THE 1959 HEBGEN LAKE, MONTANA, EARTHQUAKE: TWO GEOLOGIC POINTS OF VIEW

by Irving J. Witkind
U.S. Geological Survey
Denver, CO 80225

Some 16 years ago a major earthquake, centered near Hebgen Lake, Montana, shook Yellowstone National Park, and abruptly brought to an end the bustling 1959 tourist season. That earthquake, formally known as "The Hebgen Lake, Montana, earthquake of August 17, 1959", was widely publicized, and as a result of the public's keen interest in the geologic features formed during the earthquake, the Forest Service set aside the area of

major damage as an educational and recreational area. Now, attractive exhibits and skilled naturalists explain the various geologic phenomena to the many tourists who annually pass through the area.

Immediately after the earthquake the Geological Survey began a series of intensive geologic investigations of the epicentral area. It soon became apparent that geologists viewing the same phenomena interpreted them differently. Two major concepts evolved each with its own adherents, and as the field work continued it became obvious that a vexatious controversy had begun. Neither side could uncover convincing evidence that would resolve the conflict. Finally, as the time came to prepare a formal report on the completed studies, the geologists concerned agreed to disagree.

Now, some 16 years later after additional geologic and geophysical work, where do we stand? It would be pleasant indeed to indicate that these additional studies have resolved the problem. In fact, the results are inconclusive and seemingly favor neither concept.

THE TWO CONCEPTS

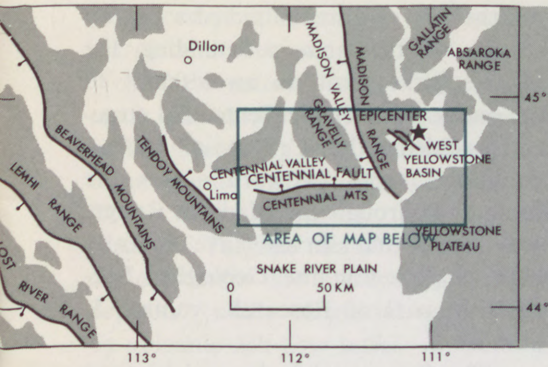
As geologists studied the epicentral area shortly after the earthquake it quickly became apparent that large blocks of the Earth's crust had subsided, but there were sharply different opinions as to which blocks had subsided and the exact pattern of deformation impressed on these blocks.

Single-basin concept.—One group of geologists concluded that the deformation pattern was best satisfied by the uneven subsidence of a single crustal block deformed into a basin. In their interpretation, the axis of this basin slopes gently northeastward from near the northeast edge of the Henrys Lake basin to end against the reactivated northwest-trending Hebgen and Red Canyon faults. They assume that the Madison Range subsided along with the flanking basins, but not as much.

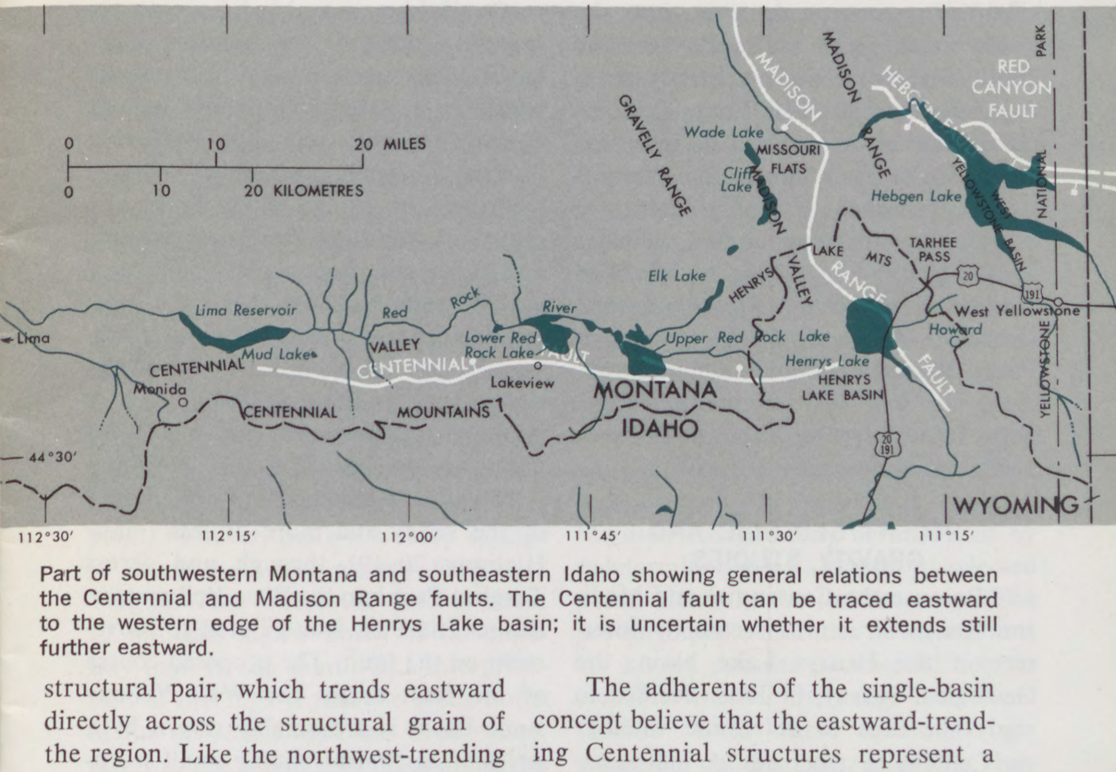
Dual-basin concept.—A second group of geologists concluded that the deformational pattern involved two basins of subsidence, one on each side of a tectonically stable Madison Range. Each of these basins slopes gently northeastward to end against reactivated faults; the West Yellowstone Basin (east of the Range) ends against the reactivated Hebgen and Red Canyon faults, and the Missouri Flats (west of the Range) end against the reactivated Madison Range fault. In this interpretation the Madison Range did not subside.

STRUCTURAL SETTING

Underlying this controversy is the fact that the advocates of each concept interpret the regional structure differently. This part of southwestern Montana and southeastern Idaho is marked by northwest-trending mountain ranges separated by narrow valleys —typical basin-and-range structures that result from extensional block faulting (see map). Most of these mountains are bordered on one flank by a high-angle range-front normal fault in which the valley is downthrown relative to the range. Thus, for example, the northwest-trending Madison Range is separated from the Madison Valley by the high-angle Madison Range normal fault. Similarly, the other northwest-trending ranges are separated from their adjacent valleys by high-angle normal faults. This persistent northwest trend of these structural mountain and valley pairs is interrupted by the Centennial Mountains–Centennial Valley



Index map of southwestern Montana and southeastern Idaho showing the basin-and-range pattern in this part of the northern Rocky Mountains. The general northwest structural grain of the region is disrupted by the eastward-trending Centennial Mountains-Centennial Valley structural pair. Heavy lines indicate high-angle normal faults. Bar and ball are on downthrown side.



Part of southwestern Montana and southeastern Idaho showing general relations between the Centennial and Madison Range faults. The Centennial fault can be traced eastward to the western edge of the Henrys Lake basin; it is uncertain whether it extends still further eastward.

structural pair, which trends eastward directly across the structural grain of the region. Like the northwest-trending structures, the Centennial Mountains also are separated from the Centennial Valley by a high-angle normal fault—the Centennial fault. Here too, the valley is downthrown relative to the mountains. Fresh scarps along the Madison Range and Centennial faults, as well as along most of the other high-angle faults, indicate that segments of virtually all the faults have been active within recent geologic time.

The adherents of the single-basin concept believe that the eastward-trending Centennial structures represent a fundamental change in a long-established structural pattern. In their view these are younger structures that are being extended eastward across the older northwest-trending structures represented by the Madison Range–Madison Valley structural pair. Consequently, they consider the earthquake to have been caused by movement on an eastward-trending deep-seated fault related to these Centennial structures. They suggest that primary movement on this deep-seated fault triggered secondary movement on the northwest-trending Hebgen and Red Canyon faults now marked by spectacular scarps. To support this view they suggest that the deformational pattern impressed on the downthrown crustal blocks is best described as a single basin of subsidence whose axis is alined with the eastward-trending Centennial structures.

By contrast, proponents of the dual-basin concept believe that the causative faults of the earthquake are the newly reactivated northwest-trending Hebgen and Red Canyon faults. They point to the geologic pattern near these faults as evidence that the renewed movement on these faults was merely one more episode in a sequence that began in the middle to late Tertiary time, and that has continued unbroken to the present. They see no evidence that the Centennial structures, some 40 km west of the epicentral area, have played any role in this particular earthquake.

RECENT GEOLOGIC AND GRAVITY STUDIES

Because the Centennial and Madison Range structures seemingly intersect in the Henrys Lake basin, the Geological Survey, in 1968, decided to study the area to determine whether the Centennial structures, do indeed extend across the southern ends of the Madison Valley and Madison Range. Consequently, the 15-minute Henrys Lake quadrangle (which includes the Henrys Lake basin) was mapped at a scale of 1:24,000, and subsequently published at a scale of 1:62,500 in the Miscellaneous Investigations map series of the Geological Survey as Map I–781–A. As the geologic work was going on, the Survey also conducted a gravity survey of the area surrounding the Henrys Lake basin in an attempt to determine whether the Centennial structures—chiefly the Centennial fault—could be traced eastward across the basin and through the Madison Range. Results of that survey have recently been published in the Geological Survey's Journal of Research, volume 3, number 2.

The Centennial fault can be traced eastward from near Mud Lake to the western edge of the Henry's Lake basin. Wherever exposed, it dips northward (valleyward) with the north block downthrown relative to the south one. Eastward beyond the western edge of the basin the extent of the fault is in doubt. A series of northeast-trending linear features have been interpreted as the fault trace. Of these, the most striking are two or three straight northwest-facing embankments (implying down-throw of the north block) which point directly toward the mouth of the valley of Howard Creek. The fault is thought to extend into the mouth of the valley and more or less follow Highway 20–191 through and across Targhee Pass into the West Yellowstone Basin. The Pass is attributed to movement on the fault. The proposed course of the fault across the West Yellowstone Basin is presumably shown by a series of eastward-trending small scarplets which face north and were formed during the 1959 earthquake.

These features, however, can also be interpreted as relicit valley walls formed when torrential melt waters, produced from the waste of an ice mass which lay in the West Yellowstone Basin, escaped southwestward through Targhee Pass and the valley of Howard Creek and removed the north half of an ancestral alluvial fan. The minor scarplets that break the floor of the West Yellowstone Basin may be the result of slump and compaction of basin fill resulting from the shaking that occurred during the 1959 earthquake. Does the Centennial fault extend through Targhee Pass? Regrettably, critical details are masked by surficial deposits, chiefly of glacial origin, and by volcanic ash-flow tuffs.

The results of the gravity survey showed a low with about 10 milligals of closure coinciding with the Henrys Lake basin. The gravity data in the basin are too few to determine whether the Centennial fault does extend eastward across the basin. The data do indicate a southwest-dipping gradient along the front of the Madison Range that reflects the Madison Range fault. Seemingly there is no break in the trend of the isogals where they cross the mouth of the valley of Howard Creek—the point where the Centennial fault is thought to cross the Madison Range fault and extend into the Madison Range. Northeastward beyond this point, however, there is a sharp change in intensity in the gravity field near Targhee Pass where the field is about 12 milligals higher north of the highway than to the south. One interpretation of this high is that the block north of the projected fault has been raised, but if so this is the only place along the Centennial fault where the north block is upthrown. It seems more likely that this gravity high is due to more dense Precambrian crystalline rocks which are exposed north of the highway, but are concealed beneath about 1460 metres of less dense sedimentary rocks south of the highway.

CONCLUSIONS

Despite the additional geologic and geophysical work done since 1959, it seems reasonable to conclude that definitive data which would either prove or disprove the single basin or dual-basin concepts have not been found. The present data still permit differing and conflicting interpretations. Two major questions still remain to be answered: Does the Centennial fault extend eastward across both the Madison Range fault and the southern end of the Madison Range? And, did the Madison Range subside along with the flanking basins during the earthquake—a precept inherent in the single-basin concept.

The first question may be answered by additional geophysical work. The second question—subsidence of the Madison Range—may be answered by redetermination of altitudes of selected points along the crest of the range. The pre-earthquake altitudes of these points are known and the data would help us evaluate whether the range did indeed subside. Until these questions are answered, the final details of the Hebgen Lake Earthquake continue to elude us.