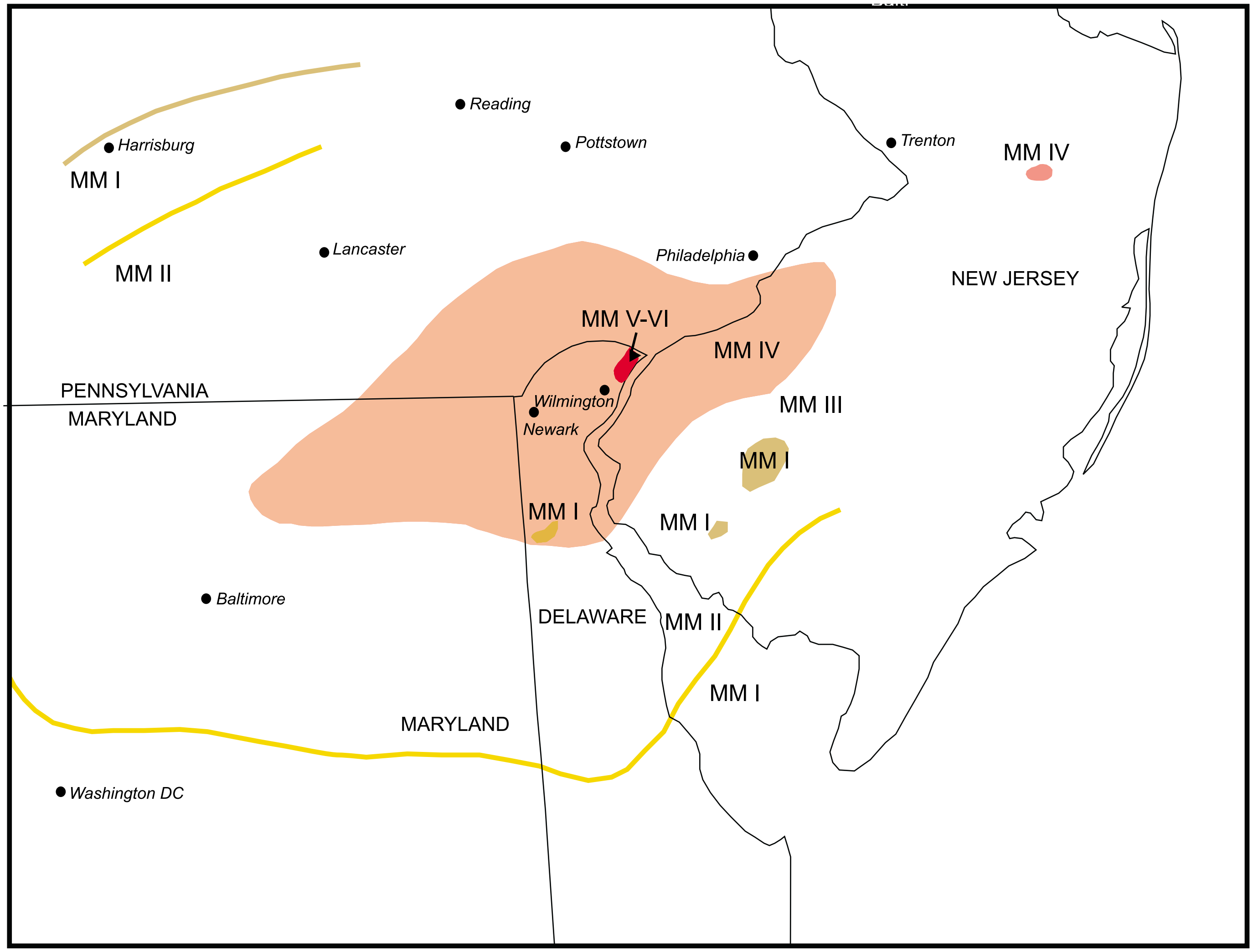

Figure 5. Contoured intensity map of felt reports received after February 1973 earthquake in northern Delaware. (Modified from Woodruff et al., 1973.)

Recording Earthquakes

The *seismoscope* is believed to be the first device used in the investigation of earthquakes and was developed by a Chinese scholar in 132 AD (Figure 6). The instrument was a large bronze jar with a pendulum suspended on the inside. Eight dragon heads were mounted to the outside of the jar, each with a ball in a hinged mouth. Beneath the head of each dragon was a bronze toad with its mouth in an open position. As the ground shook during an earthquake, a ball was released from a dragon's mouth into the mouth of a frog indicating the direction of ground motion (Dewey and Byerly, 1969).

Advancements in earthquake detection were made in the 18th century as scientists attempted to record the nature of ground motion and time associated with earthquakes. Nicholas Cirillo was the first European who, in 1747, noted that the amplitude of the oscillations of a simple pendulum could be used in the study of earthquakes. In the late 18th century, Atanagio Cavalli designed the first instrument able to record the time of an earthquake; however, there is no record that this instrument was ever built (Dewey and Byerly, 1969).

In the late 19th century, three British scientists (John Milne, James Ewing, and Thomas Gray) obtained the first known seismic records recorded as a function of time and used their seismograph to study ground behavior during an earthquake. Observations made by Ewing of early seismograms provided scientists with a clear representation of earthquake motion (Dewey and Byerly, 1969).

Modern seismometers tend to be sensitive electromagnetic devices. As the ground shakes, "…a voltage is generated either by the displacement of a coil in a constant magnetic field…or by variations of the magnetic field enclosed by a coil…" (Kulhanek, 1990). The electrical impulse is amplified, turned into a signal that can be

Figure 6. Model of earliest seismoscope invented in 132 A. D.
From U.S. Geological Survey web site
http://wwwneic.cr.usgs.gov/general/handouts.

transmitted as a tone, radio, or microwave signal and is recorded on a seismograph that may be located near to or miles away from the seismometer. Incoming signals from seismometers can be recorded in either analog (on paper) or digital format. The digital format enables scientists to determine more rapidly and precisely the times and locations of seismic events and to share such information with emergency managers, the public, and adjacent networks.

The Delaware Geological Survey currently operates a network of five seismic stations in Delaware which are strategically located between stations in northern New Jersey and New York, and southwestern Virginia, thereby providing a vital technological link between stations in those areas. With expertise provided by Lamont-Doherty Earth Observatory (LDEO) the DGS upgraded its seismic system to digital format which enables the DGS to enhance the incoming seismic signals thereby allowing DGS staff to more accurately determine an earthquake's parameters.

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GLOSSARY

amplitude (wave): half the height of the crest of a wave above the adjacent troughs (Jackson, 1997).

asthenosphere: semi-platic layer beneath the earth's *lithosphere*. Its upper boundary begins about 100 km below the surface and extends to a depth of about 300 km. The upper limit is marked by an abrupt decrease in the velocity of seismic waves as they enter this region. The temperature and pressure in this zone reduce the strength of rocks, so that they flow plastically (Lapidus, 1987).

body wave: a seismic wave that travels through the interior of the Earth. A body wave may be either longitudinal (P wave) or transverse (S wave) (Jackson, 1997).

crust: the outermost layer of the earth. The entire crust represents less than 0.1% of the earth's total volume. The continental crust is distinct from the oceanic crust in age, physical, and chemical characteristics. (Lapidus, 1987).

earthquake: a sudden motion or trembling in the Earth caused by the abrupt release of slowly accumulated strain (Jackson, 1997).

epicenter: the point on the Earth's surface directly above the focus of an earthquake (Jackson, 1997).

fault: a fracture in the earth along which the opposite sides have been relatively displaced parallel to the plane of movement (Lapidus, 1987).

fault plane: a fault surface that is more or less planar (Jackson, 1997)

focus: the initial rupture point of an earthquake, where strain energy is first converted to elastic wave energy; the point within the Earth which is the center of an earthquake. (Jackson, 1997).

footwall: the mass of rock below a fault plane; the wall rock beneath a fault or inclined vein (Lapidus, 1987).

hanging wall: the overlying side of a fault; the wall rock above a fault or inclined vein (Lapidus, 1997).

intensity: a measure of the effects of an earthquake at a particular place. Intensity depends not only on the earthquake magnitude but also on the distance from earthquake to epicenter and on the local geology (Jackson, 1997).

left lateral fault: displacement along a fault such that, in plan view, the side opposite the observer appears displaced to the left (Jackson, 1997).

lithosphere: the solid outer, rigid shell of the earth above the asthenosphere. In plate tectonics, a lithospheric plate is a segment of the lithosphere that moves over the plastic asthenosphere below (Lapidus, 1987).

Love wave: a type of surface wave with horizontal shear motion perpendicular to the direction of propagation. It is named after A. E. H. Love, the English mathematician who discovered it (Jackson, 1997).

magnitude: A measure of the strength of an earthquake or the strain energy released by it, as determined by seismographic observations (Jackson, 1997).

m_b (body wave magnitude): magnitude of an earthquake as estimated from the wave period (0.1 <= period <= 3.0), the ground amplitude (not necessarily the maximum), distance from the station to the epicenter, and the focus depth (U.S. Geological Survey National Earthquake Information Center Internet web site).

M_L (local magnitude): another name for Richter magnitude used in the western United States which uses the maximum trace amplitude recorded on a standard short-period seismometer and distance where distance <=600 km (U.S. Geological Survey National Earthquake Information Center Internet web site).

M_n (local magnitude): magnitude of a local or regional event in the eastern United States which uses ground amplitude and period calculated from the vertical component 1-second Lg waves, and distance in geocentric degrees. The designator M_{bLg} often is used in place of M_n (Stover and Coffman, 1993).

Modified Mercalli Intensity scale: an arbitrary scale of earthquake intensity. Scale ranges from I (detectable only by instruments) to XII (total destruction). The scale was modified and updated by American researchers to adapt it to North American conditions (Lapidus, 1987).

M_S (surface wave magnitude): magnitude of an earthquake calculated from maximum ground amplitude, surface wave period and the distance from the station to the epicenter in geocentric degrees (Stover and Coffman, 1993).

M_W (moment magnitude): magnitude of an earthquake based on the area of the earthquake fault, the average fault slip over that area, and by the shear modulus of the fault rocks (Stover and Coffman, 1993).

normal (gravity) fault: a fault in which the hanging wall appears to moves down relative to the footwall. The angle of dip is generally 45 to 90° (Jackson, 1997).

period: the interval of time required for the completion of a cyclic motion or recurring event, such as the time between two consecutive like phases of the tide or a current or a wavetrain (Jackson, 1997).

plate tectonics: a geological and geophysical model in which the earth's crust is divided into six or more large rigid plates. The movements of these crustal plates produce regions of tectonic activity along their margins; these regions are the sites of most large earthquakes, volcanism, and mid-oceanic ridges. The theory of plate tectonics unified and expanded the earlier hypothesis of continental drift and sea-floor spreading (Lapidus, 1987).

primary wave (P wave): Type of seismic body wave that involves particle motion (alternating compression and expansion) in the direction of propagation. It is the fastest of the seismic waves. The P stands for primary; it is so named because it is the first arrival from earthquakes (Jackson, 1997).

Rayleigh wave: a type of surface wave having a retrograde, elliptical motion at the free surface. It is named after Lord Rayleigh, the English physicist who predicted its existence (Jackson, 1997).

reverse fault: a fault in which the hanging wall appears to move up relative to the footwall. The angle of dip is generally 45° or more.

Richter scale: a numerical scale developed in 1935 by seismologist C. F. Richter that describes an earthquake independently of its effect on people, objects, or buildings. Negative and small numbers represent earthquakes of very low energy; higher values indicate earthquakes capable of great destruction (Lapidus, 1987).

right lateral fault: displacement along a fault such that, in plan view, the side opposite the observer appears displaced to the right (Jackson, 1997).

secondary wave (S wave): a seismic body wave propagated by a shearing motion that involves oscillation perpendicular to the direction of motion. It does not travel through liquids, or through the outer core of the Earth. Its speed is often about half that of P-waves. The S stands for secondary, so named because it arrives later than the P wave (Jackson, 1997).

seismogram: the record made by a seismograph (Jackson, 1997).

seismograph: an instrument that detects, magnifies, and records, as a function of time, the motion of the Earth's surface caused by seismic waves.

seismometer: an instruments that detects Earth motions (Jackson, 1997).

seismoscope: an instrument that merely indicates the occurrence of an earthquake (Jackson, 1997).

strain: the change in the shape or volume of a body in response to stress, or a change in relative position of the particles of a substance (Lapidus, 1987).

stress(es): in a solid, the force per unit area that acts on or within a body (Lapidus, 1987).

strike-slip fault: a fault along which the movement has been predominantly horizontal, parallel to the strike (Lapidus, 1987).

subduction zone: an extended region along which one crustal block descends relative to another, and along which deep oceanic trenches occur (Lapidus, 1987).

surface wave: a seismic wave that travels along the surface of the Earth, or along a subsurface interface. Surface waves include the Rayleigh wave and the Love wave (Jackson, 1997).

thrust fault: a type of reverse fault with a dip of 30° or less, over much of its extent, on which the hanging wall appears to have moved upward and laterally relative to the footwall. Its characteristic feature is horizontal compression rather than vertical displacement (Jackson, 1997).