Chapter 5: Earthquakes

5 Earthquake characteristics

An earthquake is a trembling of the ground that results from the sudden shifting of rock beneath the earth's crust. Earthquakes may cause landslides and rupture dams. Severe earthquakes destroy power and telephone lines, gas, sewer, or water mains, which, in turn, may set off fires and/or hinder firefighting or rescue efforts. Earthquakes also may cause buildings and bridges to collapse.

By far, earthquakes pose the largest single event natural hazard faced by Montana. They may affect large areas, cause great damage to structures, cause injury, loss of life and alter the socioeconomic functioning of the communities involved. The hazard of earthquakes varies from place to place, dependent upon the regional and local geology. Western Montana contains a zone of high seismicity, the Intermountain Seismic Belt, which also covers parts of Nevada, Arizona, Utah, Wyoming and Idaho. In Montana, this seismic belt trends north from Yellowstone National Park to Helena, then heads northwest, terminating beyond Flathead Lake. Most of the earthquake activity in the state occurs within this zone.

Earthquakes occur along faults, which are fractures or fracture zones in the earth across which there may be relative motion. If the rocks across a fault are forced to slide past one another, they do so in a *stick-slip* fashion; that is, they accumulate strain energy for centuries or millennia, then release it almost instantaneously. The energy released radiates outward from the source, or focus, as a series of waves - an earthquake. The primary hazards of earthquakes are ground breaking, as the ricks slide past on another, and ground shaking, by seismic waves. Secondary earthquake hazards result from distortion of the surface materials such as water, soil, or structures.

Ground shaking may affect areas 65 miles or more from the epicenter (the point on the ground surface above the focus). As such, it is the greatest primary earthquake hazard. Ground shaking may cause seiche, the rhythmic sloshing of water in lakes or bays. It may also trigger the failure of snow (avalanche) or earth materials (landslide). Ground shaking can also change the mechanical properties of some fine grained, saturated soils, whereupon they *liquefy* and act as a fluid (liquefaction). The dramatic reduction in bearing strength of such soils can cause buried utilities to rupture and otherwise undamaged buildings to collapse.

The earth's crust breaks along uneven lines called faults. Geologists locate these faults and determine which are active and inactive. This helps identify where the greatest earthquake potential exists. Many faults mapped by geologists, are inactive and have little earthquake potential; others are active and have a higher earthquake potential.

When the crust moves abruptly, the sudden release of stored force in the crust sends waves of energy radiating outward from the fault. Internal waves quickly form surface waves, and these surface waves cause the ground to shake. Buildings may sway, tilt, or collapse as the surface waves pass.

Ground shaking from earthquakes can collapse buildings and bridges; disrupt gas, electric, and phone service; and sometimes trigger landslides, avalanches, flash floods, fires, and huge, destructive ocean waves (tsunamis). Buildings with foundations resting on unconsolidated landfill and other unstable soil, or trailers and homes not tied to their foundations are at risk because they can be shaken off their mountings during an earthquake. When an earthquake occurs in a populated area, it may cause deaths and injuries and extensive property damage.

Aftershocks are smaller earthquakes that follow the main shock and can cause further damage to weakened buildings. Aftershocks can occur in the first hours, days, weeks, or even months after the quake. Be aware that some earthquakes are actually foreshocks, and a larger earthquake might occur.

Ground movement during an earthquake is seldom the direct cause of death or injury. Most earthquake-related injuries result from collapsing walls, flying glass, and falling objects as a result of the ground shaking, or people trying to move more than a few feet during the shaking (FEMA 2004).

5.1 Measuring an Earthquake

Earthquakes are measured in two ways. One determines the power, the other describes the physical effects. Magnitude is calculated by seismologists from the relative size of seismograph tracings. This measurement has been named the Richter scale, a numerical gauge of earthquake energy ranging from 1.0 (very weak) to 9.0 (very strong). The Richter scale is most useful to scientists who compare the power in earthquakes. Magnitude is less useful to disaster planners and citizens, because power does not describe and classify the damage an earthquake can cause. The damage we see from earthquake shaking is due to several factors like distance from the epicenter and local rock types. Intensity defines a more useful measure of earthquake shaking for any one location. It is represented by the modified Mercalli scale. On the Mercalli scale, a value of I is the least intense motion and XII is the greatest ground shaking. Unlike magnitude, intensity can vary from place to place. In addition, intensity is not measured by machines. It is evaluated and categorized from people's reactions to events and the visible damage to man-made structures. Intensity is more useful to planners and communities because it can reasonably predict the effects of violent shaking for a local area.

Table 5.1. Modified Mercalli Earthquake Intensity Scale.

Intensity	Description
I.	Only instruments detect the earthquake
II.	A few people notice the shaking
III.	Many people indoors feel the shaking. Hanging objects swing.
IV.	People outdoors may feel ground shaking. Dishes, windows, and doors rattle.
V.	Sleeping people are awakened. Doors swing, objects fall from shelves.
VI.	People have trouble walking. Damage is slight in poorly-built buildings.
VII.	People have difficulty standing. Damage is considerable in poorly-built buildings.
VIII.	Drivers have trouble steering. Poorly-built structures suffer severe damage, chimneys may fall.
IX.	Well-built buildings suffer considerable damage. Some underground pipes are broken.
X.	Mast buildings are destroyed. Dams are seriously damaged. Large landslides occur.
XI.	Structures collapse. Underground utilities are destroyed.
XII.	Almost everything is destroyed. Objects are thrown into the air.

(IGS 2004)

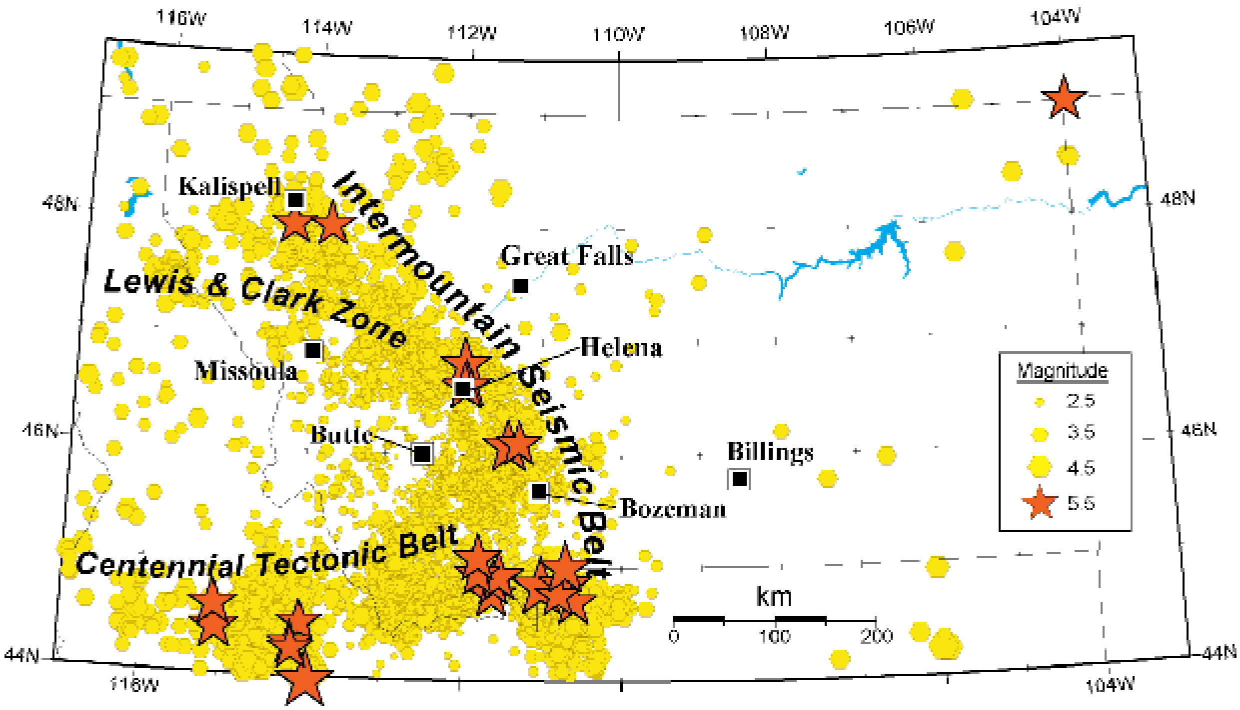
5.2 Earthquake Profile in Montana

Montana is one of the most seismically active States in the Union. Since 1925, the State has experienced five shocks that reached intensity VIII or greater (Modified Mercalli Scale). During the same interval, hundreds of less severe tremors were felt within the State.

A belt of seismicity known as the Intermountain Seismic Belt extends through western Montana, from the Flathead Lake region in the northwest corner of the state to the Yellowstone National

Park region where the borders of Montana, Idaho, and Wyoming meet. The Intermountain Seismic Belt continues southward through Yellowstone Park, along the Idaho-Wyoming border, through Utah, and into southern Nevada. In western Montana, the Intermountain Seismic Belt is up to 100 km wide. A branch of the Intermountain Seismic Belt extends west from the northwest corner of Yellowstone Park, through southwestern Montana, into central Idaho. This so called Centennial Tectonic Belt and includes at least eight major active faults and has been the site of the two largest historic earthquakes in the northern Rocky Mountains, the August 18, 1959 Hebgen Lake, Montana, earthquake (M 7.5), and the October 28, 1983 Borah Peak, Idaho, earthquake (M 7.3). Although it has been over four decades since the last destructive earthquake in Montana, small earthquakes are common in the region, occurring at an average rate of 7-10 earthquakes per day.

Figure 5.1 Intermountain Seismic Belt in Montana.

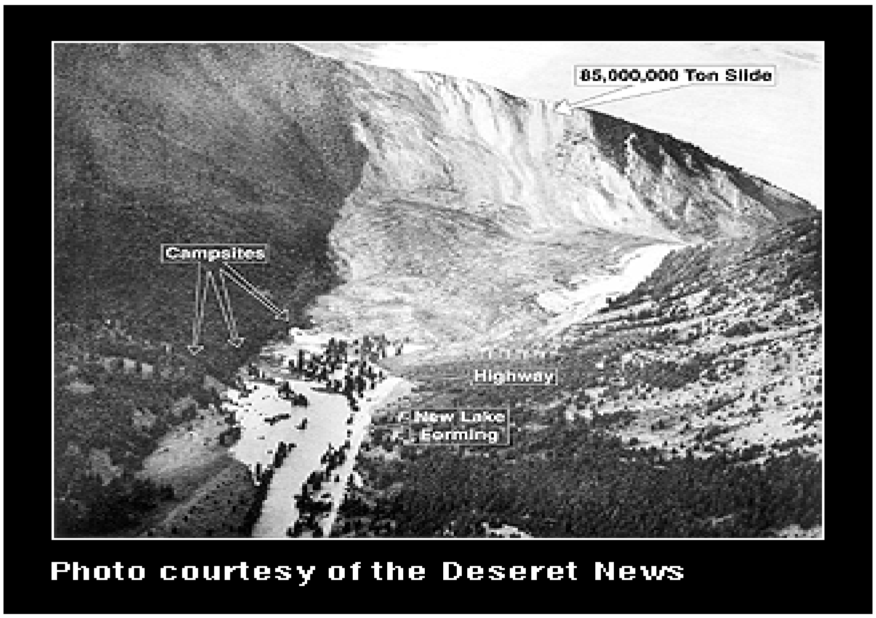


Although earthquakes are common in Montana, the early history of felt shocks is incomplete. Only four felt earthquakes that occurred before 1900 are on record. The first was a shock on May 22, 1869, that reached intensity VI at Helena. In 1872, Helena was shaken again, this time by two earthquakes, one on December 10 and the other on December 11, both intensity VI. The fourth pre-1900 earthquake was an intensity VI shock that struck Dillon November 4, 1897.

The largest earthquake in Montana's history was the magnitude 7.1 earthquake of August 17, 1959. At 11:37 p.m., Mountain Standard Time, the earth beneath Hebgen Lake suddenly warped and rotated, generating a seiche that continued for about 11 1/2 hours. The first few waves were over 1 meter in height, large enough to flow over Hebgen Dam, a concrete core earthfill structure that was completed in 1914. Although the dam's concrete corewall cracked in 16 places, only a minor amount of seepage occurred. The surface of the lake, which contained 324,000 acre-feet at the time of the earthquake, dropped more than 3 meters because of the violent geologic changes.

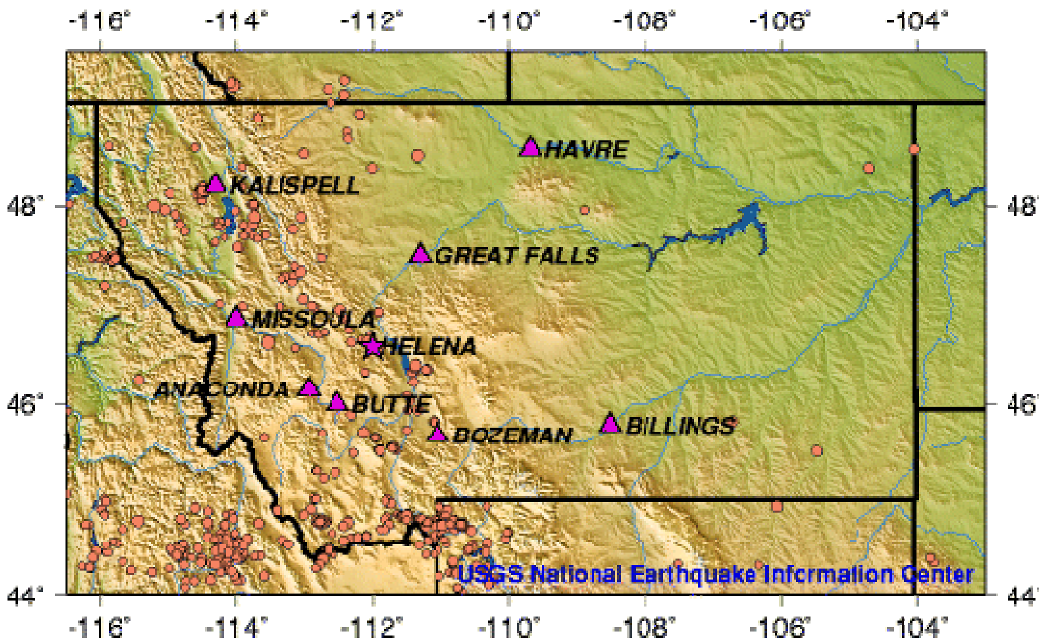
The main tremor triggered a major landslide in the Madison River Canyon, about 9 kilometers downstream from Hebgen Dam. An estimated 80 million tons of rock jarred loose by the earthquake slid down the south wall of the canyon. The slide's volume was estimated at 37 to 43 million cubic yards. Nearly 2 kilometers of the river and highway (Montana 287) were buried to depths as great as 120 meters. At least 26 people in the Rock Creek Campground were buried by the slide. Two other campers were killed by a rolling boulder at Cliff Lake, west of Madison Valley. The slide formed a natural dam in Madison Canyon which blocked the flow of the Madison River and created a new lake which within a few weeks was about 60 meters deep, and extended almost to Hebgen Dam. It has been appropriately named "Earthquake Lake."

Figure 5.2 Landslide caused by Hebgen Lake Earthquake in 1959.



The Forest Service of the U.S. Department of Agriculture later established the Madison River Canyon earthquake area to preserve the earthquake features and provide for public use and safety. A visitor center which includes a visible-recording seismograph is maintained by the Forest Service. Also, there is a memorial marker to those whose lives were lost during the earthquake. Although the scene of large-scale destruction and tragedy, the locality is of great scientific and general interest because it provides a dramatic example of mountain-building and earth-shaping processes.

Figure 5.3. Seismicity of Montana from 1990 - 2001.



5.2.1 Teton County Earthquake Profile

Geological and seismological studies show that earthquakes are likely to happen in any of several active zones in Montana and adjacent states.

The 1991 Uniform Building Code (UBC), a nationwide industry standard, sets construction standards for different seismic zones in the nation. UBC seismic zone rankings for Montana are among the highest in the nation. When buildings are built to these standards they have a better chance to withstand earthquakes. In 2002, the International Building Code (IBC) adopted the 1991 UBC earthquake standards. Teton County has no building codes; however, individual communities have adopted UBC standards.

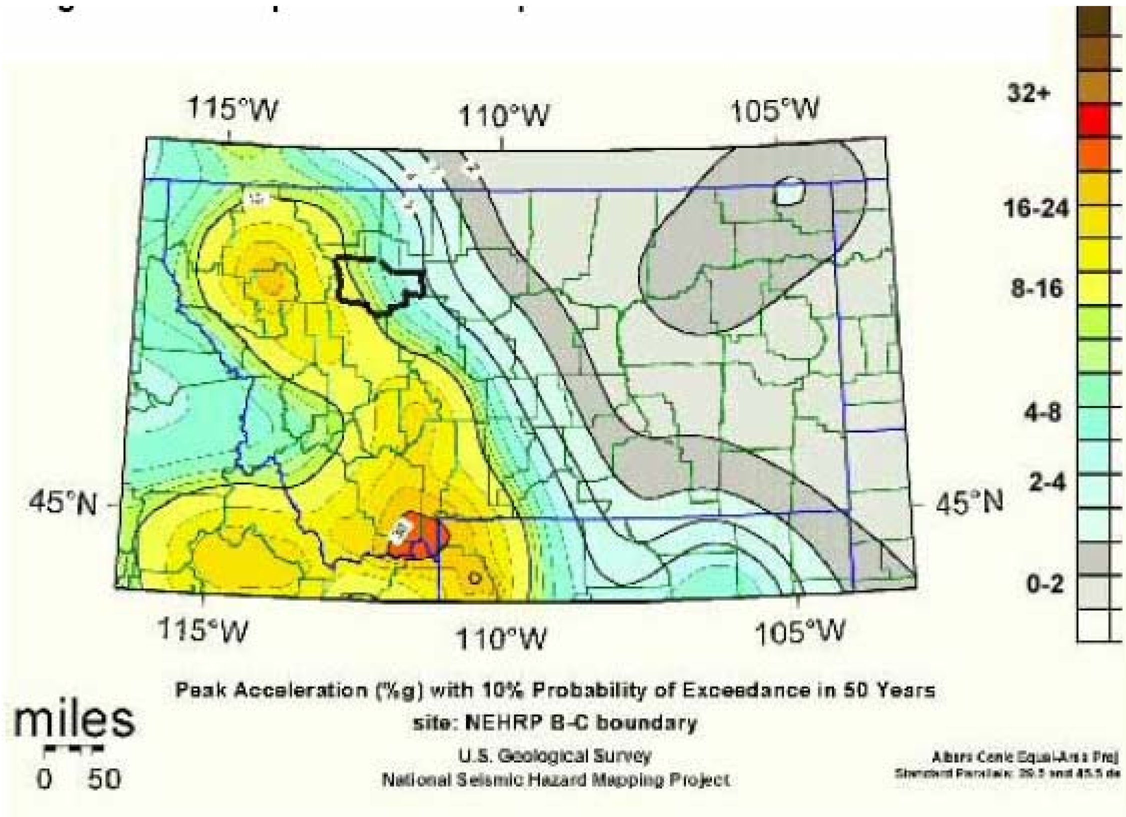
Studies of ground shaking in Montana during previous earthquakes have led to better interpretations of the seismic threat to buildings. In areas of severe seismic shaking hazard, older buildings are especially vulnerable to damage. Older buildings are at risk even if their foundations are on solid bedrock. Areas shown on the map with high seismic shaking hazard can experience earthquakes with intensity VII where weaker soils exist. Most populated areas in Montana are located on or near alluvial deposits which provide poorer building site conditions during earthquakes. Older buildings may suffer damage even in areas of moderate ground shaking hazards.

A belt of seismicity known as the Intermountain Seismic Belt extends through western Montana, from the Flathead Lake region in the northwest corner of the state to the Yellowstone National Park region. In western Montana, the Intermountain Seismic Belt is up to 100 km wide. The western part of Teton County is included in this area. Engineers use national maps of the earthquake shaking hazard in the United States to create the seismic-risk maps and seismic design provisions contained in building codes.

Local government agencies use building codes, such as the Uniform Building Code, to help establish the construction requirements necessary to preserve public health and safety in earthquakes.

The 1996 U.S. Geological Survey shaking-hazard maps for the United States are based on current information about the rate at which earthquakes occur in different areas and how far strong shaking extends from quake sources. Colors on the particular map show the levels of horizontal shaking that have a one in ten chance of being exceeded in a 50 year period. Figure 5.2 indicates the severity of earthquakes is likely to be higher in western Teton County. The County is generally rated in the low to mid range for earthquake hazards.

Figure 5.4. Earthquake Hazard Map for Teton County and the Rest of Montana.



5.2.2 Teton County Geology

The surface of Teton County is the result of geological activity that has continued for over four billion years. The oldest rocks in the County are more than 600 million years old and consist primarily of Precambrian Belt sedimentary rocks. Seas continuously flooded most of Montana during the Paleozoic Era that lasted from 600 to 225 million years ago, and also during the Mesozoic Era which lasted from 225 million years ago. This resulted in many more layers of sediment being deposited on top of the Precambrian sedimentary rocks.

The Rocky Mountains began forming approximately 135 million years ago. The region began breaking up into uplifted fault-blocks containing many combination rocks from previous eras. Teton County occupies a transitional zone between the Rocky Mountains and the Northern Great Plains. The mountains were formed after the Mesozoic era by a fault known as the "Northern Overthrust Belt". They rise 2,000 to 4,000 feet above the gravel capped plateaus and are eroded into sharp barren peaks and serrated ridges. The mountains comprise a strip along the western border of the County approximately 10 to 12 miles wide and consist primarily of rock or shallow and poorly developed soils along the steeper slopes, with some soils along the streams and level areas that can support grass and other vegetation.

The intense geological activity continued on through the Tertiary Period until about 3 million years ago. During this time the climate was relatively dry and the valleys were filled with large amounts of sediment because of insufficient water to carry it out onto the plains. Since that time, a series of ice ages and increased rainfall during the inter-glacial periods resulted in sediment being spread across what is now the high plains of northcentral Montana.

The eastern half of the County is characterized by these plains and consists primarily of Cretaceous sedimentary rock called Colorado Shale. This material was deposited 60 million years ago just prior to the draining of the last sea from Montana. As mentioned above, thick layers of gravel eroded from the mountains subsequently buried the Colorado shale. Since that time the landscape has been modified by continental glaciation and the continuing action of streams and rivers.

Currently geological activity includes the potential for the mass movement of earth and rock. Mass movement is the downslope movement of materials in response to gravity and can include rock fall, soil creep, earth flow, slumping, bedding plan failure, and debris slide or flow. Slumping or soil creep, the continuous slow downward movement of soil, is the most likely occurrence of mass movement in the County. Susceptible areas are along the transitional zone between benches and low lands and along streambanks where erosion on the outside curves of the creeks and rivers can gradually undercut the bank until it collapses. This is especially critical along Muddy Creek and portions of the Teton River. (Schiappa & Link 2002)

5.3 Seismic Shaking Hazards

Geological and seismological studies show that earthquakes are likely to happen in any of several active zones in Montana and adjacent states.

The 1991 Uniform Building Code (UBC), a nationwide industry standard, sets construction standards for different seismic zones in the nation. UBC seismic zone rankings for Montana are among the highest in the nation. When buildings are built to these standards they have a better chance to withstand earthquakes.

The U.S. Geological Survey has gathered data and produced maps of the nation, depicting earthquake shaking hazards. This information is essential for creating and updating seismic design provisions of building codes in the United States. The USGS Shaking Hazard maps for the United States are based on current information about the rate at which earthquakes occur in different areas and on how far strong shaking extends from quake sources. Colors on the maps show the levels of horizontal shaking that have a 1 in 10 chance of being exceeded in a 50-year period. Shaking is expressed as a percentage of “g” (g is the acceleration of a falling object due to gravity). This map is based on seismic activity and fault-slip rates and takes into account the frequency of occurrence of earthquakes of various magnitudes. Locally, this hazard may be greater than that shown, because site geology may amplify ground motions.

Studies of ground shaking in Montana during previous earthquakes has led to better interpretations of the seismic threat to buildings. In areas of severe seismic shaking hazard, older buildings are especially vulnerable to damage. Older buildings are at risk even if their foundations are on solid bedrock. Areas shown on the map with high seismic shaking hazard can experience earthquakes with high intensity where weaker soils exist. Most populated areas in Montana are located on or near alluvial deposits that provide poorer building site conditions during earthquakes. Older buildings may suffer damage even in areas of moderate ground shaking hazards (IGS 2004).

5.4 Fault Line Geology

We live on the thin crust of a layered Earth. The crust or surface of our planet is broken into large, irregularly shaped pieces called plates. The plates tend to pull apart or push together slowly, but with great force. Stresses build along edges of the plates until part of the crust suddenly gives way in a violent movement. This shaking of the crust is called an earthquake.

The crust breaks along uneven lines called faults. Geologists locate these faults and determine which are active and inactive. This helps identify where the greatest earthquake potential exists. Most faults mapped by geologists, however, are inactive and have no earthquake potential.

When the crust moves abruptly, the sudden release of stored force in the crust sends waves of energy radiating outward from the fault. Internal waves quickly form surface waves, and these surface waves cause the ground to shake. Buildings may sway, tilt, or collapse as the surface waves pass.

The constant interaction of crustal plates in western North America still creates severe earthquakes. Montana is situated in the Rocky Mountain geomorphic province. Most of Montana has undergone the effects of tremendous crustal stretching. Western Montana's high mountain ranges are striking evidence of these powerful earth movements over millions of years. The Borah Peak earthquake of 1983 was another event in the stretching that forms long deep valleys and tall, linear mountain ranges. Earthquakes from the crustal movements in the adjoining states of Idaho and Wyoming also cause severe ground shaking in Montana.

5.5 County Wide Potential Mitigation Activities

Many researchers have unsuccessfully tried to forecast earthquake occurrence. Even guessing that an event will occur within six months cannot be done with any degree of accuracy. Predicting the area where an earthquake will happen is an easier, more reliable task. Since earthquakes are usually associated with faulting, any region containing active faults is potentially dangerous. Unfortunately and inexplicable, earthquakes also strike within zones that do not contain faults, and, because the community is unaware of the potential hazard, extensive damage often occurs.

Instead of predicting when an earthquake will strike, an estimate of their likelihood of recurring within a given time frame is given. Some thoughts:

- In all of western Montana an event of magnitude greater than 5.0 can be expected every 1.5 years, a magnitude of 6.0 or greater should occur ever ten years, and a magnitude 7.0 or greater should occur every 77 years.
- The highest recurrence rate of large earthquakes in Montana occurs in the Hebgen Lake-Yellowstone Region, followed by Helena and Three Forks.
- In the Three Forks and Helena-Ovando regions the return time for a magnitude 6+ event is about 70 years, and that of a magnitude 7+ si 360 to 470 years.
- The number of large earthquakes in the Flathead Lake region is abnormally small compared to the number of small events. The recent discovery of an active fault system in that area identifies it as a potential location for a large magnitude (6.0 to 7.5) seismic event.

Although earthquake prediction is difficult at best, there are warning signs which can be interpreted to indicate both the place and the time of an impending event. Earthquakes most commonly occur in the same place as prior earthquakes, that is, along active faults. The term *active* is often interpreted by non-scientists as meaning *active during historical time (the last 100 years).* Active faults are most commonly indicated by micro-seismicity (earthquakes so small they can only be detected by instruments) and by the presence of scarps. Scarps are steep, linear slopes, up to 65 feet high, showing offset of the ground surface. They are commonly found along the base of mountain ranges.

As the stress builds, an impending earthquake may be signaled by precursors: Phenomena which occur in a characteristic way prior to an earthquake. Precursors include an increase in micro-seismicity, which has been credited with causing unusual animal behavior. Dogs have howled and cattle have left an area hours before an earthquake. Instruments, however, may be more reliable. The velocities of seismic waves through stressed rocks may decrease immediately prior to an event. Well water quality may change, as well as spring discharge. The ground surface may also be slightly deformed. *Earthquake lightning* has been observed just prior to an earthquake, and is believed to be due to the development of an electrical charge on stressed quartz grains.

Teton County comprehensive plan and strategy for preparing for earthquakes should include:

- Assessment of seismic hazards to quantify and understand the threat;
- Adoption and enforcement of seismic building code provisions;
- Implementation of land-use and development policy to reduce exposure to hazards;
- Implementation of retrofit, redevelopment, and abatement programs to strengthen existing structures;
- Support of ongoing public-education efforts to raise awareness and build constituent support; and
- Development and continuation of collaborative public/private partnerships to build a prepared and resilient community.

There are several earthquake-related mitigation activities outlined in the Montana State Hazard Mitigation Plan that pertain to Teton County including:

- Change purchasing specifications for non-structural items to include seismic safety (SHMP-HM13)
- Improve school safety by establishing a special fund for grants to schools to reduce non-structural seismic hazards (SHMP-HM14)

The media can raise awareness about earthquakes by providing important information to the community. Here are some suggestions:

- Publish a special section in your local newspaper with emergency information on earthquakes. Localize the information by printing the phone numbers of local emergency services offices, the American Red Cross, and hospitals.
- Conduct a week-long series on locating hazards in the home.
- Work with local emergency services and American Red Cross officials to prepare special reports for people with mobility impairments on what to do during an earthquake.
- Provide tips on conducting earthquake drills in the home, schools and public buildings.

- Interview representatives of the gas, electric, and water companies about shutting off utilities.
- Circulate “Earthquake Safety for People Who Work in Old Masonry Buildings” published by the Montana Bureau of Disaster Services to promote safety for communities with old unreinforced masonry buildings still in public or private use (FEMA 2004).