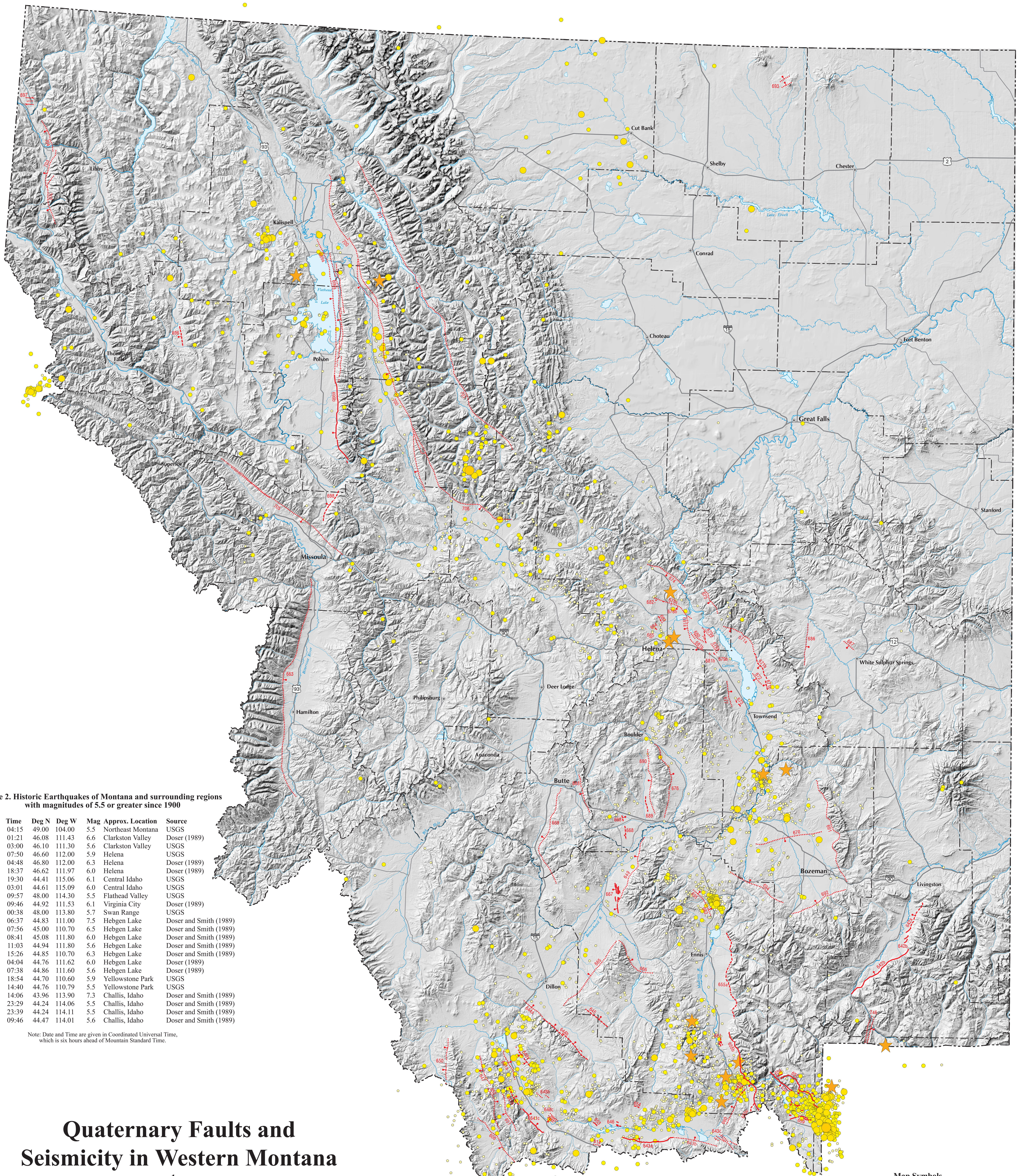


Table 2. Historic Earthquakes of Montana and surrounding regions with magnitudes of 5.5 or greater since 1900

Date	Time	Deg N	Deg W	Mag	Approx. Location	Source
05/16/09	04:15	49.00	104.00	5.5	Northeast Montana	USGS
06/28/25	01:21	46.08	111.43	6.6	Clarkston Valley	Doser (1989)
02/16/29	03:00	46.10	111.30	5.6	Clarkston Valley	USGS
10/12/35	07:50	46.60	112.00	5.9	Helena	USGS
10/19/35	04:48	46.80	112.00	6.3	Helena	Doser (1989)
10/31/35	18:37	46.62	111.97	6.0	Helena	Doser (1989)
07/12/44	19:30	44.41	115.06	6.1	Central Idaho	USGS
02/14/45	03:01	44.61	115.09	6.0	Central Idaho	USGS
09/23/45	09:57	48.00	114.30	5.5	Flathead Valley	USGS
11/23/47	09:46	44.92	111.53	6.1	Virginia City	Doser (1989)
04/01/52	00:38	48.00	113.80	5.7	Swan Range	USGS
08/18/59	06:37	44.83	111.00	7.5	Hebgen Lake	Doser and Smith (1989)
08/18/59	07:56	45.00	110.70	6.5	Hebgen Lake	Doser and Smith (1989)
08/18/59	08:41	45.08	111.80	6.0	Hebgen Lake	Doser and Smith (1989)
08/18/59	11:03	44.94	111.80	5.6	Hebgen Lake	Doser and Smith (1989)
08/18/59	15:26	44.85	110.70	6.3	Hebgen Lake	Doser and Smith (1989)
08/19/59	04:04	44.76	111.62	6.0	Hebgen Lake	Doser (1989)
10/21/64	07:38	44.86	111.60	5.6	Hebgen Lake	Doser (1989)
06/30/75	18:54	44.70	110.60	5.9	Yellowstone Park	USGS
12/08/76	14:40	44.76	110.79	5.5	Yellowstone Park	USGS
10/28/83	14:06	43.96	113.90	7.3	Challis, Idaho	Doser and Smith (1989)
10/29/83	23:29	44.24	114.06	5.5	Challis, Idaho	Doser and Smith (1989)
10/29/83	23:39	44.24	114.11	5.5	Challis, Idaho	Doser and Smith (1989)
08/22/84	09:46	44.47	114.01	5.6	Challis, Idaho	Doser and Smith (1989)

Note: Date and Time are given in Coordinated Universal Time, which is six hours ahead of Mountain Standard Time.

Quaternary Faults and Seismicity in Western Montana

by
Michael C. Stickney, Kathleen M. Haller, and Michael N. Machette
2000

Map Symbols

- Faults with offset during historic or Holocene (last 15,000 years)
- Faults with offset during late Quaternary (last 130,000 years)
- Faults with offset during Quaternary (last 1.6 million years)
- Selected earthquake epicenters located by MBMG since 1982 (scaled to magnitude)
- Epicenters of post-1900 earthquakes having magnitudes of 5.5 or larger

Table 1. Names and parameters of Quaternary faults in western Montana.

Fault no.	Fault name	Most recent earthquake	Slip rate (mm/yr)	End-to-end length (km)	Strike (average)	Fault type, down direction
606	Deadman fault*	<1.6 Ma	<0.2 (?)	70.8	306°	Normal, SW
614	Unnamed fault near Monida*	<1.6 Ma	<0.2 (?)	13.7	302°	Normal, SW
641	Red Rock fault	--------	------	40.7	326°	Normal, NE
641a	Unnamed (north) section	<1.6 Ma	<0.2 (?)	14.4	337°	Normal, NE
641b	Timber Butte section	<130 ka	<0.2 (?)	9.3	327°	Normal, NE
641c	Sheep Creeks section	<15 ka	0.2-1.0 (?)	14.8	316°	Normal, NE
642	Emigrant fault	--------	------	52.0	41°	Normal, NW
642a	Unnamed (north) section	<130 ka	0.2-1.0 (?)	12.9	21°	Normal, W
642b	Unnamed (south) section	<15 ka	0.2-1.0	40.0	48°	Normal, NW
643	Centennial fault*	--------	------	62.5	282°	Normal, N
643a	Western Centennial Valley section	<15 ka	0.2-1.0 (?)	23.2	87°	Normal, N
643b	Red Rock Lakes section	<1.6 Ma	1.0-5.0	20.0	280°	Normal, N
643c	Red Rock Pass section	<1.6 Ma	<0.2 (?)	9.8	308°	Normal, NE & SW
644	Blacktail fault	--------	------	39.7	311°	Normal, NE
644a	Unnamed (northwest) section	<1.6 Ma	<0.2 (?)	11.8	310°	Normal, NE
644b	Cottonwood section	<130 ka	<0.2 (?)	27.6	320°	Normal, NE
645	Sweetwater fault	<130 ka	<0.2	13.2	307°	Normal, NE
646	Lima Reservoir fault	<130 ka	<0.2 (?)	2.9	289°	Normal, N & S
647	Kissick fault	<1.6 Ma	<0.2 (?)	14.2	337°	Normal, SW
648	Red Rock Hills fault	--------	------	38.2	314°	Normal, SW
648a	Monument Hill section	<130 ka	<0.2 (?)	10.7	324°	Normal, SW
648b	Unnamed (central) section	<1.6 Ma	<0.2 (?)	6.7	307°	Normal, SW
648c	Unnamed (south) section	<1.6 Ma	<0.2 (?)	5.4	311°	Normal, SW
649	Tobacco Root fault	<1.6 Ma	<0.2 (?)	32.4	20°	Normal, W
650	South Horse Prairie Basin fault*	<1.6 Ma	<0.2 (?)	24.8	2°	Normal, W
651	East Muddy Creek fault	<1.6 Ma	<0.2 (?)	18.2	337°	Normal, SW
652	West Muddy Creek fault	<1.6 Ma	<0.2 (?)	19.7	341°	Normal, E
653	Unnamed fault near Trail Creek	<15 ka	<0.2 (?)	2.3	308°	Normal, SW
654	Unnamed fault near Middle Creek	<130 ka	<0.2 (?)	2.4	284°	Normal, S
655	Madison fault	--------	------	98.7	341°	Normal, W
655a	Unnamed (north) section	<130 ka	<0.2 (?)	38.8	352°	Normal, W
655b	Madison Canyon section*	<15 ka	0.2-1.0	37.9	338°	Normal, W
655c	Unnamed (south) section*	<130 ka	------	22.3*	327°	Normal, SW
656	Hebgen fault	1959	1.0-5.0	12.9	307°	Normal, SW
657	Red Canyon fault	1959	1.0-5.0	18.1	300°	Normal, SW
658	West Fork fault	1959	<0.2 (?)	2.8	64°	Normal, SE
659	Unnamed fault in Hebgen Lake basin	1959	0.2-1.0 (?)	12.5	284°	Normal, NE, SW, & NW
660	Unnamed fault near Mile Creek	<130 ka	<0.2 (?)	3.9	39°	Normal, NW
661	Wolf Creek graben	<130 ka	<0.2 (?)	4.0	341°	Normal, W & E
662	Bradley Creek fault	<1.6 Ma	<0.2 (?)	9.6	329°	Normal, NE
663	Bitterroot fault	<1.6 Ma	<0.2 (?)	98.4	1°	Normal, E
664	Unnamed fault near Cliff Lake	<130 ka	<0.2 (?)	2.7	304°	Normal, SW
665	Ruby Range western border fault	<1.6 Ma	<0.2 (?)	38.0	37°	Normal, NW
666	Ruby Range northern border fault	<1.6 Ma	<0.2 (?)	21.8	310°	Normal, NE
667	Georgia Gulch fault	<15 ka	<0.2 (?)	14.2	348°	Normal, W
668	Vendome fault	<130 ka	<0.2 (?)	11.4	347°	Normal, E & W
669	Rocker fault	<1.6 Ma	<0.2 (?)	43.4	0°	Normal, W
670	Central Park fault	<1.6 Ma	<0.2 (?)	30.3	77°	Normal, S
671	Canyon Ferry fault	--------	------	35.0	321°	Normal, SW
671a	Unnamed (north) section	<1.6 Ma	<0.2 (?)	18.2	308°	Normal, SW
671b	Unnamed (south) section	<130 ka	<0.2 (?)	17.8	335°	Normal, SW
672	Lower Duck Creek fault	<1.6 Ma	<0.2 (?)	6.8	317°	Normal, SW
673	Indian Creek faults	<130 ka	<0.2 (?)	3.9	322°	Normal, NE & SW
674	Hilger fault	<750 ka	<0.2 (?)	20.5	299°	Normal, SW
675	Soup Creek fault	<1.6 Ma	<0.2 (?)	12.9	329°	Normal, SW
676	Boulder River valley western border fault	<750 ka	<0.2 (?)	33.5	350°	Normal, E
677	Beaver Creek fault	<750 ka	<0.2 (?)	12.3	346°	Normal, E
678	Helena Valley fault	--------	------	19.9	294°	Normal, SW
678a	Unnamed (main range-bounding) section	<1.6 Ma	<0.2 (?)	19.9	295°	Normal, SW
678b	Unnamed (piedmont) section	<750 ka	<0.2 (?)	4.7	284°	Normal, S
679	Spokane Hills fault	--------	------	13.8	321°	Normal, SW
679a	Unnamed (range-bounding) section	<1.6 Ma	<0.2 (?)	13.8	320°	Normal, SW
679b	Unnamed (piedmont) section	<130 ka	0.2-1.0 (?)	1.3	335°	Normal, SW
680	Regulating Reservoir faults	<1.6 Ma	<0.2 (?)	8.2	315°	Normal, SW
681	Spokane Bench fault	--------	------	20.4	330°	Normal, SW
681a	Unnamed (north) section	<750 ka	<0.2 (?)	10.2	350°	Normal, W
681b	Unnamed (south) section	<1.6 Ma	<0.2 (?)	11.8	309°	Normal, SW
682	Diamond Springs fault	<130 ka	<0.2 (?)	0.7	6°	Normal, E
683	Iron Gulch fault	<130 ka	<0.2 (?)	3.9	327°	Normal, NE
684	Franklin Mine Road fault	<130 ka	<0.2 (?)	1.1	53°	Normal, SE
685	Fort Harrison fault	<1.6 Ma	<0.2 (?)	1.6	90°	Normal, N
686	Camas Creek fault	<1.6 Ma	<0.2 (?)	19.2	2°	Normal, E
687	Smith Valley fault	<1.6 Ma	<0.2 (?)	6.5	307°	Normal, SW
688	Continental fault	<1.6 Ma	<0.2 (?)	18.2	342°	Normal, W
689	Whitetail Creek fault	<130 ka	<0.2 (?)	7.3	350°	Normal, W
690	Bull Mountain western border fault	<1.6 Ma	<0.2 (?)	29.6	351°	Normal, W
691	Bridger fault	<1.6 Ma	<0.2 (?)	48.3	341°	Normal, W
692	Gallatin Range fault	<1.6 Ma	<0.2 (?)	26.9	63°	Normal, NW
693	Unnamed faults near Sweet Grass Hills	<1.6 Ma	<0.2 (?)	5.7	59°	Normal, NW
694	Elk Creek fault	<1.6 Ma	<0.2 (?)	28.1	298°	Normal, NE
695	Carmichael fault	<1.6 Ma	<0.2 (?)	4.9	311°	Normal, NE
696	Thompson Valley fault	<130 ka	<0.2 (?)	9.6	348°	Normal, W
697	Pine Creek Valley fault	<1.6 Ma	<0.2 (?)	3.3	85°	Right lateral
698	Jocko fault	<130 ka	<0.2 (?)	15.8	23°	Normal, NW
699	Mission fault	--------	------	101.9	352°	Normal, W
699a	Flathead Lake section	<1.6 Ma	<0.2 (?)	65.4	353°	Normal, W
699b	Mission Valley section	<15 ka	0.2-1.0 (?)	39.9	348°	Normal, W
700	Swan fault	<1.6 Ma	<0.2 (?)	155.9	337°	Normal, SW
701	South Fork Flathead fault	<1.6 Ma	<0.2 (?)	147.7	329°	Normal, SW
702	Bull Lake fault	<1.6 Ma	<0.2 (?)	21.9	356°	Normal, W
703	Savage Lake fault	<1.6 Ma	<0.2 (?)	17.7	10°	Normal, W
704	O'Brien Creek fault	<1.6 Ma	<0.2 (?)	14.9	337°	Normal, SW
705	Ninemile fault	<1.6 Ma	<0.2 (?)	70.1	305°	Normal, SW
706	Unnamed fault near Ovando	<1.6 Ma	<0.2 (?)	28.9	288°	Normal, S
746	East Gallatin Reese Creek fault system**	<1.6 Ma	<0.2 (?)	38.8	5°	Normal, E

*fault extends into Idaho **fault extends into Wyoming

Explanation of Parameters Listed in Table 1

Fault number—An arbitrary three-digit number used to identify faults. Shorter sections of long faults that may have different earthquake histories from other sections of the fault are denoted with an appended lowercase letter.

Fault name—The name of a fault as used in published references.

Most Recent Earthquake—Time since the most recent surface faulting earthquake in thousands of years (ka) or millions of years (Ma). These times are typically estimated from geomorphic and paleoseismic data. Only the 1959 Hebgen Lake earthquake has caused historic surface rupture in Montana, which is denoted by the year of occurrence.

Slip rate—The slip rate of a fault is determined by measuring the fault offset of a feature (geologic deposit or geomorphic surface) and dividing that offset by the appropriate time interval(s) between surface faulting earthquakes. In most cases, neither value is well constrained, and thus, the slip rates are characterized as numerical ranges.

Length—The horizontal distance along which a fault may be traced or inferred to extend. For those faults composed of multiple sections, the total fault length may not equal the sum of the fault sections because the overall fault length is taken as the straight-line distance between opposing end points and does not account for curvature, overlap, or gaps between sections.

Strike—The average strike direction of a fault or fault section as measured in degrees clockwise from north.

Fault type, down direction—Faults may slip in one of three general ways (figure 2). A normal fault dips steeply downward into the Earth's crust, and one block moves down (briefly, during earthquakes) relative to the adjacent block. Normal faulting over extended geologic periods typically results in steep-fronted mountain ranges (uplifted fault blocks) flanking deeply filled alluvial valleys. Most young faults in Montana are normal faults and form in response to extension or stretching of the Earth's crust driven by underlying tectonic forces.

The second fault type, strike slip, results when one side of a steeply dipping fault moves horizontally relative to the other side. Strike-slip faults exhibit either a right-handed or left-handed sense of movement. A fault that offsets a reference marker (a road or fence line for example) to the right when viewed across the fault is known as a right-lateral strike-slip (or dextral) fault. Conversely, a fault which offsets a marker to the left is known as a left-lateral strike-slip (or sinistral) fault. Strike-slip faults form in both extensional and compressional tectonic environments but are most prevalent along transform plate boundaries. The best known example is California's San Andreas fault, a right-lateral strike-slip fault. There is only one recognized young strike-slip fault in Montana (Pine Creek Valley fault, number 697), located northwest of Libby in extreme northwestern Montana.

The third fault type is reverse or thrust faulting. In reverse faulting, one side of a fault is forced up and over an adjacent block along a steeply dipping fault (>45°). Thrust faults have a similar sense of movement, but the fault planes dip less steeply (<45°). Reverse and thrust faults form in response to horizontal compressive forces. No young thrust or reverse faults are known in Montana; however, many are known from the previous tectonic regime that ended some 50 million years ago.

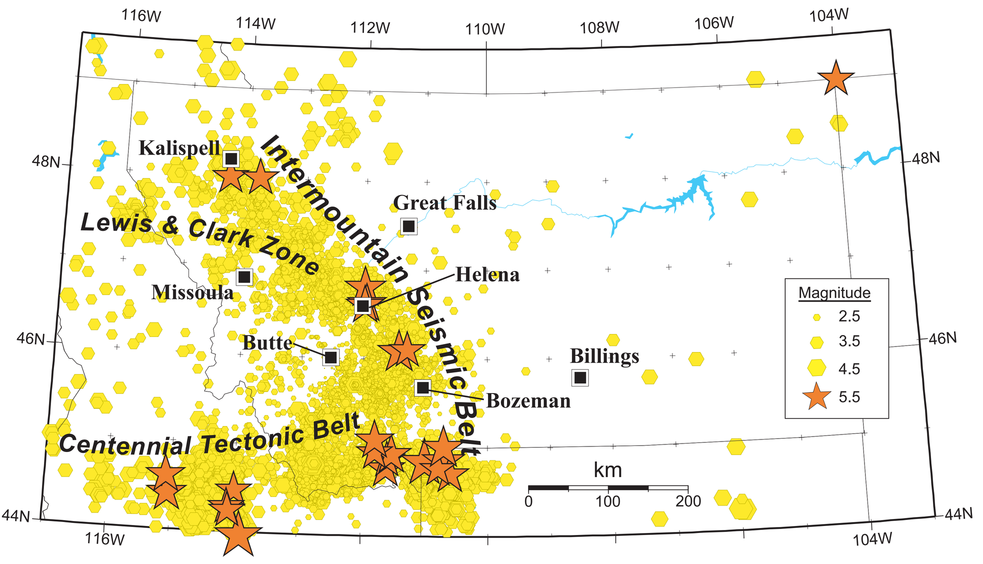


Figure 1. Montana Region Seismicity 1982–1999.

Yellow hexagons mark the epicenters of over 14,000 earthquakes located by the Montana Bureau of Mines and Geology since 1982. Larger hexagons indicate earthquakes with larger magnitudes. Orange stars mark earthquakes since 1900 with magnitudes of 5.5 or greater. The concentrated zone of seismicity in western Montana defines the northern Intermountain Seismic Belt. A west-trending branch, also known as the Centennial Tectonic Belt, extends from southwest Montana into central Idaho. At latitude 46.5° north, the Intermountain Seismic Belt bends northwestward. This westward deflection of epicenters coincides with the Lewis and Clark zone, a zone of about 12 older west-northwest-trending faults running from Helena through Missoula nearly to Spokane, Washington.

Except for a few cases near Helena, faults in the Lewis and Clark zone lack evidence for Quaternary movement. The cluster of epicenters along the Lewis and Clark zone near the Montana-Idaho border is centered in the Coeur d' Alene Mining District. Deep underground mining triggers most of these seismic events, known as rockbursts. These induced seismic events are hazardous to miners and may significantly impact mining operations.

All magnitude 5.5 or greater earthquakes in Montana this century have occurred in the Intermountain Seismic Belt, except one—the May 16, 1909 earthquake in northeast Montana. Because of its early date, no local seismographs existed to record it; however, its widespread area of perceptibility and strong shaking near the epicenter suggest a magnitude of at least 5.5. The 1909 earthquake and a few recent smaller earthquakes demonstrate that other regions of Montana outside the Intermountain Seismic Belt are not immune from earthquakes.

Introduction
The year 1999 marked the fortieth anniversary of the last destructive Montana earthquake. In contrast, the previous 40 years (1920–1960) saw the occurrence of four major earthquake sequences in Montana. Considering the state's history of damaging earthquakes, it is natural that one may ponder the causes and sources of these earthquakes. In western Montana and throughout the Intermountain West, only the very largest historic earthquakes can be ascribed to specific faults with certainty. This is because western Montana earthquakes typically result from slip (movement) along faults at depths of 2–10 miles (3–15 km) below the ground surface. Only during the largest earthquakes (those generally larger than magnitude 6.5) does fault slip propagate up to, and offset, the Earth's surface. This offset of the Earth's surface results in a fault scarp. Young fault scarps (those less than 15,000 years old) mark steep mountain range fronts (Madison, Centennial, Absaroka, and Tendoy ranges for example). These mountain ranges are fault blocks uplifted by repeated earthquakes over millions of years and subsequently carved by ice and water into rugged mountains. Sediment eroded from the mountains filled broad valleys overlying the adjacent, downthrown fault blocks (Madison, Centennial, Emigrant, and Red Rock valleys).

The only historic surface-rupturing earthquake in Montana is the 1959 Hebgen Lake earthquake, centered just west of the northwest corner of Yellowstone National Park. The magnitude 7.5 Hebgen Lake earthquake offset the Earth's surface for a distance of 20 miles (32 km) along two principal faults and produced up to 20 feet (6 m) of vertical offset. Earthquakes as large as the 1959 earthquake occur infrequently (perhaps once in a few thousand to tens of thousands of years) in western Montana.

It is these large but infrequent earthquakes that are preserved in the geologic record and modify the landscape, creating fault scarps along which a mountain block is uplifted or a valley floor is lowered. Many other faults have ruptured during the Quaternary (past 1.6 million years) but the age of the last rupture is not well constrained. The long elapsed time since the last major earthquake on these faults may suggest they are no longer active, but their potential to produce an earthquake cannot be completely ignored because many faults in the Intermountain West have very long recurrence times.

Small- and moderate-magnitude earthquakes (with magnitudes less than 6.5) generally do not alter the Earth's surface. However, they occur more frequently than surface-rupturing earthquakes and may be powerful enough to cause damage. Thus, much of the seismic hazard facing western Montana comes from smaller but more frequent earthquakes on faults lying hidden beneath the Earth's surface as well as major but infrequent earthquakes along mapped faults.

Faults
This map displays faults, earthquakes, and topography in western Montana. Funded through the Earthquake Hazards Reduction Program, the U.S. Geological Survey (USGS) compiled Quaternary faults in western Montana as part of a larger effort sponsored by the International Lithosphere Program. The USGS conducted a detailed review of published and unpublished maps and literature concerning Quaternary faults in western Montana . Fault data were entered into a data base and used to compile a map showing the locations, ages, and estimated slip rates of Quaternary (past 1.6 million years of geologic time) faulting in western Montana (table 1). Fault traces were taken from original sources and compiled on 1:250,000-scale quadrangle base maps and digitized for use in a geographic information system (GIS) package. In addition to location and style of faulting, the data characterize the time of most recent movement and estimated slip rate for each fault. Also included are geographic and other paleoseismologic parameters and a bibliographic reference. Information from this data base is available on CD-ROM from the Montana Bureau of Mines and Geology (MBMG).

Characteristics of several faults significantly change along the length of the fault (Red Rock and Madison faults for example), indicating that different parts of the fault (sections) behave independently of each other. Faults with two or three sections are indicated on the map and in Table 2 with a lowercase letter following the fault number (ie. 644a). If the available information does not imply a multi-sectioned fault, then the fault is described as a simple fault and designated with a three digit number (*i.e.*, 687).

Most of the faults that have produced earthquakes in recent geologic time originated many millions of years ago. These ancient faults have moved in various ways as different tectonic events shaped Montana's geologic history. The Lewis and Clark zone (figure 1) is an example of a fault zone formed over a billion years ago, which may still have the potential to produce damaging earthquakes. About 12 major faults make up the Lewis and Clark zone that extends from the Helena region west-northwestward through Missoula to the Montana-Idaho state line near Lookout Pass, and beyond to the vicinity of Coeur d'Alene, Idaho. The Lewis and Clark zone is a general name describing this group of faults with horizontal offsets measured in kilometers to tens of kilometers as well as strongly deformed rock strata (Wallace *et al.* 1990). These faults accommodated slip during the formation of the overthrust belt in the mountainous western one-third of Montana some 50 to 80 million years ago. Younger slip of a different direction along several faults in the Lewis and Clark zone has helped to shape the modern landscape through formation of valleys. However most Lewis and Clark zone faults do not have documented Quaternary movement.

Earthquakes
Also depicted on the map are selected earthquake epicenters determined by the MBMG, which operates a network of seismograph stations in western Montana. Network data have been used to determine epicenters and magnitudes for over 14,000 earthquakes occurring from 1982 to 1998. Information about recent earthquakes is available from the MBMG web site at http://mbmgsun.mtech.edu.

The number and proximity of seismometers that record an earthquake are the most important factors influencing the accuracy of an epicenter determination. Before 1995, seismograph network stations were generally limited to southwest Montana. Thus, the quality for epicentral locations of pre-1995 earthquakes in northwest Montana is generally below that for southwest Montana. For the same reason, many small northwest Montana earthquakes went undetected prior to 1995.

The quality of seismic monitoring in northwest Montana improved dramatically in 1995 when the MBMG entered into a cooperative agreement with the Confederated Kootenai and Salish Tribes (CSKT) in order to establish six seismographs on the Flathead Reservation, north of Missoula. Also in 1995, the MBMG received funding through a National Earthquake Hazards Reduction Program grant to install nine stations in west-central Montana between Helena and St. Regis. By 1998, the Montana seismograph network consisted of 31 seismographs distributed between Flathead Lake in northwest Montana and the north and west borders of Yellowstone National Park. Seismic data are recorded in Butte at the MBMG's Earthquake Studies Office (ESO), in Ronan at the CSKT Safety of Dams Office, and in Missoula at The University of Montana Geology Department. All seismic data are analyzed and archived in Butte. Additional data from seismographs operated by other agencies in surrounding states and Canada are routinely incorporated into Montana earthquake locations. Stickney (1995) described seismic instrumentation and data-analysis procedures employed in preparation of the Montana earthquake catalog.

A subset of 5,148 earthquake epicenters from western Montana was selected from the MBMG earthquake catalog and shown on this map. These selected earthquakes include all earthquakes with Richter magnitudes over 2.5 and those earthquakes of magnitude 1.5 or larger with better quality epicentral locations. Earthquake epicenters that lie more than 6 miles (10 km) outside the Montana border are not shown. The distribution of earthquake epicenters (figure 1) generally reflects the northern Intermountain Seismic Belt and eastern Centennial Tectonic Belt (Stickney and Bartholomew 1987).

Stars show earthquakes of magnitude 5.5 or greater since 1900. The epicenter locations for historic Montana earthquakes are not as accurately determined as those after 1965 because prior to1965, few if any seismograph stations operated in Montana. Pre-1982 epicenters were taken from the National Oceanic and Atmospheric Administration hypocenter files, or later studies of these earthquakes if available (table 2).

Topographic data
The topographic representation of western Montana is based on digital elevation models (DEMs) created by the USGS. Western Montana DEMs were obtained from the Montana State Library National Resources Information System (NRIS). A full description of these data is available from the NRIS web site at http://nris.state.mt.us. The topographic visualization was derived from 30-meter and 3-arc-second DEMs. The 3-arc-second DEMs include some vertical accuracy problems, primarily in the northeast part of the map area. The data from areas with contrasting data quality were smoothed in ARC/INFO GRID using filtering techniques to minimize these artifacts.

The appearance of shaded relief topography was accomplished with the aid of ARC/INFO TIN conversion routines and hill-shading techniques. The visualization of a topographic surface was created by artificially illuminating the DEM with an afternoon sun source (azimuth 315 degrees, altitude 55 degrees, and vertical exaggeration 1.5). The map was created by projecting the illuminated DEM data into a Lambert Conformal Conic Projection using the Montana State Plane Coordinate System with the following parameters: Central Meridian -109.5º, 1st standard parallel 45º north, 2nd standard parallel 49.0º, origin 44.25º and false easting 600,000. Other data shown on the map such as county boundaries, lakes, rivers, highways, and cities are derived from 1:100,000-scale U.S. Census Bureau Tiger files that also were obtained from NRIS.

Acknowledgements
Funds to produce this map came from the Hazard Grant Mitigation Program administered by the Disaster and Emergency Services Division of the Montana Department of Military Affairs. Larry Akers and Jerry Smithers of DES were helpful in guiding us through the grant application process and program administration–their assistance is gratefully acknowledged. Richard Dart of the USGS supplied the digital fault data in ARC/INFO format. The MBMG Earthquake Studies Office, Confederated Salish and Kootenai Tribes' Safety of Dams Office, and the University of Montana Geology Department provided seismograph data for locating and cataloging western Montana earthquakes. The National Earthquake Hazards Reduction Program has provided two previous grants (awards 1434-94-G-2516 and 1424-95-G-2628) to the MBMG that expanded seismic monitoring capabilities and re-analysis of previously recorded earthquake data. Finally, thanks to GIS specialists Bill Myers and Paul Thale (MBMG) for GIS production of the map and cartographer Susan Smith (MBMG) for cartographic production.

References
Doser, D.I., 1989, Source parameters of Montana earthquakes (1925–1964) and tectonic deformation in the northern Intermountain Seismic Belt: Bulletin of the Seismological Society of America v. 79, p. 31–50.

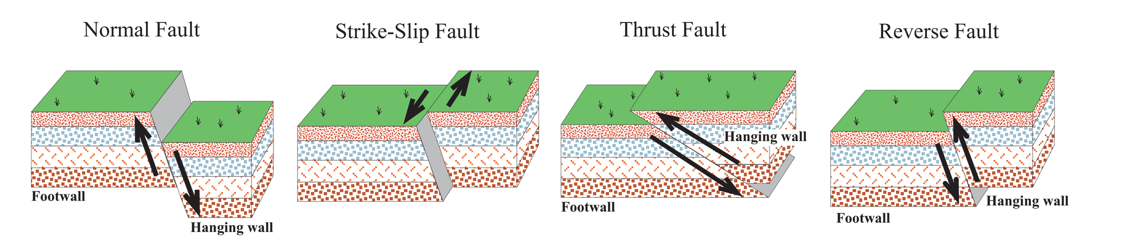
Doser, D.I. and Smith, R.B., 1989, An assessment of source parameters of earthquakes in the Cordillera of the Western United States: Bulletin of the Seismological Society of America, v.79, p. 1383–1409.

Stickney, M.C., 1995, Montana seismicity report for 1990: Montana Bureau of Mines and Geology Miscellaneous Contribution 16, 44 p.

Stickney, M.C. and Bartholomew, M.J., 1987, Seismicity and late Quaternary faulting of the northern Basin and Range Province, Montana and Idaho: Bulletin of the Seismological Society of America, v. 77, p. 1602–1625.

Wallace, C.A., Lidke, D.J., and Schmidt, R.G., 1990, Faults of the central part of the Lewis and Clark line and fragmentation of the Late Cretaceous foreland basin in west-central Montana: Geological Society of America Bulletin, v. 102, p. 1021–1037.

Figure 2. Diagrams illustrating the sense of fault offset along normal, strike slip, thrust, and reverse faults.



A fault along which the hanging wall moves down with respect to the footwall.

A fault along which one side moves horizontally with respect to the other side.

A fault along which the hanging wall moves up and over the footwall at a low (<45°) angle.

A fault along which the hanging wall moves up and over the footwall at a high (>45°) angle.

Figure 3. Levels of seismic shaking possible in western Montana.

This acceleration map is an outgrowth of the U.S. Geological Survey's National Seismic Hazard Mapping Project (URL: http://geohazards.cr.usgs.gov/eq/index.shtml). It reflects the strength of seismic shaking (measured as a percentage of the acceleration of gravity, %g) that has a 10% probability of being exceeded during a 50-year period. Conversely, this means there is a 90% chance that the levels of shaking indicated on this map will not occur during a 50-year period. The shaking levels are derived from the historic earthquake catalog and young faults with estimated slip rates. The acceleration ranges shown correspond approximately to seismic zones on the International Conference of Building Official's seismic zonation map of the United States. For example, 7.5%g–15%g corresponds to zone 1, and 30%g–40%g corresponds to zone 3. To be consistent with the older seismic zonation maps zone 2 is divided into two zones—zone 2a includes accelerations from 15%g to 20%g and zone 2b includes accelerations from 20%g to 30%g. The new information excludes zone 4, which was present on older maps, from Montana because the shaking levels in southern Beaverhead, Madison, Gallatin, and Park counties reach only 38%g, just below the 40%g threshold that defines zone 4.