Virginia Department of Mines Minerals and Energy

EARTHQUAKES

Plate tectonics is a theory that states that the Earth's crust is composed of a dozen or more rigid "plates" that slowly bump and grind against each other. Most earthquakes are the result of strain release along zones of weakness (faults) in response to the slow movement of those crustal plates (Figure 1). The famous San Andreas Fault in California is the boundary between the Pacific plate on the west and the North American plate on the east. On average, these two plates move past each other at two to three inches per year.

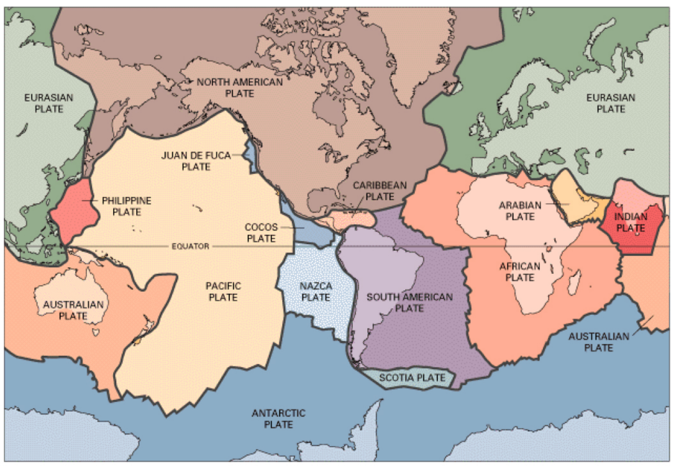

Figure 1. Map of the tectonic plates. Virginia is located on the North American Plate (modified after Shedlock and Pakiser, 1995).

Virginia is located near the center of the North American plate, far from a plate boundary, and thus experiences a much lower rate of seismicity than California. Earthquake activity that occurs within the interior of a tectonic plate is known as "intraplate seismicity." Such earthquakes occur less frequently than earthquakes at plate boundaries, but their impacts can still be extensive and severe.

California earthquakes also often break the ground surface, while earthquakes in Virginia usually occur on faults at depths of from 3 to 15 miles. Thus, the earthquakes felt in the Commonwealth today generally have no relationship with faults seen at the surface.

SEISMIC WAVES

Seismographs are instruments that record ground motion no matter what the source, including earthquakes, commercial mining blasts, and trains. The recordings of those ground motions are called seismograms. When a fault ruptures, energy is released in the form of seismic waves. The first waves to reach the earth's surface are primary or "P" waves (Figure 2). P waves are compressional waves that travel at a speed of about four miles per second near the surface - faster as depth increases. The next waves to reach the earth's surface are secondary or "S" waves. S waves are shear waves that move at a speed of about 1.5 miles per second.

P and S waves are body waves that travel through the earth much like sonar waves travel through water. Surface waves, which are slower than S waves, travel along the surface of the earth much like waves at the surface of the ocean. S waves and surface waves cause the most destruction at the earth's surface.

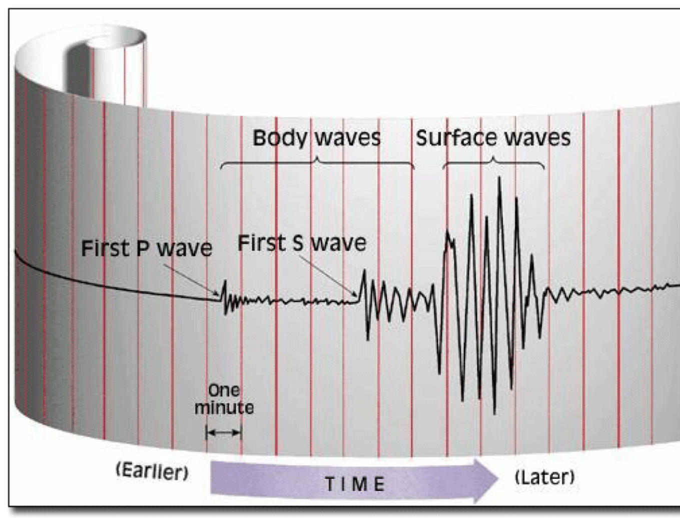

Figure 2. An idealized seismogram showing P, S, and surface waves generated by an earthquake.

Figure 3 shows the travel paths of P, S, and surface waves as they travel through the Earth. The time interval between the arrival of the P wave and S wave can be used to estimate the distance between the recording seismograph and the earthquake. One interesting aspect of shear waves is that they do not travel through fluids. It was this characteristic that led to the discovery that the earth's core was molten.

EARTHQUAKE SIZE

Magnitude is the most common method of describing the "size" of an earthquake. The magnitude of an earthquake is derived by measuring the amplitude of seismic waves on a seismogram. The amplitude readings from several seismograms and the distance from the earthquake to each seismograph are used to calculate a single magnitude value for each earthquake. The first and most well-known magnitude scale was developed by Charles Richter in the 1930s. Magnitude scales are logarithmic which means that an increase of one unit, for example from four to five, implies a 10-fold increase in ground displacement. Moreover, a two unit increase in magnitude implies a 100 times (10 x 10) increase in ground displacement. The amount of energy released is about 30 times greater for each unit increase in magnitude. Thus, the energy released in a magnitude six earthquake is about 900 times (30 x 30) the energy released in a magnitude four earthquake. In general, a modern seismograph can record waves from a magnitude five earthquake anywhere in the world.

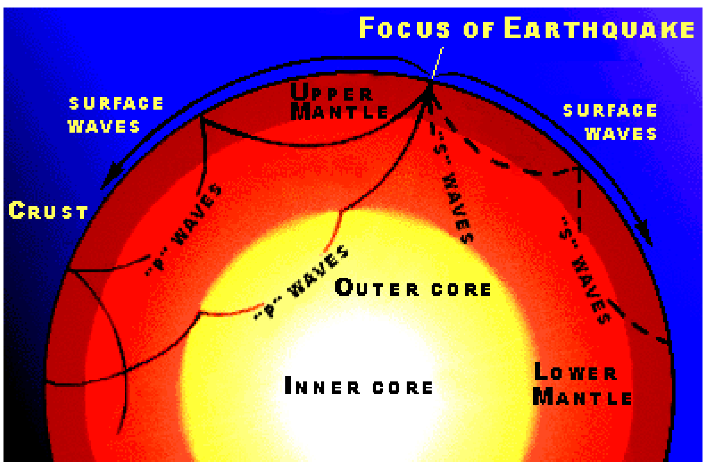

Figure 3. *Cut-away view of the earth showing paths taken by seismic waves (Shedlock and Pakiser, 1995).*

EARTHQUAKE EFFECTS

The Modfied Mercalli Intensity Scale is based on the effects experienced by individuals and the observed damage-- mainly to man-made objects (Figure 4). The scale uses Roman numerals from I to XII, where I would be for a site at which vibrations are slightly felt by very few observers, and XII implies total destruction. For earthquakes that occurred prior to the installation of seismographs, intensities are usually determined from newspaper accounts and diaries.

Whereas there is only one magnitude value associated with an earthquake, there can be many intensity reports for a single earthquake. In general, the intensity is greatest at the epicenter and decreases with distance from the epicenter. The observed effects of an earthquake are very dependent on the earthquake magnitude, distance from the epicenter, and the type of geologic material underlying structures.

Intensities are generally greater on soft soils (alluvium) than on solid rock. Seismic shaking can cause several effects on alluvium such as liquefaction, landslides, fissuring, and slumping. Liquefaction occurs when soil is shaken to the point where it can no longer support the weight of any object that happens to be on it. An example of widespread earthquake liquefaction was the sinking of houses and apartment buildings in The Marina District of San Francisco during the 1989 Loma Prieta earthquake (the World Series earthquake).

	Modified Mercalli Scale	Richter Magnitude Scale
I	Detected only by sensitive instruments	1.5
II	Felt by few persons at best, especially on upper floors; delicately suspended objects may swing	2
III	Felt noticeably indoors, but not always recognized as an earthquake; standing autos rock slightly, vibrations like a passing truck	2.5
IV	Felt indoors by many; outdoors by few, at night some awaken; dishes, windows, doors disturbed; standing autos rock noticeably	3
V	Felt by most people; some breakage of dishes, windows, and plaster; disturbance of tall objects	3.5 4
VI	Felt by all, many frightened and run outdoors; falling plaster and chimneys, damage small	4.5
VII	Everybody runs outdoors; damage to buildings varies depending on quality of construction; noticed by drivers of autos	5
VIII	Panel walls thrown out of frames, walls, monuments, chimneys fall; sand and mud ejected; drivers of autos disturbed	5.5 6
IX	Buildings shifted off foundations, cracked, thrown out of plumb; ground cracked; underground pipes broken	6.5
X	Most masonry and frame structures destroyed; ground cracked, rails bent, landslides	7
XI	Few structures remain standing; bridges destroyed, fissures in ground, pipes broken, landslides, rail bent	7.5
XII	Damage total; waves seen on ground surface, lines of sight and level distorted, objects thrown up into air	8

Figure 4. Generalized relationship between epicentral modified Mercalli intensities and magnitude (modified after Hansen, 1994).

REGIONAL EARTHQUAKES

Virginia, like most states on the eastern seaboard, has a moderate level of risk from earthquakes. The largest earthquake known to have occurred in the region was the 1886 Charleston, South Carolina, earthquake (estimated magnitude 6.6-6.9). That quake was felt as far north as Canada, as far west as Missouri, and as far south as Cuba. Table 1 lists the damaging effects of the 1886 earthquake at some sites in Virginia. Recent studies indicate that large earthquakes have occurred near Charleston in the centuries prior to the 1886 shock. Although earthquakes outside Virginia (e.g. 1886 Charleston, South Carolina) have caused damage in the Commonwealth in the past, the most likely sources for future damaging shaking in Virginia are known seismically active zones, primarily in Central Virginia and an area including Giles County.

Locality	Effects
Culpeper	Chimneys knocked down
South Boston	Chimneys knocked down
Henrico County	Difficult to remain standing
Richmond	Population in the streets; chimneys knocked down; prisoners riot in cells at penitentiary; militia and police called out to restore order; pictures and plaster fell from the walls; many residents felt nausea caused by the vibrations; people thrown from their feet
Abingdon	Plaster shaken down
Chesterfield County	Chimney and plaster damage
Danville	Chimney damage; walls cracked
Farmville	Plaster and chimney damage
Lee County	Plaster and chimney damage; broken windowpanes
Lynchburg	Chimney damage
Norfolk	Chimneys broken; light framework thrown down; large warehouse damaged; panic at Opera House; many people nauseated
Petersburg	Windowpanes broken
Patrick County	Bricks thrown from courthouse
Surry County	Plaster damage
Williamsburg	Plaster damage

Table 1. Effects of the Charleston Earthquake of 1886 in Virginia.

VIRGINIA EARTHQUAKES

Since 1774, the year of the earliest documented Virginia earthquake, there have been over 300 earthquakes in or near the Commonwealth. Of those, 20 earthquakes had reports of intensity VI or higher (Table 2). The largest earthquake in Virginia was the August 23, 2011 Louisa County earthquake. The maximum intensity was VIII, primarily around the epicentral area of Mineral, VA and had a magnitude of 5.8. According to the USGS “Did You Feel It?” website (http://earthquake.usgs.gov/earthquakes/dyfi/), the earthquake was felt in over a dozen states and several Canadian provinces and may be the mostly widely felt in U.S. history (Horton and Williams, 2012). The second largest earthquake in Virginia history was in Giles County in 1897. While the magnitude for this earthquake was 5.9, felt reports were not nearly as widespread as during the 2011 earthquake.

In 1963, as part of the Worldwide Standard Seismograph Network program, seismographs were installed at Georgetown University in Washington, DC, and at Blacksburg, Virginia. In 1977, several more seismographs were installed and operated by Virginia Tech and the Virginia Department of Mines, Minerals, and Energy - Division of Geology and Mineral Resources. From 1978 through 1993, over 160 earthquakes were detected in and around the Commonwealth. Twenty-six of those earthquakes were felt by local residents. This averages out to about ten earthquakes per year, of which one or two are felt. (This apparent increase in the number of events: 300 in 200+ years versus 160 in the last 16 years, is a result of the recent 130+ small earthquakes not felt locally but detected by seismographs.) Some earthquake activity worth noting includes the 1981 Scottsville, Virginia earthquake sequence in which three felt earthquakes (maximum intensity IV) with magnitudes of 3.4, 3.2, and 2.9, occurred within an eight minute period. A series of 11 small (magnitude 1.5-2.2) shallow earthquakes were strongly felt (maximum intensity V) in Richmond in the winter of 1986-1987. One of the most persistent areas of activity is in Carroll County, Virginia. Since 1978, five small felt earthquakes have occurred near Hillsville, Virginia.

Date (Yr-Mo-Day)	Maximum Intensity	Felt Area (Sq Miles)	Locality
1774-02-21	VI	58,000	Petersburg
1833-08-27	VI	52,000	Goochland Co.
1852-04-29	VI	174,500	Grayson Co.
1852-11-02	VI	32,000	Buckingham Co.
1875-12-23	VII	50,000	Buckingham Co.
1885-10-10	VI	25,000	Nelson Co.
1897-05-03	VII	89,500	Giles Co.
1897-05-31	VII	280,000	Giles Co.
1998-02-05	VI	34,000	Wytheville
1907-02-11	VI	5,600	Arvonia
1918-04-10	VI	65,000	Luray
1919-09-06	VI	-	Warren Co.
1929-12-26	VI	1,000	Albemarle Co.
1954-01-02	VI	-	Bell Co., KY / Lee Co., VA
1959-04-23	VI	2,050	Giles Co.
1969-11-20	VI	100,000	Elgood, WV/ Rich Creek, VA
1975-11-11	VI	-	Giles Co.
1976-09-13	VI	9,000	Carroll Co.
2003-12-09	VI	200,000	Powhatan Co.
2011-08-23	VIII	1,700,000	Louisa Co.

Table 2. Earthquakes in and around Virginia (VI or greater).

REFERENCES

Hansen, C., 1994, Earthquakes in Ohio: Ohio Division of Geological Survey, Educational Leaflet No. 9, revised edition 1994, leaflet.

Horton, J.W. and Williams, R.A., 2012, The 2011 Virginia Earthquake: What are scientists learning?: Eos, vol. 93, no. 33, 317-318. Available online: http://www.agu.org/pubs/pdf/2012EO330001_rga.pdf.

Shedlock, K.M. and Pakiser, L. C., 1995, Earthquakes: U. S. Geological Survey pamphlet, 20 p. Available online: http://pubs.usgs.gov/gip/earthq1/.

Prepared by M. S. Sibol, M. C. Chapman, and S. S. Johnson; revised by A.C. Witt, 2/2014.

Division of Geology and Mineral Resources
900 Natural Resources Drive, Suite 500
Charlottesville, VA 22903
Geologic Information: *(434) 951-6341*
FAX: *(434) 951-6366*
Sales Hours: *10:00 AM – 3:00 PM Mon. - Thurs.*

http://www.dmme.virginia.gov/dgmr/divisongeologymineralresources.shtml