Madison Range

David R. Lageson

# Montana Geology '98

## January

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*Montana Bureau of Mines and Geology*
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Montana Tech
THE UNIVERSITY OF MONTANA

# *The Madison Range*

The Madison Range of southwestern Montana is one of the most beautiful and rugged mountainous landscapes in the state. Rising to heights in excess of 11,000 ft (3,400 m) and composing the bulk of the Lee Metcalf Wilderness, the Madison Range is an imposing fortress of rock units that span the geologic time scale. The core of the range contains Archean metamorphic "basement rocks" that exceed 2.5 billion years in age, among the oldest rocks in the Northern Rocky Mountains. In contrast to these ancient rocks, the Madison Range also is noted for its geologic youth as indicated by currently active faulting and seismic activity.

Tectonic forces initially uplifted the Madison Range towards the end of the Cretaceous Period, around 65 million years ago. At that time, the Madison and Gravelly ranges to the west were connected as one large, uplifted crustal block referred to as the Madison-Gravelly arch. The present-day Madison Range is the east limb of this arch, whereas the Gravelly Range is the west limb. The modern Madison valley was formerly the crest of this huge arch, which collapsed over the past few million years to form the present-day valley (figure 1).

The southern end of the Madison Range and valley, along with the Hebgen Lake area to the east, is the most seismically active region in Montana and the lower 48 states outside California and Nevada. This region has experienced six historical earthquakes with magnitudes of 6.0 or greater. A magnitude 6.3 earthquake on 23 November 1947 struck the southern Gravelly Range, toppling chimneys and breaking windows in Virginia City, 37 miles (60 km) north of the epicenter. On 17 August 1959 at 11:37 P.M., a magnitude 7.5 earthquake rocked Hebgen Lake and the surrounding region. The largest earthquake in recorded history along the Intermountain Seismic Belt, the 1959 Hebgen Lake earthquake was followed by four aftershocks with magnitudes ranging from 6.0 to 6.5 within 20 hours, and hundreds of moderate-to-small magnitude aftershocks during the next five years. Over 25 mi (41 km) of fault scarp formation accompanied this quake. Two principal faults northeast of Hebgen Lake—the Hebgen and Red Canyon faults—accounted for 21 miles (34 km) of these fault scarps. A maximum scarp height of 22 ft (6.7 m) was observed along the Hebgen fault. The sudden northeastward tilting of the Hebgen Lake basin in response to the fault offset generated a seiche—a large wave that sloshed back and forth across Hebgen Lake—overtopping Hebgen Dam three times and washing several cabins off of their foundations and into the lake. Severe seismic shaking in the Hebgen Lake basin accompanied the main shock and reached intensity X on the Modified Mercalli Intensity Scale (table 1). Shaking was felt by persons up to 570 miles (927 km) away from the epicenter—a 602,000 square-mile (1.554 million km$^2$) region extending from Seattle, Washington, to western North Dakota and from southern Canada to Salt Lake City, Utah. The earthquake also triggered the largest seismically induced landslide in North America during recorded history. In less than 60 seconds, the 37 million cubic yard Madison Canyon slide formed a dam across the Madison River up to 200 ft thick, burying part of Rock Creek campground where 26 people died and forming Earthquake Lake (photo below). Numerous other smaller landslides and rockfalls occurred within a region extending 20 mi (32 km) north-south, and 50 mi (81 km) east-west of the epicenter.

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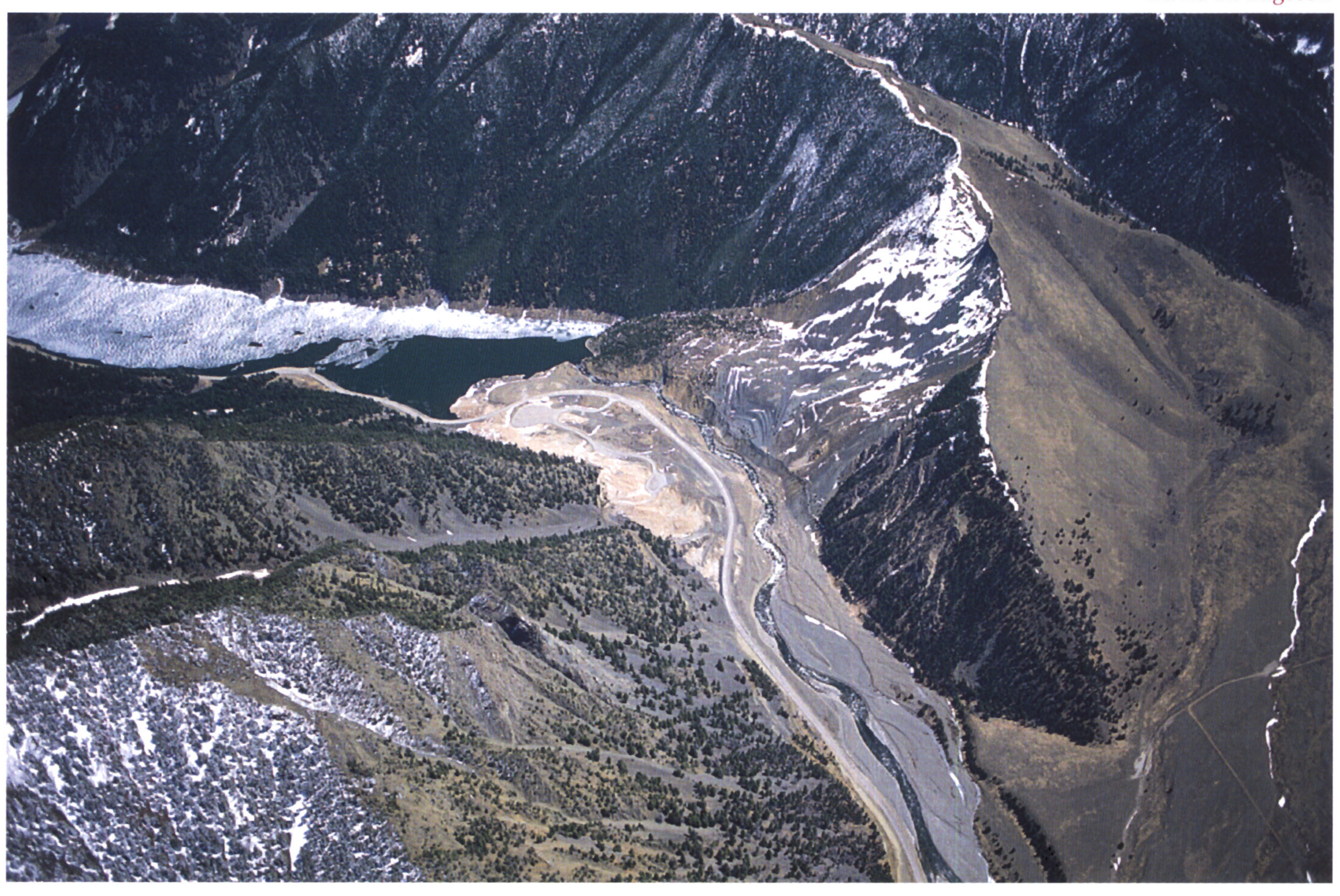

The Hebgen Lake/Madison valley region continues to exhibit a high level of seismic activity. Using data from the Montana seismograph network and the Yellowstone network (now operated by the University of Utah), the Montana Bureau of Mines and Geology has determined epicenter locations for over 2,200 earthquakes in the region since 1982. An analysis of the number of earthquakes at various magnitude levels (table 2) suggests that on average 70 earthquakes with magnitudes of 2.5 or larger occur annually; that an earthquake of magnitude 4.0 should occur once during a 1½-year period; and that an earthquake of magnitude 6.0 or greater may be expected once every 680 years. This analysis is based solely on earthquake activity recorded since 1982. Historic levels of seismicity are clearly greater than recent levels, to suggest a temporary decrease in seismicity following the aftershock sequence of the 1959 Hebgen Lake earthquake.

**Table 1. Modified Mercalli Intensity Scale of 1931 (Abridged, Wood and Neumann 1931)**

| Intensity | Effects |
|---|---|
| I. | Not felt except by a very few under especially favorable circumstances. |
| II. | Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing. |
| III. | Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing automobiles may rock slightly. Vibration like passing truck. Duration estimated. |
| IV. | During the day, felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, and doors disturbed; walls make creaking sound. Sensation like heavy truck striking building. Standing automobiles rocked noticeably. |
| V. | Felt by nearly everyone; many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbance of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop. |
| VI. | Felt by all; many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight. |
| VII. | Everyone runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures. Some chimneys broken. Noticed by persons driving automobiles. |
| VIII. | Damage slight in specially designed structures; considerable in ordinary substantial buildings, with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving automobiles disturbed. |
| IX. | Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken. |
| X. | Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks. |
| XI. | Few if any (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly. |
| XII. | Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into the air. |

**Table 2. Predicted number of annual earthquakes, return times (inverse of annual number), and average annual number of earthquakes observed at various magnitude levels in the Hebgen Lake/Madison valley region based on recorded seismicity 1982–May 1997.**

| Magnitude | Predicted annual number of earthquakes | Predicted return rate | Observed annual number of earthquakes |
|---|---|---|---|
| 2.5 | 70. | 0.014 | 32.8 |
| 3.0 | 15. | 0.067 | 12.2 |
| 3.5 | 3.2 | 0.31 | 3.7 |
| 4.0 | 0.69 | 1.45 | 0.3 |
| 4.5 | 0.15 | 6.7 | 0.07 |
| 5.0 | 0.032 | 31.4 | 0 |
| 5.5 | 0.0068 | 146. | 0 |
| 6.0 | 0.0015 | 681. | 0 |

The tectonic forces responsible for seismicity and faulting in the Hebgen Lake/Madison valley region are related to the Intermountain Seismic Belt, a zone of seismic activity extending from northwest Montana to southern Nevada. A branch of the Intermountain Seismic Belt—the Centennial Tectonic Belt—extends west from Yellowstone Park through southwest Montana and into central Idaho. Earthquakes along both seismic zones result from gradual stretching or extensional forces rather than compressional forces. Throughout the western Centennial Tectonic Belt and most of the northern Intermountain Seismic Belt, these extensional forces are oriented northeast-southwest. However where these two seismically active zones meet in the Hebgen Lake/Madison valley area, the extensional forces are oriented nearly north-south. Tectonic activity here is likely influenced by the proximity of the Yellowstone volcanic province located to the east in Yellowstone National Park.

Recent seismicity in this region occurs dominantly within an east-west belt extending westward from Yellowstone National Park through Hebgen Lake, the southern Madison valley, and southwestward across the Gravelly Range and into the Centennial valley. While the Madison valley north of Missouri Flats is largely devoid of recent seismicity, the Gravelly Range to the west is evenly peppered with epicenters. Most of the seismicity does not line up along the major active faults (Madison, Red Canyon, Hebgen, and Centennial faults) and in fact, most small earthquakes cannot be attributed to faults mapped at the Earth's surface. A recent study indicates that most of these earthquakes result from north-south extensional forces, similar to those responsible for the 1959 Hebgen Lake earthquake. Repeated surveys of monuments surrounding the Hebgen Lake basin by the U.S. Geological Survey over a 14-year period indicate the basin is extending in a roughly north-south direction at a rate of 8 mm/year.

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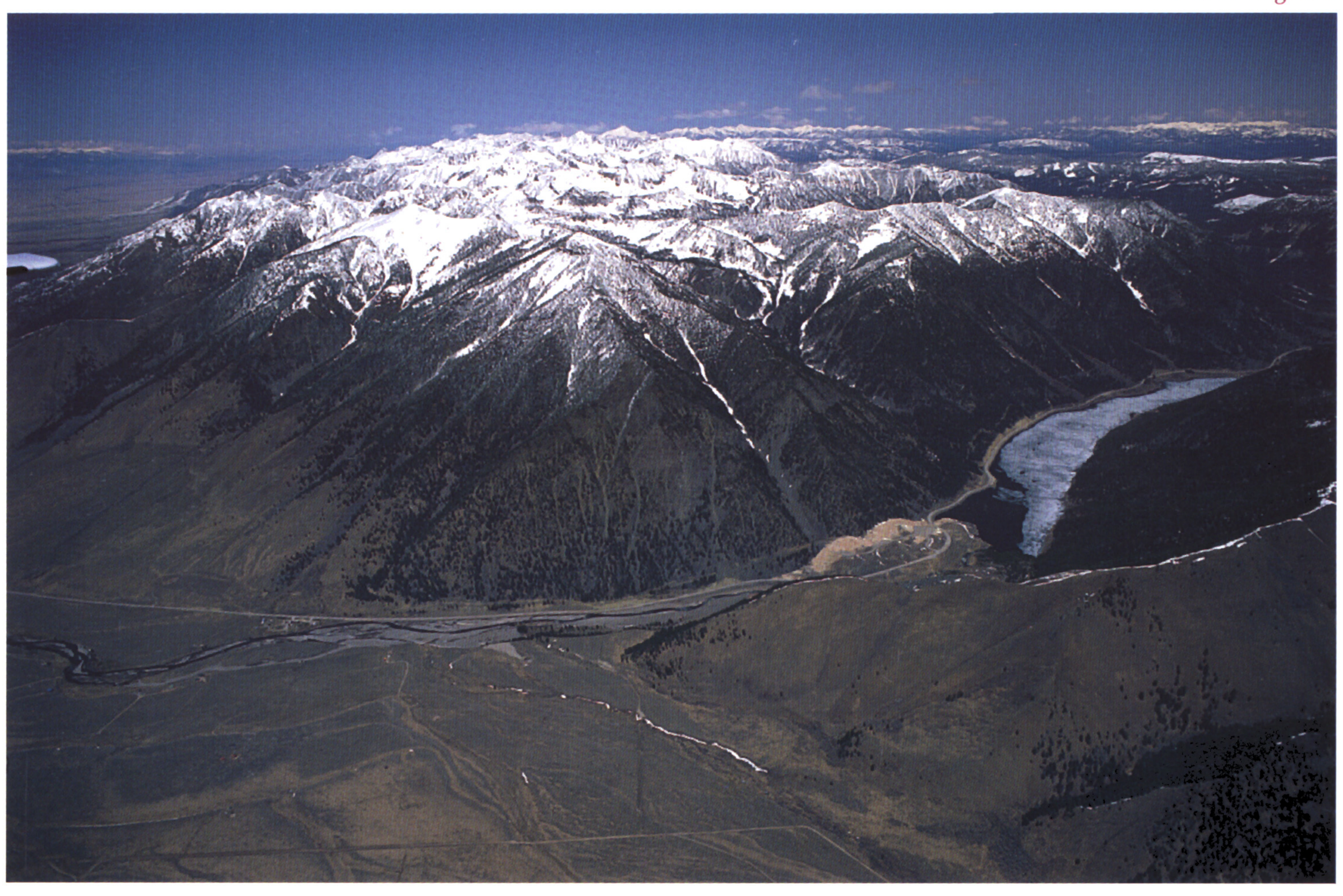
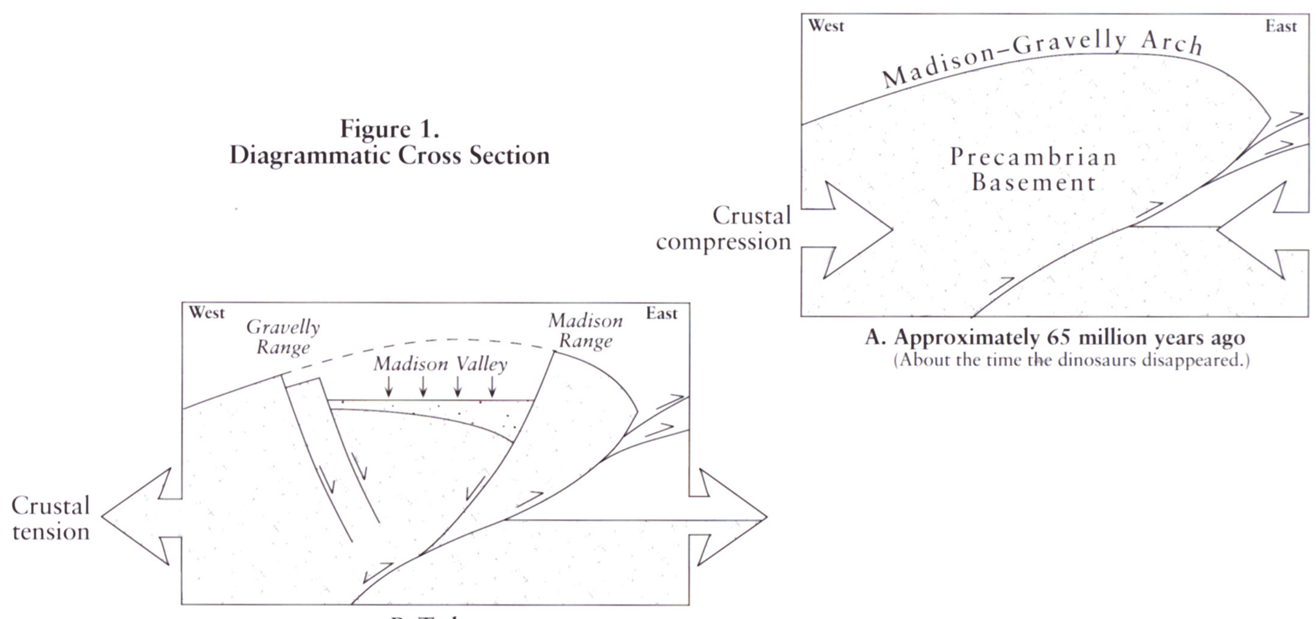


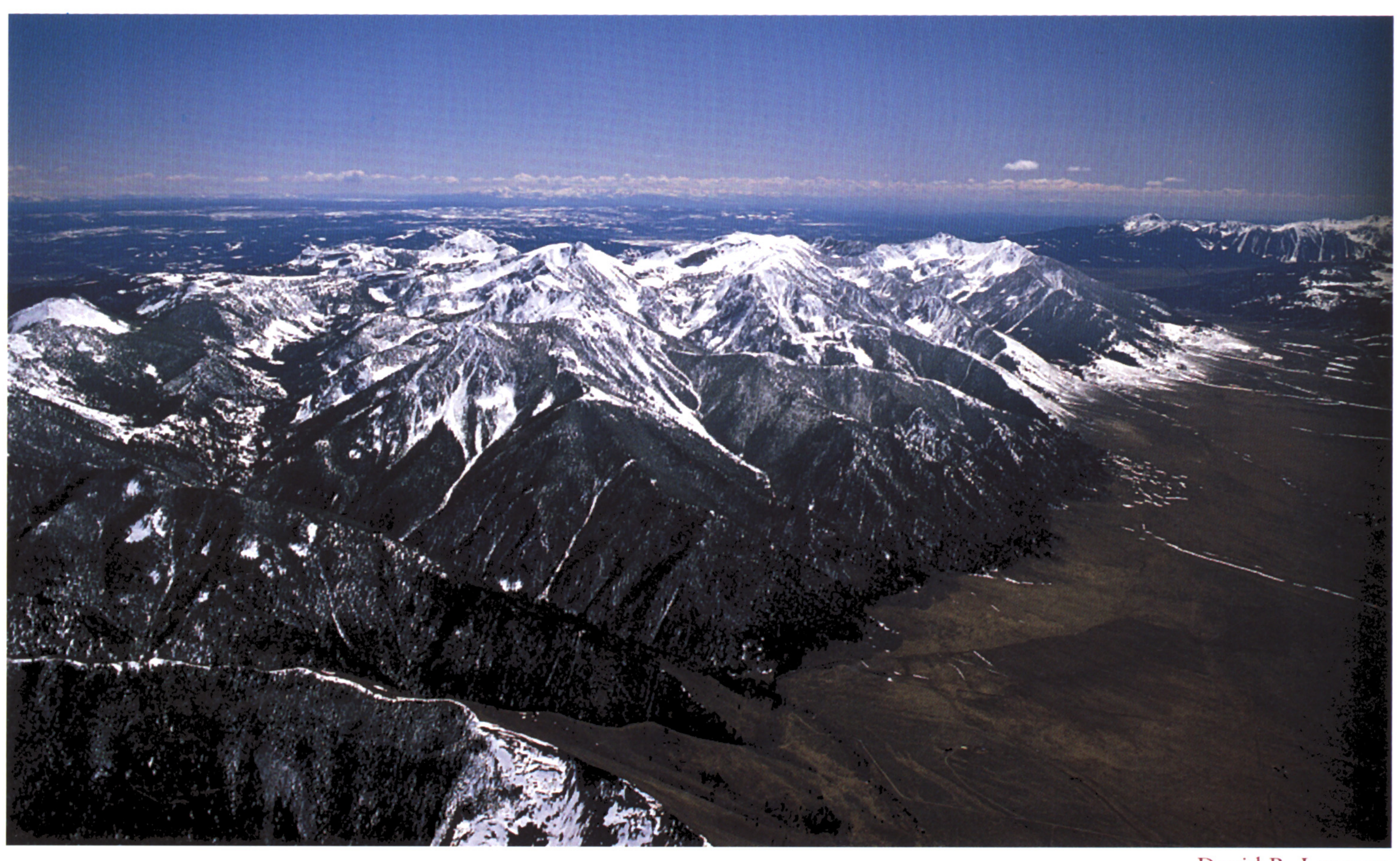
↑View of the Madison Range looking north from just south of the Madison River and the 1959 Madison Canyon landslide. Earthquake Lake is partly frozen over at the right side of the photo, and the Madison valley extends northward along the left side of the photo. Note the fault scarps at the break-in-slope along the western base of the range, at lower center and left center.

←View of the earthquake-triggered 1959 Madison Canyon slide, Earthquake Lake (partly frozen over), which was created by the slide, and the Madison River. The bedrock involved in the slide was steeply north-dipping (50–70°) biotite schist and dolomitic marble, blocks of which may be seen next to the parking lot at the Visitor's Center. Soon after the slide occurred, the Army Corps of Engineers cut a channel through the landslide dam to prevent the lake from eventually overtopping the dam and washing it away, causing potentially disastrous downstream flooding. The dark-colored bedrock in the lower left of the photo, north of the slide, is chlorite-hornblende schist and diabase dikes.

**Figure 1.**
**Diagrammatic Cross Section**




↓ View looking south from the Madison Canyon slide (break-away zone of the slide is visible at the bottom center of the photo) over the southern Madison Range. Near Henrys Lake (just out of view), the southern Madison Range is called the "Henrys Lake Mountains," but the geology is essentially the same as the main Madison Range to the north. Note the sharp range front break-in-slope at the western base of the range (right side) marking the trace of the Madison fault. The southern Madison valley has been down-dropped along this fault, whereas the adjacent Madison Range has been relatively uplifted. The eastern Centennial Mountains, also uplifted along an active normal fault, are visible in the upper right portion of the photo, while the Yellowstone volcanic plateau forms the low-relief topography beyond the southern Madison Range.



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Front photo: The Madison Range front fault continues north of the Madison Canyon for 65 mi (105 km) along the western base of the Madison Range. At the mouth of Wolf Creek Canyon, the fault scarp clearly cuts across the Wolf Creek "moraine" that forms a lobe of hummocky topography on the Madison valley floor. Wolf Creek has cut its modern channel across the fault scarp and into the moraine. Based on geomorphic youthfulness of this fault scarp, it is estimated to have been created by an earthquake approximately 3,600 years ago. Furthermore, the length and height of this scarp suggest the causative earthquake must have been at least of magnitude 7.0. Older geologic deposits are offset greater amounts than younger deposits, indicating that the Madison fault slips repeatedly in major earthquakes, perhaps with a frequency of 3000–5000 years. In addition to the fault scarp, other landforms created by recent fault displacement include the triangular "faceted spurs" along the range front between canyons and the narrow entrance to each canyon at the range front.


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# Montana Bureau of Mines and Geology

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## Scope and Organization

The Montana Bureau of Mines and Geology (MBMG) was established in 1919 as a public service agency and research entity for the State of Montana, *to conduct and publish investigations of Montana geology, including mineral and fuel resources, geologic mapping, and ground-water quality and quantity.*

In accordance with the enabling act, MBMG conducts research and provides information but has no regulatory functions. To carry out its duties more effectively, MBMG operates in five divisions: Research, Analytical, Information Services, Computer Services, and Administration, while the director holds the position of State Geologist.

## Science and Service for Montana

- **Analytical Services**–analyzing the chemical quality of ground water and surface water; analyzing soils and biological tissue for metal content
- **Coal Hydrology**–investigating ground water in coal areas before, during, and after mining
- **Coal Resources**–evaluating effective reserves and establishing regional data bases
- **Computerized Resource Data Storage and Retrieval Systems**–compiling and storing Montana's coal, water, and mineral resources information
- **Earthquake Studies Research**–monitoring and analyzing seismic activity in Montana
- **Economic Geology**–making detailed studies of Montana's metalliferous deposits, industrial minerals, and coal and reporting on the activities of Montana's mineral industry
- **Environmental Sampling and Monitoring**–providing objective analysis of contaminated water and soils
- **Geographic Information Systems**–generating digital maps of geology, minerals, and hydrology
- **Geologic Maps**–field mapping and compilation of bedrock and surficial geology; digital publication of quadrangle maps and other maps at various scales
- **Geothermal Investigations**–mapping and measuring Montana's natural hot water resources
- **Ground-Water Resources Investigations**–evaluating the quality and the quantity of ground water in Montana
- **Hydrogeological Research**–assessing water-related environmental concerns, including saline seep and mine water drainage
- **Lectures and Public Addresses**–speaking to public groups on MBMG research, and Montana geology and hydrology
- **Mine Hydrology and Mine Waste Disposal**–investigating mine impacts on ground water and surface water
- **Mineral Museum**–displaying over 1,200 high-quality mineral specimens, group tours available
- **Montana Ground-Water Characterization**–monitoring and characterizing the state's ground-water aquifers
- **Montana State Map**–revising and updating the state geologic map and derivative maps in 1° x 2° quadrangles
- **Public Inquiry**–providing information on Montana geology and ground water
- **Publication and Map Sales**–providing documents on bureau research, USGS topographic and geologic maps, derivative maps, and access to federal aerial photos
- **Small Miners Assistance**–providing assistance to operators of small mines and prospectors
- **Statewide Ground-Water Assessment**–systematically evaluating Montana ground water and aquifers
- **Topical Studies in Regional Geology**–conducting investigations of Montana geology
- **Water Supply Evaluation**–evaluating the quality and quantity of water for municipalities and state agencies