Geological Survey Undertakes Concentrated Investigation of Montana Earthquake

The U. S. Geological Survey is making an all-out effort to investigate as many problems as possible connected with the recent earthquake in Montana. More than 25 geologists, geophysicists, hydrologists, and geochemists have been sent to the area most affected by the quake.

Two geological field parties were mapping in the area when the earthquake occurred. Irving J. Witkind was in camp overlooking Hebgen Lake; Jarvis B. Hadley was farther down the Madison River at Ennis. GeoTimes is privileged to have first hand accounts of on-the-spot observations by these two U.S.G.S. men.

In the first days after the quake, Witkind and Hadley served as ambulance drivers and emergency radio operators helping the Forest Service rescue injured and others stranded because of the landslide in the Madison River gorge below Hebgen Lake. According to Hadley, more than 200 persons were rescued by the Forest Service; both he and Witkind have expressed high praise for good work by the Forest Rangers.

Seismological data about the earthquake are being gathered by the Coast and Geodetic Survey and representatives of the Seismological Society. These data will appear in the bulletin of the Society.

The Survey men working on the earthquake, in collaboration with representatives of the Coast and Geodetic Survey, Seismological Society, Forest Service, Corps of Engineers, Park Service, and Highway Department are planning a comprehensive report on the earthquake that will discuss such diverse problems as:

1. The area immediately affected and extent of the damage;
2. A history of earthquakes in this seismically active area;
3. The new fault scarps and the tilting of the floor of Hebgen Lake;
4. Late Pleistocene and Recent faulting in the region;
5. Landslides and damage to highways, dams, buildings, and other structures;
6. Changes in surface water and ground water regimen;
7. Changes in chemistry of the water along and near new faults;
8. Fluctuations in level of surface water and ground water at recording stations throughout the United States, attributable to the earthquake;
9. Changes in quantity of water discharged by geysers, and changes in chemistry and thermal energy that can be inferred or measured;
10. Possible changes in depth and position of the epicenter during the period of continued tremors.

The water in Hebgen Lake is turbid as a result of the quake; if it clears before weather becomes too cold, Survey geologists adept at skin diving will explore the lake floor to study bottom sedimentation and erosion effects.

Individuals engaged in these studies express hope that most of their manuscripts can be completed by the first of November and sent on the way toward early publication. A special report on the earthquake observations and studies is being scheduled at the Pittsburgh meeting of the Geological Society of America, Nov. 2-4.

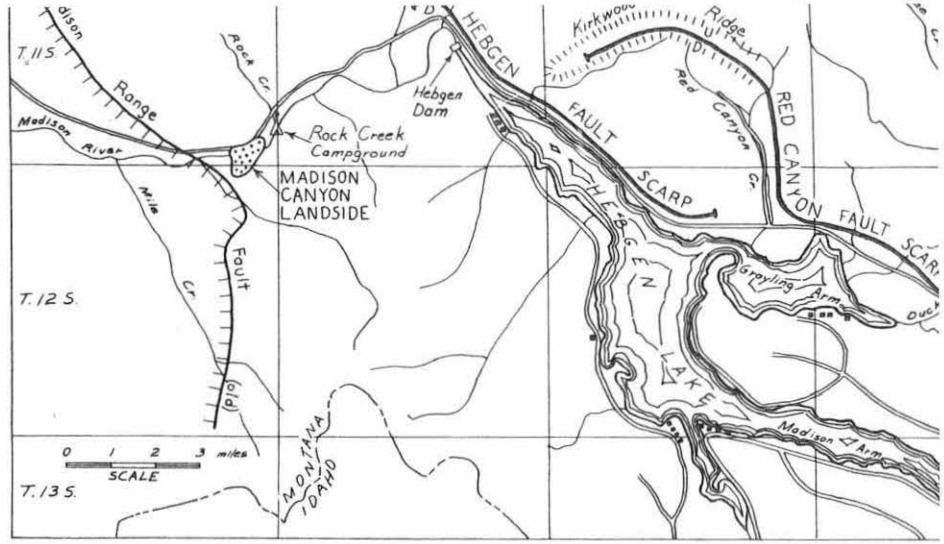

Figure 1. Map showing new fault scarps in Hebgen Lake area.

THE HEBGEN LAKE EARTHQUAKE

by Irving J. Witkind [2]

The surface effects of the earthquake that rocked southwestern Montana August 17 and 18 were centered at Hebgen Lake, and I propose that the earthquake be named the Hebgen Lake earthquake. I had been mapping that area for the Survey and was camped only a mile north of the Lake when the earthquake occurred. I am convinced that the epicenter of this earthquake was directly under my trailer and no deeper than a few yards; not 20 miles to the southeast and 20 miles deep as reported by the seismologists!

The earthquake occurred about 11:40 PM, August 17. The first shock was the most severe one and, thinking back, I estimate its duration to have been somewhere between 10 seconds and 1 minute. This first tremor was followed by a series of subsequent shocks of lesser intensity at about 5 minute intervals.

My first reaction to the shaking was that my trailer had broken loose from its moorings and was carrying me downhill! I was neither cool, calm, nor collected as I scrambled to the door to escape from my run away carriage. But outside, on allegedly terra firma, I found the trees were swaying but no wind blowing. Then I realized what had happened.

The geologic effects of the earthquake are several fold, chiefly: new faults, tilting of the floor of Hebgen Lake, landslides, and changes in water occurrence.

The position of the new scarps of faults that were formed are shown on the accompanying map (fig. 1). These are reactivated old faults belonging to one of the major sets of faults in the region. Views of the scarps are given in figures 2 and 3. About midnight I left my trailer to drive around the countryside and see what had happened. I discovered my access road had been broken and displaced by a fault scarp 15 feet high. The main highway also was displaced, and an automobile travelling south drove off the scarp and overturned.

The hills north of Hebgen Lake consist of folded Paleozoic and Mesozoic sedimentary rocks cut by both reverse and normal faults. The hills west of the lake and the canyon below consist of Precambrian crystalline rocks. The scarps of the new faults are near and parallel to the old normal faults that already had been mapped, but they are formed in alluvium, colluvium or other surficial deposits and are difficult to trace in the bedrock hills. At places the faults separate surficial deposits from bedrock. Although manifested at the surface only by displaced surficial material, it is clear that at depth the faults extend into the bedrock, and that the new scarps represent renewed movement on old faults. Displacement on the faults is almost en-

[1] Publication authorized by Director, U. S. Geological Survey.

[2] Irving J. Witkind, U. S. Geological Survey, Federal Center, Denver, Colorado.

tirely vertical; the horizontal displacement in few places is more than a few inches.

In addition to the conspicuous fault scarps, all of which dip south and are 3 to 20 feet high, the faults are marked by a series of open fissures. These have jagged outlines; they gape from 1 inch to about 2 feet at the surface and are 1 to 10 feet deep. The length of individual cracks ranges from a few feet to a few tens of feet. Similar cracks in the alluvium along the shores of the lake served as vents for sand and gravel boils, some as much as 50 feet long, 20 feet wide and 12 feet deep.

As a result of the faulting, the floor of the valley containing Hebgen Lake has been tilted northeastward. The Madison Arm of the lake (fig. 1) has emerged whereas the northeast shore has been submerged. The exact amount of shift is not yet known partly because we await new precise leveling, but also because it is difficult as yet to tell displacement attributable to the faulting from displacement attributable to landsliding that resulted from the faulting. It appears though that the northeast shore of the lake has been submerged by about 10 feet and that the southwest shore has emerged about an equal amount. Figure 4 is a view of the emergent southwest shore of the lake; figure 5 shows the submerged northeast shore where a landside has engulfed part of the highway.

Hebgen Lake, formed in 1915 when the dam was built, is less than 100 feet deep. As a result of the shaking the lake water still is very turbid but plans are being made to survey the floor of the lake for any changes attributable to the earthquake.

In an accompanying article, Hadley describes details of the tremendous landslide that dammed the Madison River—the slide that caused most of the casualties and still is a matter of some apprehension because of flood hazard. Many smaller landslides were caused by the shaking; when these have been studied we may be able to relate their distribution and other habit more directly to the faulting.

Changes in occurrence of surface water and ground water as a result of the faulting and shaking are being studied by hydrologists and geologists of the Geological Survey's Water Resources Division. Springs, streams, and the lake have become clouded with exceedingly fine-grained sediment and the condition has persisted 3 weeks to the time of this writing.

THE MADISON CANYON LANDSLIDE[1]

by Jarvis B. Hadley [3]

The most dramatic and disastrous effect of the Hebgen Lake earthquake was a great landslide in the canyon of the Madison River six miles below Hebgen Dam. Thirty-five million cubic yards of broken rock slid into the canyon in less than a minute, covering the river and highway for nearly a mile to a depth of 100 to 300 feet. Water impounded by the slide formed a lake which, three weeks after the slide, was 175 feet deep and extended almost to Hebgen Dam. The slide itself spread upriver to the edge of a campground full of vacationers sleeping in tents and trailers and on the ground (figs. 6 and 7). Most of these people were more or less seriously injured and lost their immediate possessions. A number of campers as yet unknown had stopped along the river bank farther downstream and were immediately engulfed in the slide.

The magnitude of the slide is dramatic enough, but it is all the more surprising that it occurred 5 miles from the nearest of the faults that were active during the quake and 8 or 10 miles west of the area of greatest surface disruption. We could find no evidence of renewed movement on nearby faults during the earthquake. We did find much evidence, however, of long standing conditions favorable for sliding, which were effectively touched off by the quake.

The configuration of the Madison River canyon where the slide occurred is shown in figure 6. The walls on both sides are steep, those on the south reaching 1,300 feet above the river, in part rocky but mostly thickly forested. Those of the north are higher, mainly rocky slopes with many cliffs reaching 2,000 to 3,000 feet above the river.

On both sides are pre-Belt crystalline rocks. About one-third of the part that slid from the south wall of the canyon consists of fine-grained dolomite that forms steep bare slopes immediately west of the

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[3] Jarvis B. Hadley, U. S. Geological Survey, Federal Center, Denver, Colorado.

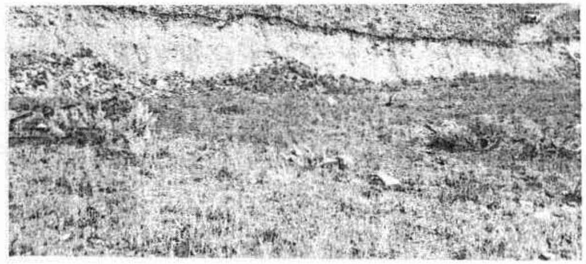


Figure 2. New scarp of Red Canyon fault where a road has been displaced. The Survey camp was in the aspen grove at upper left.

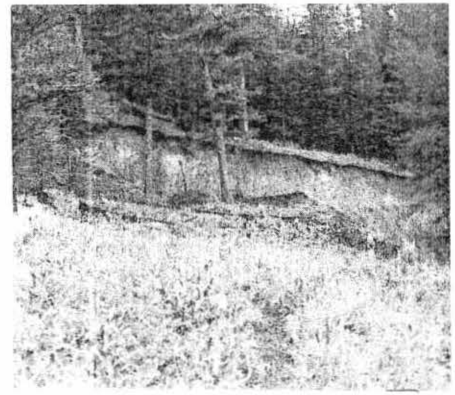


Figure 3. New scarp of the Red Canyon fault as it is typically exposed in the forested hills north of Hebgen Lake.

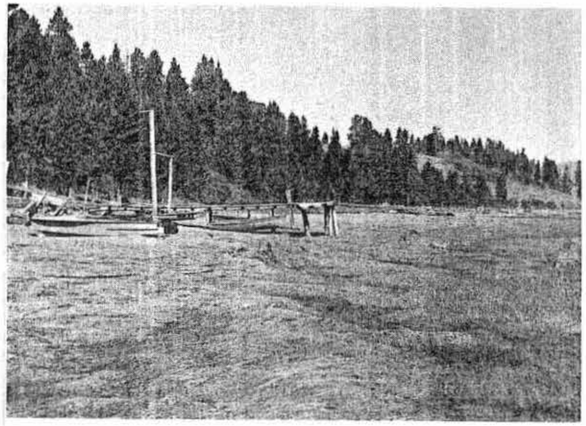
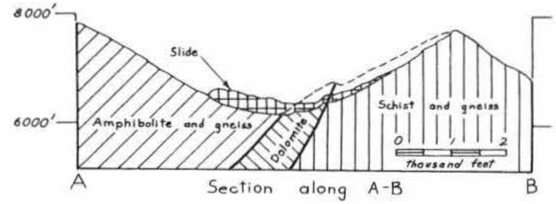


Figure 4. Emergent southwest shore of Hebgen Lake. Water weeds laid flat by the rapidly receding water.

Figure 5. Submerged northeast shore of Hebgen Lake. The present shore is about 10 feet higher than the old one in this area.



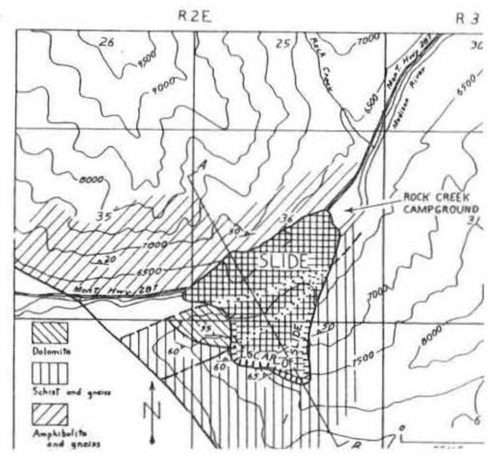


Figure 6. Geologic sketch map and cross section of the Madison Canyon landslide.

Figure 7. View upstream across the upper end of Madison Canyon landslide to lake formed by damming the Madison River.

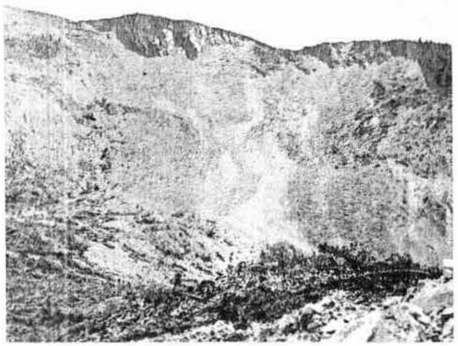


Figure 8. Scar of the Madison Canyon landslide.

slide. This rock formed most of the lower part of the slide slope. The other two-thirds of slide area consists of well foliated, micaceous schist and gneiss. In part it is highly sheared chlorite and sericite schist containing abundant quartz veins. The less foliated gneiss is hard, biotite-quartz feldspar gneiss with some massive lime-silicate gneiss adjacent to the dolomite. A zone of much sheared and altered rock 100 feet wide occurs within the schist and gneiss in the western part of the slide scar. Exposures in the slide scar as well as the material on the slide itself show that the schist and gneiss were weathered and partly decomposed to depths of 50 to 100 feet on the upper part of the slope.

Foliation, shear surfaces, and minor faults in the schist and gneiss in the slide area trend east-west to east-northeast, dip 45° to 70° north toward the canyon, and served as slip surfaces for the sliding. A little west of the slide, probably across a fault, attitudes of the foliation change abruptly and dip steeply southward into the ridge.

The dolomite is a wedge-shaped body, widest at the west edge of the slide area and tapering eastward along the base of the ridge. It also tapered upward for the southern boundary dips somewhat more steeply northward than the slope. Bedding and shear surfaces in the dolomite just west of the slide dip north 45° to 65°, changing westward to steeper more easterly dips.

The north wall of the canyon consists of amphibolite and gneiss whose layering and foliation dip north, producing a far stabler slope than that on the south wall. Joint-bounded blocks as much as five feet in diameter were dislodged from talus and bedrock at many points and some pinnacles were loosened, but no mass movement occurred on the north side of the canyon.

The slide started at the ridge crest on the south wall 1,300 feet above the canyon floor (fig. 8). It moved north across the canyon, about 800 feet wide, rose 400 feet vertically along the north wall of the canyon and spread upstream nearly a mile from its starting point. About 90 acres of slope went down, covering an area of 135 acres with slide debris averaging 150 to 175 feet thick. A very rough calculation of the volume of debris suggests that the consolidated rock on the slope that moved was 150 feet deep in many places and perhaps 200 feet deep in the deepest part. The distribution of slide debris shows that it descended in a remarkably orderly manner; the dolomite on the lower face of the original slope forming the forward edge of the mass, was followed by the lime-silicate gneiss and finally the schist. Much of the dolomite and lime-silicate gneiss is in blocks 5 feet and larger; the schist and gneiss formed finer debris, mostly less than 1 to 3 feet in size. Material from the shear zone formed a fine-textured rock-flow which produced a flow pattern on the tail of the main slide mass.

Although most of the sliding probably occurred within a few minutes after the first and strongest shock, the configuration of the slide mass shows clearly that the western part, whose original slope averaged 37° and was locally 45°, moved much faster than the eastern part whose slope was 25°. The high velocity of the western part carried debris to the highest point of the slide mass, 400 feet above the river level, piling it in a newly unstable position so that some subsequently slid back southwestward down the valley. Part of the water scooped from the river was pushed upstream in a wave that inundated the campground and left a swash mark at the edge of the slide 100 feet above the valley floor. A similar but lower downstream wave reached a terrace 15 feet above normal water level and stranded fish in the sagebrush. Broken tree trunks were carried ¾ mile down the river channel. This evidence, coupled with the fact that considerable water went over Hebgen Dam from seiches on the lake shortly after the quake, gave rise to an early but erroneous report that a flash flood had reached the lower part of the canyon before the slide. Several survivors who were near the edge of the slide reported that just before the arrival of the water and rocks a violent air blast swept over them, overturning trailers and stripping off clothing. A coating of fine sand and mud was plastered on the southwest side of trees.

The eastern part of the slide mass shows much evidence of slower movement. Its surface is less disrupted; trees, although mostly uprooted, are little damaged and a few remained standing. Large blocks of sod with grass, small bushes, and trees that grew near the crest of the ridge are abundantly scattered in upright position over the surface. In fact this part of the slide so lagged behind the western part that part of it came to rest on the tail of the faster moving mass forming a trough 100 to 150 feet deep more or less accidentally along the buried river channel.

Clearly this part of the south wall of the canyon had been potentially unstable for a long time, because the resistant dolomite at its base had protected the deeply weathered schist and gneiss from normal downhill creep and sliding on a smaller scale. The area east of the dolomite wedge had reached an equilibrium slope. To the west, the dolomite mass was large and strong enough to withstand the shock of the earthquake and the mass of schist above was insufficient to break through it. In between the earthquake presumably weakened the tapering dolomite mass and loosened the millions of tons of weakened schist above it.

Alert to the dangerous possibility of a rapid breach in the slide dam when the newly formed lake spilled over it, a unit of the U. S. Army Engineer Corps was detailed to prepare a spillway half a mile long and 200 feet wide in the trough between the two parts of the slide, cutting down the original high point by 15 feet to prevent the water from reaching Hebgen Dam 6 miles upstream. The floor and part of the wall of the spillway were armored with coarse dolomite debris from the high part of the slide to minimize erosion. The outcome of this effort was yet to be learned as this article was prepared.

ARCTIC GEOLOGY SYMPOSIUM

Calgary
Jan. 11-1

The Third Circular has been issued a nouncing the development of the progra for the First International Symposium Arctic Geology which is to be sponsor by the Alberta Society of Petroleum Geol gists in Calgary, Alberta, Canada Janua 11-13, 1960. *(GeoTimes, July-August 195*

The basic program will feature papers

(1) Stratigraphy, biostratigraphy and te tonics of the circum-Arctic territori and of the Arctic Ocean "basin".
(2) Economic Geology, oceanography, gl ciology and permafrost.

The meetings will feature exhibits organizations and individuals relating geology of the Arctic. A polar projectic base map is being specially prepared f the symposium. It will encompass th area from the Pole to the 60th parallel latitude and will be issued at the scales 1:5,000,000 and 1:10,000,000.

Further information on the Arctic Syr posium may be obtained by writing D. W R. Wilson, *General Secretary, P. O. Bo 100, Calgary, Alberta, Canada.*

Exploration Geophysicists Meet On West Coast

Los Angele
Nov. 9-12

The 29th Annual Meeting of the Societ of Exploration Geophysicists will open o November 9 in the Biltmore Hotel, Lo Angeles. There will be more than 5 papers and addresses on petroleum, minin and research geophysics during the 3 day program. A general session on Thursday, November 12, will be held jointly wit the Pacific Sections of AAPG and SEPM

Featured on the program will be a address by President E. V. McCollum. James E. White and Frank Press will present a paper, "Progress and Research in Exploration." "Tests of an Airborne Gravity Meter" will be the topic discussed by L. L. Nettleton and L. LaCosta, while R. F. Bauer will talk on "Offshore Operations in California" and related Moho data.

The General Chairman is Flint Agee, Ted Braun is Program Chairman, and Dean Walling is in charge of entertainment