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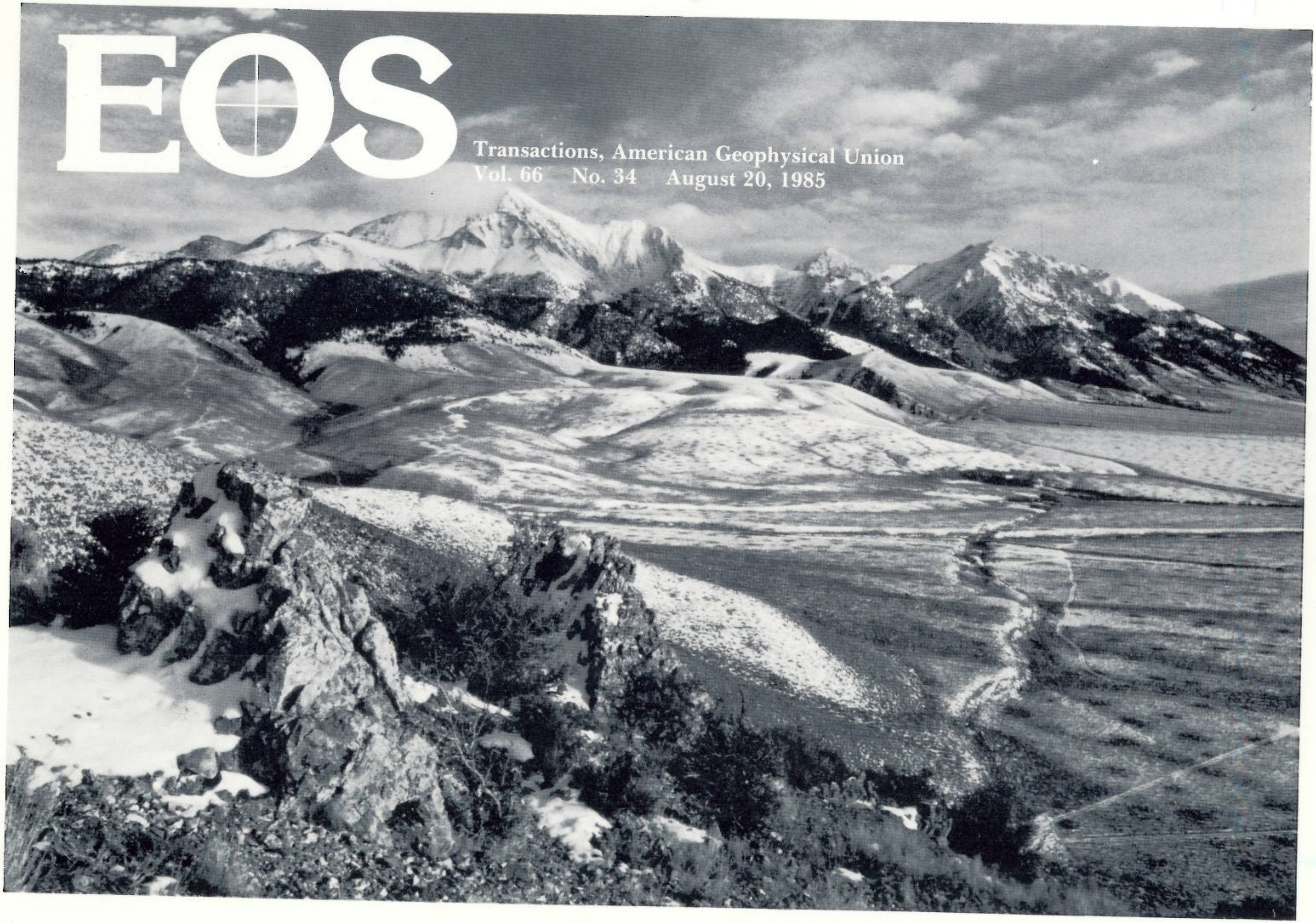

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News

Basin and Range Viewed From Borah Peak

In 1883, the brilliant geologist G. K. Gilbert wrote an article for the *Salt Lake Tribune*, "A theory of earthquakes of the Great Basin" (*American Journal of Science (3rd Series)*, vol. 27, p. 49, 1884), which began

> There are many geologists who are very wise, but even they do not understand the forces which produce mountains. And yet it must be admitted, not only that mountains have been made, but that some mountains are still rising.

Today, more than a hundred years later, Borah Peak has proved to be among those mountains still rising. During the October 28, 1983, **M** = 7 Borah Peak, Idaho, earthquake, the Lost River Range that is capped by Borah Peak was lifted 20–30 cm relative to distant points and was tilted downward away from the range-bounding Lost River fault. The downthrown side of the fault, which subsided as much as 120 cm, was also tilted down toward the fault. The similarity between the earthquake deformation and the cumulative deformation preserved by the dip of strata is striking and tends to confirm Gilbert's notion that basin and range topography is built by repeated slip events on range-bounding normal faults. The U.S. Geological Survey has just published a preliminary volume of 40 research papers on the Borah Peak earthquake, focusing on the surface faulting, seismology, geodesy, hydrology, and geology of the earthquake and its setting ("Proceedings of Workshop XXVIII on the Borah Peak, Idaho, Earthquake," edited by R. S. Stein and R. C. Bucknam, *U.S. Geological Survey Open File Report 85–290*, 720 pp., 1985; available from Muriel Jacobson, MS 977, U.S. Geological Survey, Menlo Park, CA 94025, telephone: 415-323-8111, ext. 2764). Also included is a field guide to the exploratory trench excavations and to the spectacular earthquake landforms, such as surface rupture, sandblows, and landslides.

The 35-km-long surface rupture formed by the 1983 Borah Peak earthquake on the Lost River fault mimicked the preexisting fault scarp with astounding precision. The scarp is better developed at Borah Peak than anywhere else along the 150-km-long range front fault, and for this reason it had been excavated and examined almost a decade before the 1983 earthquake. The scarp was found to have been created by at least one prehistoric slip event that cut and offset a 12,000- to 14,000-yr-old alluvial fan surface. When the fault deposits were exhumed in 1984, the old and new earthquakes were seen to have left nearly identical patterns of offset. Not only did the prehistoric and 1983 events both have an average surface slip of about 2 m, but—even more striking—the two events also displayed a similar variation in surface slip from one end of the fault to the other. Together the two earthquakes yield an average slip rate of about 0.3 mm/yr during the past 14,000 yr. This slip rate and record of earthquakes accord remarkably with the slip rate estimated from the total structural relief across the fault during the past 4–7 m.y. At this rate, events equal in size to the 1983 shock would repeat every 5,000–10,000 yr, a cycle much longer than the earthquake repeat times at plate boundaries but typical of those in the Basin and Range province.

A vast outpouring of water followed the Borah Peak earthquake for several months, amounting to an excess of nearly 1 km^3 over the expected seasonal runoff. Major changes in spring- and streamflow occurred throughout the region that had sustained slightly damaging shaking, as far as 150 km from the epicenter. In Yellowstone National Park, even Old Faithful responded to the shock, lengthening the interval between eruptions from 69 to 77 minutes. The Yellowstone geysers that changed their eruption duration and intervals lie 250 km from the earthquake, at the periphery of the felt area. In addition, about 30 giant sandblows formed or were revitalized near the main shock epicenter.

TABLE 1. Large Historical Great Basin Earthquakes

Date	Location	Moment magnitude, **M**
Jan. 9, 1872	Owens Valley, Calif.	7.8
Oct. 2, 1915	Pleasant Valley, Nev.	7.2
Dec. 10, 1932	Cedar Mountain, Nev.	7.0
Dec. 16, 1954	Fairview Peak, Nev.	7.2
Aug. 19, 1959	Hebgen Lake, Mont.	7.3
Oct. 28, 1983	Borah Peak, Idaho	7.0

Cover. Surface rupture formed by the October 28, 1983, **M** = 7.0, Borah Peak, Idaho, earthquake on the Lost River fault, viewed from atop a block of Paleozoic limestone. The 12,000- to 14,000-yr-old alluvial fan of Willow Creek had been cut and offset along the fault scarp (center) during at least one slip event before the 1983 earthquake. The dark stripe through the scarp face resulted from surface rupture during the 1983 event. The fault had been trenched a decade before the earthquake and a year after the event, revealing that the 1983 event mimicked the previous rupture with great precision. Borah Peak, Idaho's highest point, lofted an additional 10 cm into the air during the earthquake, while Chilly Sink, to the right of the fault, sank 100 cm and was partly flooded by earthquake-induced artesian spring flow. For more information on the earthquake and its aftereffects, see "Basin and Range Viewed From Borah Peak," by Ross S. Stein and Robert C. Bucknam, p. 603. (Photograph by Ross S. Stein, U.S. Geological Survey, Menlo Park, Calif.).

This postseismic effusion, a much larger volume of water than produced by any other conterminous U.S. earthquake, is still largely a mystery. It is believed that the flow did not issue from seismic depths, however, because neither the temperature nor the chemistry of the water differed much from those in the past. Either water was liberated from fractured and jointed rock and sediment during passage of the seismic waves, which generate large but transient cycles of contraction and extension alternating over periods of seconds, or water issued where the much smaller permanent strains were compressive, as when a sponge is squeezed. The predicted permanent strain changes of just a few parts per million, however, suggest that shaking may play the dominant role.

The long time interval between large Basin and Range earthquakes has made tectonic synthesis an exercise in patience, but a small yet valuable inventory of large (**M** ≥ 7) historical Great Basin shocks (Table 1) is now available for comparison with the Borah Peak earthquake. From the seismic and geodetic record, it now appears that all of the well-studied Great Basin events have occurred on moderately to steeply dipping planar normal faults that extend to about 15 km depth. This conclusion contrasts with geologic and more recent seismic reflection interpretations that favor low-angle detachment faults, which may be old thrust faults reborn, as the principal sites for accommodation of Great Basin extension. In this view, the high-angle faults must flatten or merge into the detachments or into ductile zones at comparatively shallow crustal depths. Seismic and geodetic evidence for contemporaneous slip, either on low-angle detachments or on faults that flatten with depth, is notably absent. Although it is difficult to reconcile these disparate views of continental rifting, each a long-standing proposition, it is nonetheless clear that the Borah Peak event did not reactivate the Mesozoic White Knob thrust sheet, which intersects the Lost River fault near the main shock. Instead, modeling of geodetic elevation changes and alignment of aftershocks indicate that the Lost River fault cuts cleanly through the crust in the plane of near-maximum shear stress predicted for an extending plate. Thus either the historical earthquakes are not a representative sample or slip on low-angle detachments occurs largely by creep.

The Borah Peak earthquake provided a stunning validation of the study of young fault scarps for the assessment of the location and magnitude of future large earthquakes. The maximum magnitude of earthquakes in the Basin and Range province can now be reliably estimated along particular fault sections. Although this capability falls short of earthquake prediction, it is nevertheless vital to earthquake forecasts and earthquake preparedness. Where young scarps exist, the fault slip to be expected during future earthquakes can be estimated from the measured offsets, and the length of the expected fault

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rupture can be gaged from the length of continuous fault segments. The rather uniform fault depth (about 15 km) and dip (45°–60°) of large historical Great Basin earthquakes, as inferred from seismic and geodetic analyses, indicate that the fault width (downdip dimension) of $M \geqslant 7$ events is about 20 km. Thus the fault slip, length, and width can be used to estimate the maximum seismic moment and thus the magnitude of future events. The Borah Peak fault segment meets these criteria: The south end of the 1983 rupture corresponds to a 50° bend in the Lost River fault, and the north end of the fault splays into two branches with markedly diminished prehistoric and 1983 event scarp heights. The prediction of the time of earthquakes with recurrence periods measured in thousands to tens of thousands of years is a much more tenacious problem, however, particularly given the dearth of documented precursory ground deformation or seismicity for Great Basin events. The microseismic record proved to be no oracle at Borah Peak: Although the earthquake lies within the diffuse Intermountain seismic belt, no shock of $M \geqslant 3.5$ had occurred near the epicentral region during the past 2 decades of monitoring.

Looking ahead from Borah Peak, the historically unbroken and heavily populated Wasatch frontal fault looms large. The Borah Peak shock has highlighted the fundamental similarities between the Lost River fault in Idaho and the Wasatch fault to the south in Utah. Both fault zones show greatest cumulative surface displacement and shortest measurable repeat times near the center of the ranges, and both fault zones appear to be typified by 2-m slip events. Thus the investigation of the Borah Peak event, in concert with continuing studies of the Wasatch fault-scarp morphology, slip history, and segmentation, begun by Gilbert more than a century ago, offers rare clues to assess the likely pattern of occurrence of future Wasatch fault events. It nevertheless remains uncertain whether the next great earthquake along the Wasatch fault will also strike the fault segment with the largest young scarp, as the Borah Peak shock (termed a "characteristic" earthquake) did, or whether it will occur along a segment that has no existing scarp (a "gap-filling" earthquake). The answer to this riddle will continue to elude us until it becomes known how faithfully slip at the surface records slip at seismic depths and whether variations in slip rate on adjacent scarp segments can persist for tens of thousands of years.

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