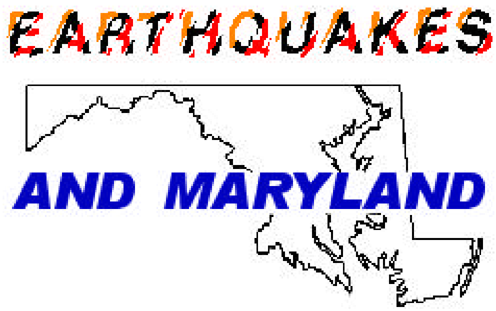

By James P. Reger

INTRODUCTION

Earthquakes can be among the most devastating and terrifying of natural hazards. Although floods, tornadoes and hurricanes account for much greater annual loss in the United States, severe earthquakes pose the largest risk in terms of sudden loss of life and property. Many interrelated factors determine the extent of loss of property and life from an earthquake. Each of the following should be prefaced with "other factors being equal."

- Amount of seismic energy released: The greater the vibrational energy, the greater the chance for destruction.
- Duration of shaking: This is one of the most important parameters of ground motion for causing damage.
- Depth of focus, or hypocenter: The shallower the focus (the point of an earthquake's origin within the earth), usually the greater the potential for destructive shock waves reaching the earth's surface. Even stronger events of much greater depth typically produce only moderate shaking at ground level.
- Distance from epicenter: The potential for damage tends to be greatest near the epicenter (the point on the ground directly above the focus), and decreases away from it.
- Geologic setting: A wide range of foundation materials exhibits a similarly wide range of responses to seismic vibrations. For example, in soft unconsolidated material, earthquake vibrations last longer and develop greater amplitudes, which produce more ground shaking, than in areas underlain by hard bedrock. Likewise, areas having active faults are at greater risk.
- Geographic and topographic setting: This characteristic relates more to secondary effects of earthquakes than to primary effects such as ground shaking, ground rupture, and local uplift and subsidence. Secondary effects include land- slides (generally in hilly or mountainous areas), seismic sea waves, or tsunamis (pretty much restricted to oceans and coastal areas), and fires (from ruptured gas lines and downed utility lines).
- Population and building density: In general, risk increases as population and building density increase. Types of buildings: Wooden frame structures tend to respond to earthquakes better than do more rigid brick or masonry buildings. Taller buildings are more vulnerable than one- or two-story buildings when

located on soft, unconsolidated sediments, but taller buildings tend to be the more stable when on a hard bedrock foundation.

- Time of day: Experience shows there are fewer casualties if an earthquake occurs in late evening or early morning because most people are at home and awake and thus in a good position to respond properly.

Although earthquakes have been the object of study and superstition for many centuries, the modern science of seismology really gained impetus after the famous San Francisco earthquake of 1906. Since then, geologists have learned much more about the structure and composition of the earth's interior and, more recently, have made progress in earthquake forecasting and in hazard and risk mitigation.

ORIGIN OF EARTHQUAKES

Most earthquakes occur when great stresses building up within the earth are suddenly released. This sudden release of this stored energy causes movement of the earth's crust along fractures, called faults, and generates shock waves. These shock waves, or seismic waves, radiate in all directions from the focus, much as ripples radiate outward in two dimensions when a pebble is dropped into a pond.

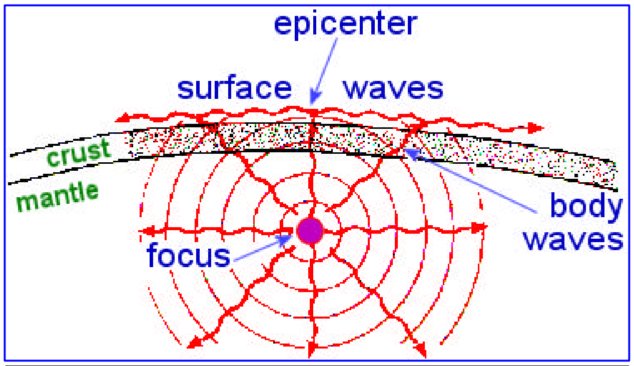

Figure 1. Highly generalized cross section of earth's crust and upper mantle depicting seismic waves, earthquake focus and an epicenter.

The two basic types of seismic waves are body waves, or primary waves, which travel through the interior of the earth, and surface waves, which travel along the earth's surface and are believed to be responsible for most earthquake damage.

There are two types of body waves: P waves, or primary waves, and S waves, or secondary waves. The faster moving P waves are compressional waves, and the slower S waves are shear waves. Compressional waves involve a "push-pull" vibration of earth material in the same direction as the P waves are moving. In contrast, shear waves "shake" material at right angles to their path. Differences in P- and S-wave characteristics have provided much information about the structure and composition of the earth's interior.

Although most earthquakes are associated with movement along faults, they can also be triggered by volcanic activity, by large landslides, and by some types of human activity. However, in areas not known for frequent earthquakes, pinpointing the cause of the rare tremor can be very difficult.

The theory of plate tectonics explains most earthquake occurrences. Ninety percent or more of all earthquakes occur along boundaries between large, slowly moving slabs, or plates, of the earth's crust and upper mantle, collectively called the lithosphere. (For more background on plate tectonics, the reader is encouraged to refer to a recent introductory geology text or a good encyclopedia.)

Most earthquakes are shallow (0-40 miles to the focus), occurring in the lithosphere. The mechanism for most very shallow earthquakes probably involves fracturing of brittle rock in the crust or relief of internal stresses due to frictional resistance locking opposite sides of a fault.

Very little is known about the causes of earthquakes in the eastern United States. In general, there is no clear association among seismicity, geologic structure, and surface displacement, in contrast to a common association in the western U.S.

The mid-Atlantic and central Appalachian region, including Maryland, is characterized by a moderate amount of low-level earthquake activity, but their cause or causes are largely a matter of speculation. In Maryland, for example, there are numerous faults, but none is known or suspected to be active. Because of the relatively low seismic energy release, this region has received relatively little attention from earthquake seismologists (Bollinger, 1969).

In the Atlantic Coastal Plain, it is now thought that earthquakes may be associated with nearly vertical faults that formed during the opening of the present Atlantic Ocean during the Triassic period about 220 million years ago (Hanks, 1985). Such faults would occur in the "basement" bedrock, and not in the overlying, younger Coastal Plain sediments themselves.

Recent evidence suggests that earthquakes in the Valley and Ridge Province and in the Piedmont Province occur at shallow depths (usually less than 15 miles) in the Precambrian crystalline basement rocks (Wheeler and Bollinger, 1984). The geologic structure that may be responsible for earthquake activity in these areas is a nearly horizontal fault that formed during continental collision and closing of a proto-Atlantic Ocean during late Paleozoic time approximately 300 million years ago. It is also possible that some earthquakes in the Piedmont are in some way related to igneous dikes that were intruded into surrounding bedrock during the Triassic and Jurassic periods (roughly 200-175 million years ago).

MEASURING EARTHQUAKE

The vibrations produced by earthquakes are detected and recorded by instruments called seismographs. The time of occurrence, the duration of shaking, the locations of the epicenter and focus, and estimates of the energy released can be obtained from data from seismographs set up around the world.

In 2002, a seismograph station was established at Soldiers Delight in Baltimore County. A live Internet link to the station can be found at:

http://www.mgs.md.gov/esic/seisnet/index.html.

The station is a cooperating partner in the Lamont Doherty Earth Observatory Seismic Network of Columbia University, along with stations in Delaware and Pennsylvania. Other regional seismograph stations are in State College, Pennsylvania; Morgantown, West Virginia; and Blacksburg, Virginia.

Measurement of the severity of an earthquake can be expressed in several ways, the two most common being intensity and magnitude. The intensity, reported on the Modified Mercalli Intensity (MMI) Scale, is a subjective measure in terms of eyewitness accounts (**Table 1**). Intensities are ranked on a 12-level scale and range from barely perceptible (I) to total destruction (XII). The lower intensities are described in terms of people's reactions and sensations, whereas the higher intensities relate chiefly to observable structural damage.

TABLE 1. The Modified Mercalli Intensity Scale of 1931 (abridged).	
I	Not felt except by very few people under especially favorable conditions.
II	Felt by a few people, especially those on upper floors of buildings. Suspended objects may swing.
III	Felt quite noticeably indoors. Many do not recognize it as an earthquake. Standing motorcars may rock slightly.
IV	Felt by many who are indoors; felt by a few outdoors. At night, some awakened. Dishes, windows and doors rattle.
V	Felt by nearly everyone; many awakened. Some dishes and windows broken; some cracked plaster; unstable objects overturned.
VI	Felt by everyone; many frightened and run outdoors. Some heavy furniture moved; some fallen plaster or damaged chimneys.
VII	Most people alarmed and run outside. Damage negligible in well constructed buildings; considerable damage in poorly constructed buildings.
VIII	Damage slight in specially designed structures; considerable in ordinary buildings; great in poorly built structures. Heavy furniture overturned. Chimneys, monuments, etc. may topple.
IX	Damage considerable in specially designed structures. Buildings shift from foundations and collapse. Ground cracked. Underground pipes broken.
X	Some well-built wooden structures destroyed. Most masonry structures destroyed. Ground badly cracked. Landslides on steep slopes.
XI	Few, if any, masonry structures remain standing. Railroad rails bent; bridges destroyed. Broad fissure in ground.
XII	Virtually total destruction. Waves seen on ground; objects thrown into the air.

Magnitude is an objective measure of earthquake severity and is closely related to the amount of seismic energy released at the focus of an earthquake. It is based on the amplitude of seismic waves as recorded on standardized seismographs. The standard for magnitude measures is the Richter Scale, an open-ended scale expressed in whole numbers and decimal fractions. The Richter Scale is logarithmic, meaning that an earthquake of magnitude 5.0 has 10 times the wave amplitude of a magnitude 4.0 and 100 times the ground vibration amplitude of a magnitude 3.0 event. As a first approximation, each whole number increment on the Richter Scale corresponds to a release of about 31 times more seismic, or vibrational, energy. Actually, there are several different methods of determining Richter magnitude. One uses surface waves, another body waves, and so on. However, the differences in results are slight.

Although the Richter scale has no upper limit, the greatest magnitude on record is 8.9 for earthquakes that occurred off the northwest coast of South America in 1906 (magnitude estimated) and off the east coast of Honshu, Japan in 1933. By comparison, the famous San Francisco earthquake of 1906 had an estimated magnitude of about 8.3 and an MMI of X.

A comparison of the Modified Mercalli and the Richter Scales is shown in **Table 2**. It is important to realize that these relationships are only generalizations and can vary for any given earthquake depending upon local geologic conditions. As a general rule of thumb, damage is slight at the magnitude 4.5 level, becomes moderate at about 5.5, and above 6.5 or so can range from considerable to nearly total (Bollinger et al., 1989). This rela- tion may not apply to earthquakes in Maryland, if recent events are any indication. A small tremor in January 1990, west of Baltimore was assigned a Modified Mercalli Intensity V near the epicenter, but registered only a 2.5 to 2.6 magnitude on the Richter Scale.

TABLE 2. Approximate relationships among earthquake magnitude, intensity, worldwide occurrence, and area affected (after U.S. Geological Survey, 1981, 1989).

General Description	Richter Magnitude	Modified Mercalli Intensity	Expected Annual Incidence	Distance Felt (miles)
Microearthquake	below 2.0	--	600,000	--
Perceptible	2.0-2.9	I--II	300,000	--
Felt generally	3.0-3.9	II-III	49,000	15
Minor	4.0-4.9	IV-V	6,000	30
Moderate	5.0-5.9	VI-VII	1,000	70
Large (Strong)	6.0-6.9	VII-VIII	120	125
Major (Severe)	7.0-7.9	IX-X	18	250
Great	8.0-8.9	XI-XII	1.1	450

EARTHQUAKES IN AND AROUND MARYLAND

To most people in the United States, damaging earthquakes are a California phenomon, but this is misleading. Even though the greatest seismicity in the United States occurs along the Pacific Coast (especially Alaska and Southern California), major earthquakes have also occurred in the central and eastern U.S.

The last earthquake to cause appreciable damage in the eastern United States occurred in 1886 near Charleston, South Carolina. It had an estimated magnitude of 6.5-7, an intensity of X, and was felt over an area of two million square miles. Even in Maryland, the felt intensity from this earthquake was IV to V.

Perhaps the greatest seismic event ever to occur in North America in historic times was a series of earthquakes that shook the mid-continent around New Madrid, Missouri in the winter of 1811-1812. Estimates of the magnitude range as high as 8.7; estimated maximum intensity was XII; and the felt area, which included Maryland, was 2 million square miles.

Other damaging earthquakes in the eastern U.S. include an intensity VIII event near Boston in 1755 and intensity VI events near New York City in 1737 and 1884.

Figure 2 shows earthquake epicenters in the eastern United States and eastern Canada for a 10-year period, 1976-1985. Although numerous, these earthquakes were all low-intensity, low-magnitude events. Most had a magnitude less than 2.0. It is definitely worth noting that Maryland seems to be part of a seismically quiet zone.

Several earthquakes in adjacent states have been felt in Maryland. Marylanders are more likely to feel one of these out-of-state earthquakes than one within Maryland. As shown by **Figure 2**, Southwestern Virginia, central Virginia, and the Atlantic seaboard northward from Wilmington, Delaware have significantly more seismic activity than does Maryland. One out-of-state earthquake that was felt in much of Maryland occurred Easter Sunday, April 22, 1984. In fact, it was reported felt in eight states and the District of Columbia, over an area of approximately 19,000 square miles. Centered about 12 miles south of Lancaster, Pennsylvania, this earthquake registered 4.1 on the Richter Scale and had an epicentral intensity of V to VI. Most notable effects in Maryland were in the northeastern part of the state, which generally experienced Modified Mercalli Intensity V effects for example, hanging pictures fell in Conowingo; windows cracked in Elkton and Joppa; and standing vehicles rocked slightly in Union Bridge (Stover, 1988). A 3.0-magnitude tremor four days earlier is considered to have been a foreshock. Ten aftershocks registering 2 to 2.5 Richter magnitudes occurred over a four-day period after the April 22 event. The Lancaster earthquake is likely related to Triassic-age structures in the area.

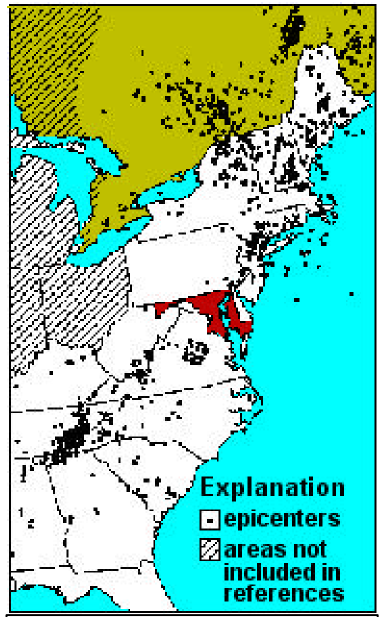

Figure 2. Earthquake epicenters in the eastern United States, 1976-1985 (from Foley et al., 1985; Sibol et al., 1985; and Stover et al., 1984).

As of late 1993, 47 earthquakes had been reported within Maryland's borders (**Table 3** and **Fig. 3**). Over the next ten years, that total reached 61. (For a frequently updated list and map of Maryland earthquakes, see Maryland Geological Survey's FactSheet 13, *Summary of Maryland Earthquakes, 1758 – 2000*. The accuracy and precision of these epicenter determinations is such that a few of the closer out-of-state earthquakes could have occurred within Maryland and some of those near the state's boundaries may actually have occurred in adjacent states. For example, not included in the list was a moderate shock that occurred on January 2, 1885 in an area near the Frederick County, Maryland-Loudon County, Virginia border. The maximum intensity was V, with the total felt area covering more than 3,500 square miles. Of the Maryland earthquakes, 2 occurred in the Valley and Ridge Province, 36 were in the Piedmont Province, and 10 were in the Coastal Plain Province.

The first reported earthquake to have actually had its epicenter in Maryland occurred south of Annapolis on April 25, 1758, but no record of its strength is known to exist. The shock lasted 30 seconds and was preceded by subterranean noises. Additional felt reports were received from a few points in Pennsylvania (U.S. Geological Survey, 1973). Maryland's strongest confirmed tremor was a 3.1-magnitude event near Hancock, Washington County, in 1978. That perhaps was rivaled by an intensity V event (unknown magnitude) near Phoenix, Baltimore County, in 1939. Earthquakes of such magnitudes or intensities are still considered to be minor, and very seldom result in significant damage or injury.

Recent confirmed earthquakes in Maryland were both felt in roughly the same location and, therefore, may possibly be related. The first of these occurred on January 13, 1990 at about 3:48 p.m. local time (EST). According to reports from nine seismograph stations, the shock's magnitude registered 2.5 to 2.6 on the Richter scale. Depth to focus was approximately 2 miles, which indicates a very shallow earthquake. Intensities ranged from MMI V in the Randallstown area; to IV at Eldersburg, Ellicott City, Granite and Woodstock; and III at Owings Mills. Several first-hand accounts of the event from the Granite-Hernwood area reported that houses shook or windows rattled, both indicative of an intensity IV. No damage was reported.

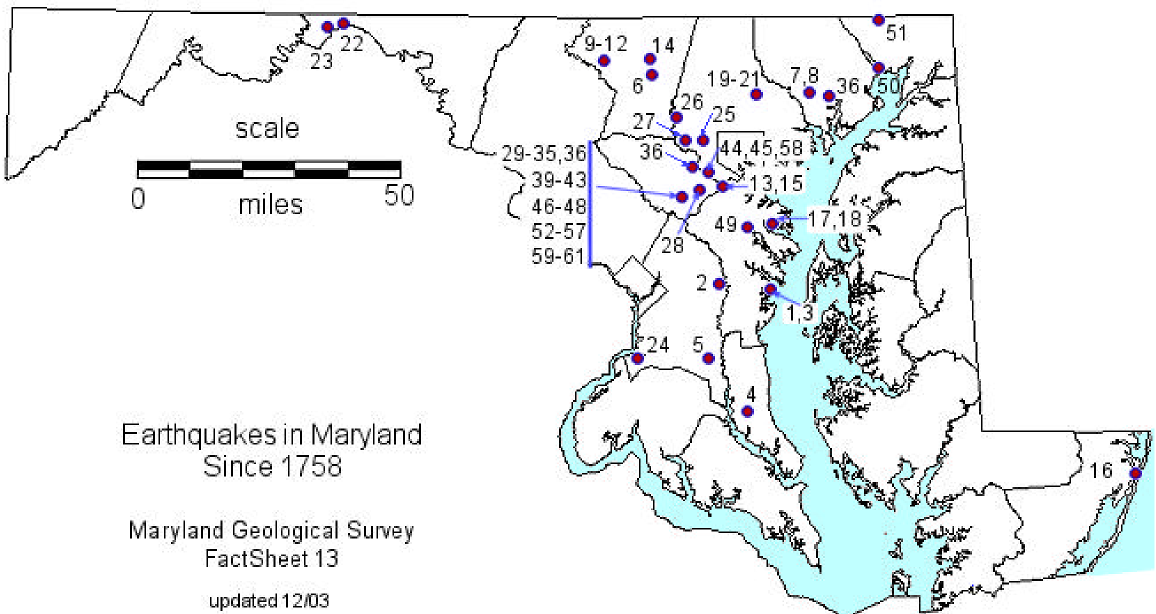

Figure 3. Map showing approximate epicenters of historic earthquakes in and near Maryland (from data in Stover et al., 1984; U.S. Geological Survey, 1990).

On April 4, 1990, reports of another small earthquake came from the Randallstown-Granite-Hernwood area. However, seismic stations in Delaware and Virginia place the epicenter in western Carroll County (Fig. 4), approximately 20 miles west of the Randallstown area. By all accounts, this event was smaller than the January tremor. Preliminary analysis of seismic records indicated a magnitude of about 1.6 or 1.7, and first-hand accounts of a few local residents suggested a Mercalli intensity of about II or III. One eyewitness described the event as starting with the sound of distant thunder, getting louder for about 25 seconds, then followed by 5 to 7 seconds of minor rumbling or shaking. Another resident of this area has reported nearly two dozen similar events, although not confirmed as earthquakes, between October, 1987 and May, 1990.

Table 3: Earthquake chronology of Maryland, 1758-2003. The numbers 1-61 refer to those on the map in Figure 3. (Data for 1758-1979 compiled primarily by the U.S. Geological Survey (USGS);1990-1993 data from Delaware Geological Survey (DGS), Lamont-Doherty Earth Observatory (LDEO), and USGS; 1996 to 2002 data from DGS, LDEO, Virginia Polytechnic Institute (VPI)., and Maryland Geological Survey.

No.	Date (UTC)[1] Yr/Mo/Day	Time (UTC)[1] (hh:mm:ss)	Epicenter[2]		General Location	Depth (km)	Intensity[3]	Magnitude[4]
			Lat	Lon				
1	1758/04/25	02:30	38.90	-76.50	Annapolis	...	V	(3.5, 3.7)
2	1828/02/24	...	38.90	-76.70	Bowie	...	...	...
3	1876/01/30	02:05	38.90	-76.50	Annapolis	...	...	...
4	1876/04/10	...	38.50	-76.60	Prince Frederick	...	III	(2.7)
5	1877/09/01	16:00	38.70	-76.80	Brandywine	...	III	(2.7)
6[5]	1881[5]/01/04	08:00[5]	39.57	-77.00	Westminster	...	IV-V	(3.1)
7	1883/03/11	23:57	39.50	-76.40	Fallston	...	IV	(3.1, 3.3)
8	1883/03/12	05:00	39.50	-76.40	Fallston	...	III	(2.7, 2.9)
9	1902/03/10	05:00	39.60	-77.20	Union Bridge	...	III	(2.7)
10	1902/03/11	10:30	39.60	-77.20	Union Bridge	...	III	(2.7)
11	1903/01/01	17:30	39.60	-77.20	Union Bridge	...	III	(2.7)
12	1903/01/01	22:45	39.60	-77.20	Union Bridge	...	II	(2.4)
13	1906/10/13	15:00	39.20	-76.70	Catonsville	...	III	(2.7)
14	1910/01/24	02:20	39.60	-77.00	Westminster	...	II	(2.4)
15	1910/04/24	02:	39.20	-76.70	Catonsville	...	III	(2.7)
16	1928/10/15	...	38.30	-75.10	Ocean City	...	IV	(2.7, 3.3)
17	1930/11/01	06:34	39.10	-76.50	Round Bay - Severna Park	...	IV	(3.1, 3.3)
18	1930/11/01	07:02	39.10	-76.50	Round Bay - Severna Park	...	III	(2.7)
19	1939/06/22	23:10	39.50	-76.60	Phoenix	...	III	(2.7)
20	1939/11/18	02:33	39.50	-76.60	Phoenix	...	IV	(3.1)
21	1939/11/26	05:20	39.50	-76.60	Phoenix	...	V	(3.5, 3.7)
22	1962/09/07	14:00	39.70	-78.20	Hancock	38	IV	(3.3)
23	1978/04/26	19:30	39.7	-78.24	Hancock	15	...	3.10
24	1986/05/23	17:48	38.69	-77.04	Accoceek - Piscataway	0.20	...	2.5
25	1990/01/13	20:48	39.36	-76.80	Randallstown (V), Eldersburg (IV), Ellicott City (IV), Granite (IV), Owings Mills (III)	3-5	V	2.6 2.5
26	1990/04/04	16:15	39.35	-76.78	Granite - Randallstown - Baltimore	7.0-10.0	II	1.7
27	1991/09/28	11:28	39.36	-76.83	Granite - Randallstown	5.0	III	2.4

Table 3: Earthquake chronology of Maryland, 1758-2003. The numbers 1-61 refer to those on the map in Figure 3. (Data for 1758-1979 compiled primarily by the U.S. Geological Survey (USGS);1990-1993 data from Delaware Geological Survey (DGS), Lamont-Doherty Earth Observatory (LDEO), and USGS; 1996 to 2002 data from DGS, LDEO, Virginia Polytechnic Institute (VPI)., and Maryland Geological Survey.

No.	Date (UTC)[1] Yr/Mo/Day	Time (UTC)[1] (hh:mm:ss)	Epicenter[2]		General Location	Depth (km)	Intensity[3]	Magnitude[4]
			Lat	Lon				
28	1993/03/10	14:32	39.2	-76.8	Columbia (IV) - Ellicott City (II) - Fulton (II)	5.0	II-IV	2.5
29	1993/03/12	00:54:00	39.19	-76.87	Columbia - Allview Estates	5.0	II-III	2.0
30	1993/03/15	04:30	39.19	-76.87	Columbia - Allview Estates - Laurel	0.9	III-V	2.7
31	1993/03/16	07:59:00	39.19	-76.87	Columbia - Allview Estates	5.0	II-III	1.8
32	1993/03/16	16:59	39.19	-76.87	Columbia - Allview Estates	5.0	II-III	1.8
33	1993/03/17	11:54	39.19	-76.87	Columbia - Allview Estates	0.5	I-II	= or < 1.0
34	1993/03/19	05:50	39.19	-76.87	Columbia - Allview Estates	0.5	I-II	1.0
35	1993/03/19	19:26	39.19	-76.87	Columbia - Allview Estates	0.5	I	<1.0
36	1993/03/21	10:55	39.47	-76.30	Aberdeen - Bel Air	...	I-II	1.5
37	1993/03/22	10:26	39.19	-76.86	Columbia - Allview Estates	0.5	not felt	about 0.0
38	1993/03/26	14:03	39.28	-76.82	Ellicott City near jct US40 & 29	...	I-II	<1.5 (est.)
39	1993/04/04	17:32	39.19	-76.87	Columbia - Allview Estates	0.5	I-III	1.5
40	1993/04/04	17:33	39.19	-76.87	Columbia - Allview Estates	0.5	I-II	1.5
41	1993/04/08	09:10	39.19	-76.87	Columbia - Allview Estates	0.5	I-II	1-1.5
42	1993/07/09	06:31	39.19	-76.87	Columbia - Allview Estates	0.5 (est.)	II-III	1.9
43	1993/07/12	21:24	39.19	-76.87	Columbia - Allview Estates	0.5 (est.)	III-IV	2.1
44	1993/10/28	06:00	39.25	-76.77	Ilchester - Ellicott City	...	IV	2.1
45	1993/10/28	06:01	39.25	-76.77	Ilchester - Ellicott City	...	IV	1.8
46 *	1993/11/17	16:35	39.19	-76.87	Columbia - Allview Estates	0.5 (est.)	III	1.7 (est.)
47 *	1993/11/27	15:26	39.19	-76.87	Columbia - Allview Estates	...	I-II	<1.5 (est.)
48 *	1993/11/27	18:43	39.19	-76.87	Columbia - Allview Estates	...	I-II	about 1.5 (est.)
49	1994/10/28	02:04	39.1	-76.60	Glen Burnie - Pasadena - Gambrills -Millersville	...	IV	2.7
50	1996/08/02	07:19	39.57	-76.08	Perryville	...	II-III	2.2
51	1996/10/17	11:43	39.7	-76.07	Rising Sun (epicenter may be in Pennsylvania)	5.4	IV	2.2, 2.3
52-54	1996/12/06	3 very small events in 35	39.19	-76.87	Columbia - Allview Estates	...	II	<1.5 (est.)

Table 3: Earthquake chronology of Maryland, 1758-2003. The numbers 1-61 refer to those on the map in Figure 3. (Data for 1758-1979 compiled primarily by the U.S. Geological Survey (USGS);1990-1993 data from Delaware Geological Survey (DGS), Lamont-Doherty Earth Observatory (LDEO), and USGS; 1996 to 2002 data from DGS, LDEO, Virginia Polytechnic Institute (VPI)., and Maryland Geological Survey.

No.	Date (UTC)[1] Yr/Mo/Day	Time (UTC)[1] (hh:mm:ss)	Epicenter[2]		General Location	Depth (km)	Intensity[3]	Magnitude[4]
			Lat	Lon				
		min.						
55-57	1996/12/14	3 very small events in 75 min.	39.19	-76.87	Columbia - Allview Estates	...	II	<1.5 (est.)
58[6]	1996/12/16	15:10	39.25	-76.77	Ilchester - Ellicott City	...	I	about 1 (est.)
59	1996/12/22	05:56	39.19	-76.87	Columbia - Allview Estates	5	III	2.0, 2.3
60	2001/12/18	...	38.19	-76.84	Columbia nr US29-Md32	...	II	1.5-2.0 (est)
61	2002/03/22	...	38.19	-76.84	Columbia nr US29-Md32	...	I	1-2 (est.)

NOTES:
* Probable, but not confirmed by seismographs in the region. Magnitude estimated from other events in the series.
1. Time (UTC): Coordinated Universal Time. For the Eastern time zone, subtract 5 hours from UTC time for Eastern Standard Time, 4 hours for Eastern Daylight Saving Time. For example: 1200 UTC (noon) = 0800, or 8:00 am EDT = 0700, or 7 am EST. Note that 00:00-04:59 UTC converts to 1800-23:59 of the previous day.
2. Epicenter, as calculated from seismograph stations =data and/or estimated by the Maryland Geological Survey on the basis of felt reports; 1962 marked the first instrumentally determined epicenter.
3. Except for event #6 in 1881 (see note 5 below), pre-instrumental (pre-1962) intensity estimates are earthquake catalogs published by various seismograph networks.
4. Except for event #6 in 1881 (see note 5 below) pre-instrumental magnitude estimates (shown in parentheses) by L. Seeber and J. Armbruster (Lamont Doherty Earth Observatory of Columbia University) and/or M. Chapman (Virginia Tech Seismological Observatory); magnitude estimates for a large number of pre-instrumental earthquakes in the region were derived using the region-specific relationships between felt area, maximum intensity and mb(Lg) magnitude developed by Sibol et al. (1987). Subsequent magnitudes are from instrumental measurements.
5. Event #6 has not been listed in any previously published earthquake list. A rather detailed account of this event appeared in the January 8, 1881 edition of the *American Sentinel* newspaper. Estimates of the epicenter and intensity have been made on the basis of the newspaper descriptions; magnitude estimates based on Sibol et al. (1987).
6. The Delaware Geological Survey states that this event may have been a sonic boom instead of an earthquake (S. Baxter, oral commun., Aug. 16, 2001).

ASSESSING THE RISK

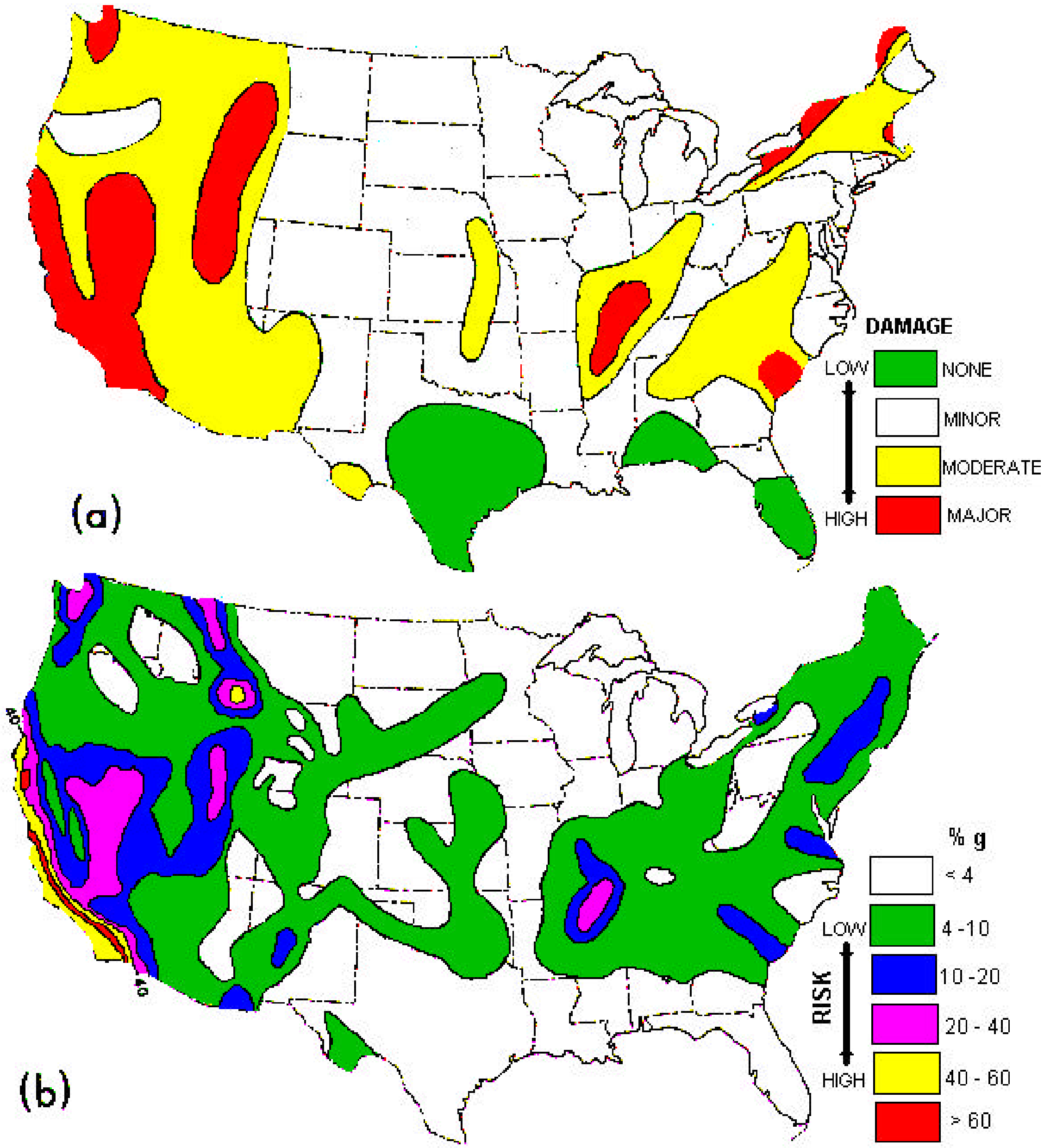

Figure 4. Earthquake risk maps of the United States: (a) Relative risk of damage, based to a large extent on known earthquake history (Algermissen, 1969).(b) Probabilistic risk map showing maximum horizontal ground acceleration with a 90-percent probability of not being exceeded in 50 years (Algermissen et al., 1982).

The earthquake hazard in the United States has been estimated in a variety of ways. Chief among them is the production of "risk maps." Such maps prove useful in establishing building codes, engineering design standards, and insurance rates in areas of high risk. Seismic risk maps are based either on relative risk or on the probability of a certain seismic event at a particular time and place.

Two examples of risk maps are shown in Figure 4. Figure 4a shows four zones that are assigned risk on a relative scale. This map is based on the known occurrence of damaging earthquakes in the past, evidence of strain release, and consideration of major geologic structures and provinces believed to be associated with earthquake activity.

For years, this map was widely used, because it was the best risk map available. However, this type of risk map has several drawbacks. For one thing, it does not consider frequency of occurrence. Furthermore, there is no justification for assuming that events larger than those observed historically, especially in the East, will not occur in the future. It is also known that ground-motion attenuation ("dying out" of the shock waves) with distance is far less in the eastern U.S. than in the western states. Felt areas are, in general, one order of magnitude greater in the East than for similar earthquakes in the West (Bollinger, 1973). Nonetheless, according to this map, Maryland is appropriately placed into a zone of minor expected damage, corresponding to Mercalli intensity V to VI.

A more recent development that is still being improved upon is the probabilistic map. One example is illustrated in Figure 4b. This particular map shows the expected maximum horizontal ground acceleration (as a percentage of g, the acceleration due to gravity, 32.2 ft/sec2) on rock sites. These ground accelerations, which are one measure of ground shaking, have a 90-percent probability of not being exceeded in 50 years. This is equivalent to a recurrence interval, or return period, of 475 years (Hays, 1980).

Damage begins to occur at about 10-15% g. Below 4% g, which is the lowest contour on this map, shaking effects are controlled by earthquakes of magnitude 4.0 or less in other words, minor earthquakes. An acceleration of 0.1% g or more is perceptible to people (Algermissen and Perkins, 1976). According to Figure 4b, Maryland has a very low chance of experiencing a damaging earthquake in a 50-year period. For moderate exposure times (10-100 years), the expected ground motion associated with earthquakes in this region would be of marginal interest (Algermissen et al., 1982). As a rough estimate, Maryland's falling in the 4-10% g category on the map in Figure 4b might translate into a maximum expected magnitude of 4.0-4.5. It is important to emphasize that these figures are only rough estimates. The difficulty in assigning maximum magnitudes is most acute where no faults are known, where seismicity is low, and where near-maximum earthquakes may not have occurred in historical times. This is true for most of the eastern United States (Algermissen and Perkins, 1976).

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