UNIVERSITY OF MINNESOTA

Minnesota at a Glance

Earthquakes in Minnesota

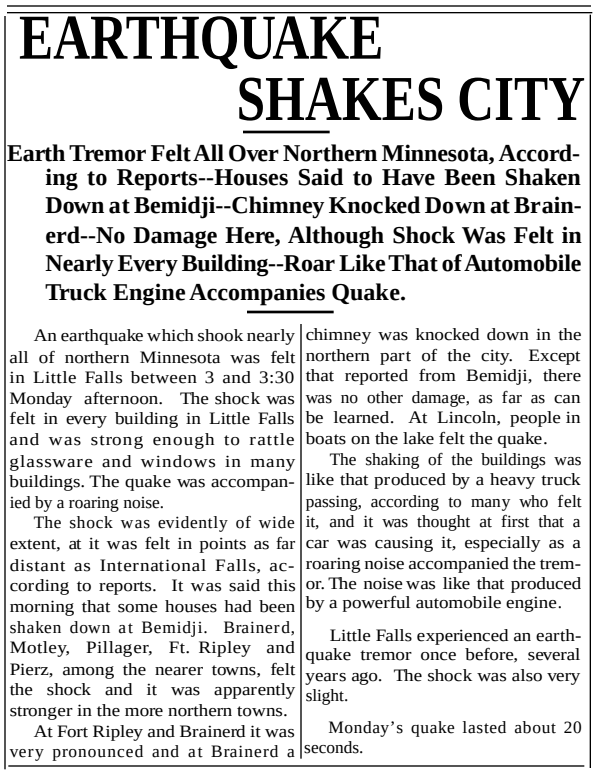
Few natural phenomena attract as much public attention as earthquakes. Seldom does a month go by that we do not hear of a destructive earthquake somewhere in the world. Events like the October 17, 1989 event near San Francisco [**Loma Prieta earthquake**] and the January 17, 1994 event near Los Angeles [**Northridge earthquake**] are grim reminders that parts of the United States are at risk from these terrible natural hazards. Even in the so-called stable interior of the United States, a strong public interest exists in earthquakes, as does some concern about the potential of destructive earthquakes in the Midwest.

What Causes an Earthquake?

Earthquakes are produced by movement of rock in the earth's interior. In volcanic regions, movement of molten rock and associated steam can result in earthquakes. Most earthquakes, however, occur when solid rock masses move past one another along fracture planes called **faults**. In large earthquakes, such as the San Francisco earthquake of 1906, displacements of tens of feet occur along many tens of miles of the fault plane. By comparison, the 1989 Loma Prieta earthquake involved maximum movement of only about 6 feet along about 25 miles of fault plane. The fault movement creates a series of waves through the earth, and we perceive these waves at the surface as the shaking of an earthquake.

Commonly the **focu**s—the center of the main rupture—is several miles below the land surface and, like the Loma Prieta and Northridge earthquakes (focal depths = 18 km—about 11 miles), may produce little or no surface evidence of the sense of movement. The surface location directly above the focus is called an **epicenter**, and earthquakes are commonly referred to by the geographic location of the epicenter. The direction and distance of fault movement, as well as focal depth and strength, are usually determined by analysis of earthquake-wave records from a network of sensitive instruments called seismographs, which are located around the world.

Most earthquakes are related to plate tectonic processes or what used to be understood as "continental drift." In the plate tectonic model, the earth's outermost shell consists of a number of rigid plates that are roughly 60 miles thick and include both the earth's crust and the uppermost mantle. These rigid plates are in a state of continual, but very slow (about an inch a year or about as fast as a fingernail grows) movement over the less solid mantle material, with new plate material being created and pushed outward by volcanic processes at mid-ocean ridges, called "spreading centers." Some earthquakes are generated by faulting and magma movement at spreading centers. Larger and more destructive earthquakes occur along faults where plates are grinding together. Such earthquakes are common where one plate is driven under the other in a "subduction zone," as is occurring in the active earthquake regions of the circum-Pacific, including Japan, Alaska, and South America[1]. Destructive earthquakes also occur where plates shear past one another horizontally on what are sometimes called "transform faults"; the San Andreas fault system is a notorious example. Although much of the differential movement between plates may be taken up along a single fault that forms the plate boundary, significant movement can occur along hundreds or even thousands of faults that flank the plate boundaries. For example, the recent Northridge earthquake near Los Angeles occurred along a previously unknown offshoot of the San Andreas fault.



EARTHQUAKE SHAKES CITY

Earth Tremor Felt All Over Northern Minnesota, According to Reports--Houses Said to Have Been Shaken Down at Bemidji--Chimney Knocked Down at Brainerd--No Damage Here, Although Shock Was Felt in Nearly Every Building--Roar Like That of Automobile Truck Engine Accompanies Quake.

An earthquake which shook nearly all of northern Minnesota was felt in Little Falls between 3 and 3:30 Monday afternoon. The shock was felt in every building in Little Falls and was strong enough to rattle glassware and windows in many buildings. The quake was accompanied by a roaring noise.

The shock was evidently of wide extent, at it was felt in points as far distant as International Falls, according to reports. It was said this morning that some houses had been shaken down at Bemidji. Brainerd, Motley, Pillager, Ft. Ripley and Pierz, among the nearer towns, felt the shock and it was apparently stronger in the more northern towns.

At Fort Ripley and Brainerd it was very pronounced and at Brainerd a chimney was knocked down in the northern part of the city. Except that reported from Bemidji, there was no other damage, as far as can be learned. At Lincoln, people in boats on the lake felt the quake.

The shaking of the buildings was like that produced by a heavy truck passing, according to many who felt it, and it was thought at first that a car was causing it, especially as a roaring noise accompanied the tremor. The noise was like that produced by a powerful automobile engine.

Little Falls experienced an earthquake tremor once before, several years ago. The shock was also very slight.

Monday's quake lasted about 20 seconds.

Figure 1. Article from the Little Falls Daily Transcript, September 4, 1917. Reports of the damage were exaggerated, but the excitement was genuine.

[1]Some Minnesotans recently had the almost unbelievable experience of feeling a subduction-related earthquake which occurred on June 9, 1994 deep below Bolivia, South America. The unusually large size (magnitude 8.2) and focal depth (630 km; 390 miles) contributed to its being weakly felt over a wide region of North America. In the history of seismology, this appears to be the greatest distance that an earthquake has ever been felt.

How Are Earthquakes Measured?

Two numbers are commonly given to describe earthquakes—intensity and magnitude. **Intensity**, also referred to as the "Mercalli scale," is a number based on people's observations (or "felt reports"). It is related to the damage caused by local ground shaking and ground failure. This scale ranges from I, which is noticed by almost nobody, up to XII, which includes virtually total destruction of all structures. Significant damage to buildings occurs at Mercalli intensities of VII or greater. Intensity decreases with distance from the epicenter, but local soil conditions—for example, the artificial fill near the shore of San Francisco Bay in the Loma Prieta earthquake—can cause higher values at distant sites.

Magnitude, commonly referred to as the "Richter scale," quantitatively describes the strength of an earthquake. It is usually based on the maximum amplitude of certain types of seismic waves recorded on a seismograph. The Richter scale was originally developed in the 1930s by seismologist Charles Richter for the analysis of earthquakes in southern California. In the following years Richter's scale was applied to earthquakes worldwide, and several new ways of computing magnitude from seismograph records were developed. For earthquakes that were not recorded on seismographs, methods have been developed to estimate magnitude from intensity data. These methods result, at least in principle, in essentially the same magnitude estimates for most earthquakes, but they can be considerably different for very large or very deep-seated earthquakes. Moment magnitude, which is sensitive to the moment (the torque or cranking force) that is associated with the actual fault movement, is one of the more consistent magnitude estimates to be used in recent years.

Regardless of how it is calculated, magnitude is expressed on a logarithmic scale, meaning that an increase in value of one digit equates to a 10-fold increase that may in turn equate to approximately 30 times more energy. The largest known earthquakes have had magnitudes around 9.0, and the famous San Francisco earthquake of 1906 had a magnitude near 8.3. In comparison, the magnitude of the recent Loma Prieta earthquake had a significantly smaller magnitude of 7.1; the 1906 earthquake was thus about 63 times more powerful. Although there have been notable exceptions, earthquakes with magnitudes less than 5.5 usually do not cause major damage or injuries.

Are Earthquakes Really Increasing?

It is commonly believed that earthquakes are becoming more frequent, but records kept by the U.S. Geological Survey's National Earthquake Information Center in Golden, Colorado, do not bear this out. Few people realize that more than 15,000 earthquakes occur worldwide every year with, on the average, 600 or so exceeding magnitude 5.5. In fact, over the last 20 years we have actually had fewer than the long-term worldwide average of 18 major (magnitude 7.0 to 7.9) earthquakes and one great (magnitude 8.0 or more) earthquake per year. The public perception that more earthquakes are happening is an artifact of more seismic stations to record earthquakes and more media coverage.

Can Earthquakes Be Predicted?

To be useful, an earthquake prediction must include information on where and how big, as well as when. We have learned much over the last 20 years, but much uncertainty remains, especially for the "when" part of a prediction. The best predictions are based on intensive long-term studies of active faults like the San Andreas in California. They rely on a variety of criteria, including geology and crustal structure along the fault, earthquake patterns along the fault and how often they occur, and the amount of stress and rate of strain associated with the fault. These predictions are given as a percentage of probability over a span of several decades. For example, a year prior to the Loma Prieta earthquake, a working group organized by the U.S. Geological Survey assigned a high risk to that part of the San Andreas fault in terms of a 50% probability of a magnitude 7.0 event within 30 years. For less intensely studied faults, prediction is much cruder and usually can go no further than extrapolating recurrence intervals from the statistical distribution of previous earthquakes. Criteria such as animal behavior, and the effects of tides, have been found to be generally unreliable in earthquake prediction.

Why Do Earthquakes Occur in the Midwest?

The Midwest of the United States is far from any plate margin, but even here, earthquakes do occasionally happen. Although the earthquake-generating mechanism in the Midwest is incompletely understood, it may be related to the westward drift of the North American plate away from its spreading center, the Mid-Atlantic ridge, toward the subduction and transform zones along the Pacific coast. This westward drift sets up a subtle but pervasive compression that is oriented roughly east-west for most of North America, and this stress can reactivate minor movement along some ancient faults. The great forces that originally formed these ancient faults have long since ceased, but the faults themselves remain as zones of weakness that, if oriented appropriately to the modern stress field, could be slightly reactivated.

In general, earthquakes in the Midwest are far less frequent and much smaller than those that occur near plate margins. However, there is one area, the New Madrid seismic zone between St. Louis, Missouri, and Memphis, Tennessee, that has the potential for generating major earthquakes. The zone has a fairly high incidence of small to moderate earthquakes, and it was associated with a tremendous series of shocks in 1811-1812[2]. Three of these may have had magnitudes greater than 8.0, and many aftershocks probably had magnitudes between 5.0 and 7.0. Such an earthquake sequence occurring today would be devastating to nearby cities, such as Memphis, and could cause severe damage throughout much of

[2]No historic accounts apparently exist for Minnesota for the 1811-1812 New Madrid earthquakes, but more recent earthquakes in the New Madrid area have occasionally been weakly felt in southern Minnesota. The most recent such event was a magnitude 5.0 earthquake near Lawrenceville, Illinois on June 10, 1987. The earthquake was associated with the Wabash Valley fault system, which may be an offshoot of the New Madrid seismic zone.

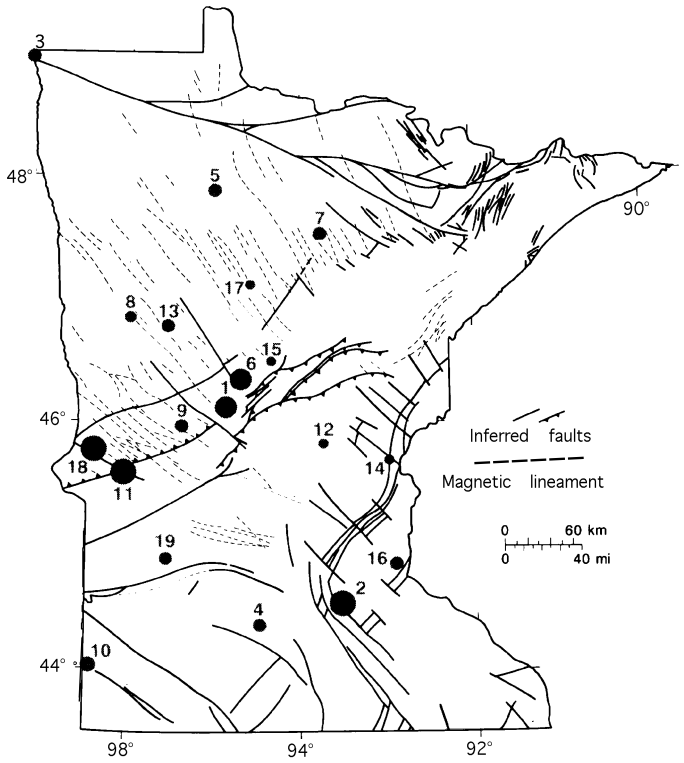


Figure 2. Epicenter locations. The numbers are keyed to the table below. Information on the 1881 New Ulm earthquake was only recently provided by the Mankato Free Press and the Brown County Historical Society.

Table 1. Historical seismicity of Minnesota
[Asterisks denote earthquakes that were recorded instrumentally.
All others and associated magnitudes based solely on intensity data from felt reports.]

Epicenter (nearest town)	Mo/day/yr	Lat.	Long.	Felt area (km2)	Maximum intensity	Magnitude
1 Long Prairie	1860-61	46.1	94.9	---	VI-VII	5.0
2 New Prague	12/16/1860	44.6	93.5	---	VI	4.7
3 St. Vincent	12/28/1880	49.0	97.2	---	II-IV	3.6
4 New Ulm	2/5-2/12/1881	44.3	94.5	v.local	VI	3.0-4.0?
5 Red Lake	2/6/1917	47.9	95.0	---	V	3.8
6 Staples	9/3/1917	46.34	94.63	48000	VI-VII	4.3
7 Bowstring	12/23/1928	47.5	93.8	---	IV	3.8
8 Detroit Lakes	1/28/1939	46.9	96.0	8000	IV	3.9-3
9 Alexandria	2/15/1950	46.1	95.2	3000	V	3.6
10 Pipestone*	9/28/1964	44.0	96.4	---	---	3.4
11 Morris*	7/9/1975	45.50	96.10	82000	VI	4.8-4.6
12 Milaca*	3/5/1979	45.85	93.75	---	---	1.0
13 Evergreen*	4/16/1979	46.78	95.55	---	---	3.1
14 Rush City*	5/14/1979	45.72	92.9	---	---	0.1
15 Nisswa*	7/26/1979	46.50	94.33	v.local	III	1.0
16 Cottage Grove	4/24/1981	44.84	92.93	v.local	III-IV	3.6
17 Walker	9/27/1982	47.10	97.6	v.local	II	2.0
18 Dumont*	6/4/1993	45.67	96.29	69500	V-VI	4.1
19 Granite Falls*	2/9/1994	44.86	95.56	11600	V	3.1

the middle Mississippi valley region; however, it probably would not cause major damage as far north as Minnesota.

Extrapolations based on the statistical distribution of historic earthquakes, together with geologic studies of prehistoric disruptions of near-surface materials, indicate that earthquakes with magnitudes of 7 or greater may not occur more frequently than every 600-700 years in the New Madrid area. However, earthquakes with magnitudes of 5.5 to 6.5 may have recurrence rates of only a few tens to a hundred years, and pose a more immediate threat. Studies by several universities and the U.S. Geological Survey have related the New Madrid seismic activity to an ancient rift (an area where the continent was split), whose unique crustal structure may concentrate modern stresses into the shallow crust.

Minnesota Earthquakes

Minnesota has one of the lowest occurrence levels of earthquakes in the United States, but a total of 19 small to moderate earthquakes have been documented since 1860. The earthquake history of the state is summarized in Table 1. Minnesota earthquakes, like those elsewhere in the Midwest, are attributed to minor reactivation of ancient faults in response to modern stresses. Although the two earliest earthquakes may have had magnitudes of 4.7 to 5.0, the 1917 Staples (see newspaper article in Figure 1) and 1975 Morris earthquakes with magnitudes of 4.3 and 4.6 to 4.8, respectively, are the largest that are well documented. Both earthquakes caused objects to fall, cracked masonry, and damaged chimneys, equating to intensities of VI to VII. In the Staples earthquake, many windows were indeed broken, but, contrary to the headline apparently no houses were shaken down. Near their epicenters these events caused considerable alarm, but the only known earthquake-related injuries were minor and in a way self-inflicted (one man fell out of a hayrack in his excitement).

Although less dramatic than the Staples or Morris events, the 1993 Dumont (Fig. 3; reported at the time as at Graceville or Wheaton) earthquake and the 1994 Granite Falls earthquake are more typical of those that occur in Minnesota. The magnitude 4.1 Dumont earthquake was felt over 69,600 square kilometers (about 27,000 square miles), and was associated with intensity V-VI near the epicenter. The shaking near the epicenter was accompanied by a loud, explosive noise that alarmed many people, but no injuries or serious damage occurred. In contrast to the Dumont event, the much weaker Granite Falls earthquake (magnitude 3.1) was felt over only about 11,600 square kilometers (about 4,400 square miles), and although intensity V may have occurred locally near the epicenter, most reported intensities were III to IV.

In summary, our current knowledge indicates that, although weak to moderate earthquakes do occur occasionally in Minnesota, a severe earthquake is very unlikely. Although we cannot assign a zero probability of a damaging earthquake occurring in the time span of a human life, the threat is very small compared to other natural hazards such as blizzards, tornadoes, and flooding. The late Harold Mooney of the

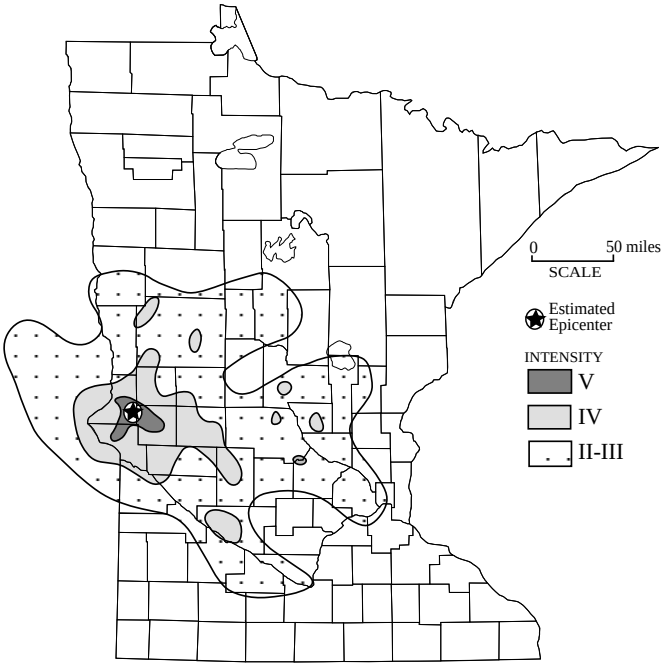


Figure 3. Mercalli intensity or isoseismal map of the Dumont, Minnesota, earthquake of June 4, 1993. The different intensity levels include the following effects:

Intensity II-III - Sensation of light vibrations or movement, felt most commonly by people at rest indoors.

Intensity IV - Dishes rattling, creaking in upper floors of house, sensation like a heavy object striking building or a heavy truck rolling by.

Intensity V - Pictures swinging on walls, small or unstable objects being upset, very minor cracking in weak masonry, such as plaster. Some places in this [intensity V] area may have had intensity VI, which includes cracking of plaster and things being shaken off walls and shelves.

University of Minnesota estimated average recurrence rates for Minnesota earthquakes as follows:

Magnitude 4	—	10 years
Magnitude 4.5	—	30 years
Magnitude 5	—	89 years
Magnitude 5.5	—	266 years

If earthquakes larger than magnitude 5.5 can occur in Minnesota, it is likely that their rate of recurrence would be many hundreds or perhaps thousands of years.

Minnesota earthquakes are of scientific interest because they provide information on crustal structure and the regional stress field. If you think that you have ever felt an earthquake in Minnesota, we would like to hear from you. The most useful reports include the place, date and time of day, where you were (in a parked car, upper floor of a building, outdoors, at rest, walking, etc.), together with what you observed.

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