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Quake replay in the Great Basin

The continent was caught in the act of pulling itself apart in the 1983 Borah Peak earthquake. When will the next one hit?

by Ross Stein and Robert C. Bucknam

The yellow line in this Landsat satellite image indicates the rupture along the Lost River fault during the 1983 earthquake. The large yellow circle near the bottom locates the main shock Smaller circles represent aftershocks in proportion to their magnitude. The yellow square north of the fault is the town of Challis.

Just after breakfast on October 28, 1983, the floor of Thousand Springs Val-ley in Idaho started to vibrate. Within seconds, the motion grew violent. In the center of the valley, the Clark house shook so hard that no one in the family could stand up long enough to get out. The Lost River fault, a seam in the earth's crust that had held for 10,000 years, was begin-ning to unstitch. Ten miles beneath the valley, a small patch of the fault sheared and ruptured. and the faces of rock slid past each other. The rupture sped north-ward along the fault; in three or four sec-onds it accelerated to a velocity of 5,000 miles per hour. The growing tear generated bundles of seismic waves as it repeatedly hit and burst through more strongly bound patches of rock on the fault Fifteen seconds after the rupture begant the faces of the fault stopped moving; the rupture was now twenty-five miles long and ten miles deep.

At ground level, the rupture had etched a notch along the fan of gravel eroded from Borah Peak, Idaho's highest point, (named for William E. Borah. 1865-1940, who served for thirty-three years in the U.S Senate). Although the fault rupture had stopped growing, the seismic waves it produced continued to spread and co-alesce, like the expanding ripples formed by a stone skipped across a lake. Ten sec-onds later the waves passed through the town of Challis twenty miles to the north, killing Travis Franck and Tara Leaton. who were on their way to school when an old masonry storefront collapsed on them. Two minutes after the earthquake began, it was felt in Salt lake City, Utah; after four minutes, the seismic waves gently rocked Portland, Oregon; Seattle, Wash-ington; and western Canada, 500 miles from Thousand Springs Valley. In the next few hours, seismometers recorded the waves as they encircled the globe, yielding a magnitude of 7 on the Richter scale for the shock. The energy released was thirty times greater than that of the 1979 eruption of Mount St Helens in Washington State. In addition to the loss of the children, the shock caused $ 15 mil-lion in property damage. But it also pro-vided a rare chance to witness and investi-gate the repeat of an earthquake yielding to the tug of the slowly disintegrating North American continent

Elk hunters Don Hendrickson and John Turner were driving their Ford Bronco down a dirt road in Arentson Gulch, at the northern end of the Lost River fault in Idaho, when Don suddenly felt light-headed "I lost my equilibrium. I felt like I was going to pass out. I was ready to tell John at that time. 'There's something wrong with me; and right after that the Bronco just started shaking like crazy. It was off the ground completely, just rock-ing like this, and right soon after that, the bank dropped and I was hanging on to the steering wheel." The fault cut the ground sixty feet in front of them and dropped the side bearing the Bronco three feet. "I looked over to John and he was flying in the passenger seat. He was between the two seat,. trying to get up. And he said. 'What's going on? I wasn't about to an-swer, because I didn't know." Later, Don recalled. "That's when the quake went into its greatest violence, and that's when the noise came in. And it was deafening, a deafening rumble." The noise may have been the sound of rock grinding along the fault face or of landslides and boulders tumbling down the sleep mountain front.

A half mile to the north of the bucking Bronco, William Knox was driving elk over a ridge while his wife, Lawana, waited below for a clear shot. When the shaking started, William felt sick and in-stantly went down on one knee. As the motion intensified, he lay on his stomach and was rolled back and forth by the ground motion. The shaking "might have been a half minute but it felt like a life-time," said Lawana, who suffered whip-lash from the quake's strong motion. When the shaking subsided, she watched the rupture cut across the mile-wide hill-side, "just as though one took a paintbrush and painted a line along the hill." In a second, it raised one side of the hill and dropped the other side three feet. Eyewit-ness accounts of the fault rupture - as op-posed to the shaking - are rare; these ob-servations help clarify the speed and character of the rupture.

The earthquake triggered an upsurge of ground water, the largest deluge ever re-corded following an earthquake in the United Stales. When the members of the Clark family finally got out of their house and into their truck to escape, they found water coming up through the road and ground and shooting ten to twenty feet into the air around them. Water cascaded down adjacent Chilly Buttes and flooded the road, barring their flight. In the fields just to the north, Del Clark saw the craters first hurl dry sand into the air, then sand and water, and finally, muddy water. In a few hours, a shallow lake had formed, and in a few days, everything froze over. A string of forty craters stretched along the ground; the largest would make an Olym-pic-size swimming pool. Each crater was surrounded by a blanket of sand thrown up by the force of the effusion. The holes at Chilly Buttes pocked the ground a few miles west of the earthquake rupture, suggesting that the water might have been released from the fault. But a few old-time ranchers remembered a simi-lar fountain effect in Thousand Springs Valley after the 1959 Hebgen Lake, Mon-tana, earthquake, which struck 150 miles away-too far away to be the result of water released from the Hebgen Lake fault. One crater formed in the valley in 1959 had been appropriated as a refuse dump. Now, twenty-five years later, the trash was ejected back to the surface in a ring around the crater. It therefore seems more likely that the passage of the seismic waves jostled blocks in the limestone buttes and the wet sand and gravel in the valley, forcing the water rapidly to the surface. (Even the name Thousand Springs Valley suggests such leakiness.) Similar sand-circumferenced craters have been found near other faults, but the erup-tive process had never before been so closely watched.

Most of the postearthquake Borah Peak effusion issued from Lost River drainages much farther from the rupture than Thou-sand Springs Valley. To the north, the Clayton silver mine flooded, and Will In-gram's Warm Springs fish hatchery - and the fish in it - dried up. A week later, Warm Springs gushed water at ten times its former rate of flow. Ingram abandoned fish farming and, making use of the in-crease in water flow to generate power, now supplies hydroelectricity to the Utah Power and Light Company. About 150 miles to the east, at Yellowstone National Park, even Old Faithful reacted to the shock,

lengthening the interval between its eruptions by eight minutes. Big Lost River, which skirts Thousand Springs Val-ley, and five other rivers coursing the neighboring valleys abruptly doubled their flow. The discharge from these streams remained high for six months. The water released by the earthquake-400 billion gallons - could supply New York City for eight months.

The Idaho earthquake took place along what is known as a basin and range fault. The immediate cause of the quake was the sudden release of stress along the Lost River fault where its two rocky sides had been slipping against each other in opposite directions for about five million years. During the quake, the ranges were raised about one foot. The opposing rocks were depressed to form the bottoms of basins. At the same time, for reasons not yet entirely clear, the opposite sides of the fault were being pulled apart horizontally. The best hypothesis offered for the spreading is that it is caused by the slow, horizontal flow of the viscous layer of material below the earth 's crust.

In September 1883, the American geologist Grove K. Gilbert wrote an article for the Salt Lake Tribune that 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." One hundred years later, Borah Peak proved to be among those mountains still rising. The Lost River Range, capped by Borah Peak, was up-lifted one foot during the earthquake, while Thousand Springs Valley subsided four feet. As a 28-year-old assistant with the 1871 Wheeler expedition, which was charged with surveying the land won in the Mexican War of 1846-48, Gilbert spent two years exploring the Great Basin, a vast inland area between Colorado and California, whose streams, rivers, and lakes have no outlet to the sea. Gilbert recognized that the regular alternation of narrow valleys and mountains-called ba-sin and range topography-had been built by repeated earthquakes on faults that slice through the earth's crust. As the two sides slip past each other, the ranges are not only lifted above the valleys, they are also moved apart horizontally. The Great Basin is thus stretching and, as a result, being thinned.

How can mountains rise while the earth's crust is thinned? The answer may lie beneath the faults. The earth's crust behaves like a stiff rubber layer floating on a viscous, honey-like fluid. When this sandwich is pulled from the ends, the rub-ber first thins and then tears, or faults. The rubber on one side of the fault springs up (the mountain) and on the other side drops down (the valley). During the long period between earthquakes, the viscous sub-strate flows beneath the uplifted layer, filling the void left by the upward-warping mountain. Thus the mountain is progres-sively tilted on end and floats on an ever--thickening viscous fluid.

During the past ten million years, the Great Basin has increased its original girth by perhaps 50 percent. Gilbert could only infer that the crust was stretching, but in the past few years, the rate of exten-sion has been measured. The arrival of faint radio impulses emitted by distant stars called quasars are timed at receivers stationed at the periphery of the Great Basin. Over the past decade, the differ-ences in the arrival times of the impulses have lengthened, corresponding to an in-crease in the distance between the receivers of one-half inch per year. These mea-surements accord well with the rate of Great Basin extension averaged over the past ten million years as deduced by sum-ming the slip on the faults that span the Great Basin. This rate may appear slow, but it means that three acres of real estate are created yearly in the Great Basin.

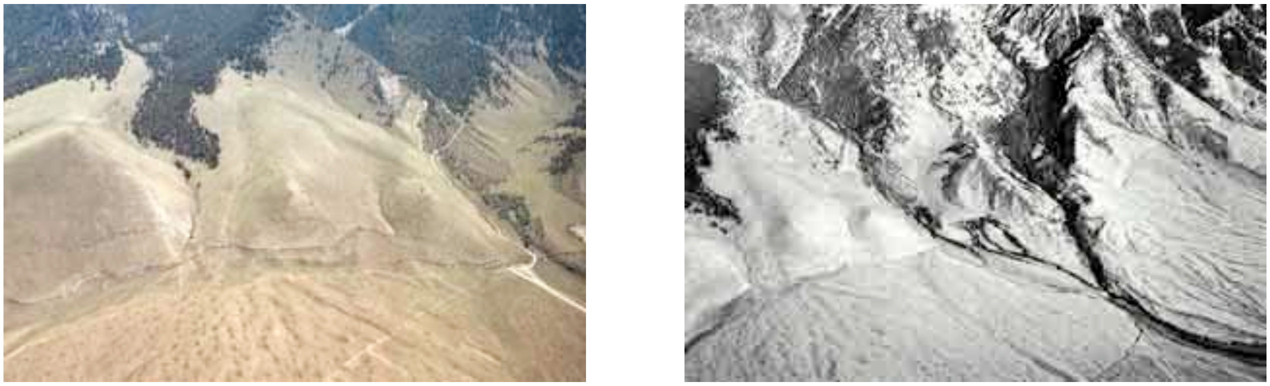
Changes in the faulted landscape of Thousand Springs Valley reveal that a major earthquake occurred there about 10,000 years ago, as well as in 1983. This remarkable encore furnishes the best evi-dence that we have ever had for the repe-tition of a major earthquake in the Great Basin. Such a pattern would have escaped notice had the 1983 Borah Peak earth-quake not been so simple and accessible an event, lending itself to scrutiny by a hundred earth scientists. The most impor-tant of their efforts was the least complex:

study of the displacement of the ground surface caused by the rupture. Material eroded from a mountain is carried by streams and deposited into a gently sloping fan of debris. An earthquake rupturing a fault cuts the fan at the base of a mountain; part is uplifted with the mountain, and part drops down with the valley. The small cliff, or step, formed in the fan is called a fault scarp; the height of the scarp records the amount the fault has slipped. Over time, the scarp erodes or is buried until it can no longer be distinguished on the fan surface, a process that takes about 100,000 years in arid Idaho, Utah, and Nevada.

A decade ago, geologists recognized that the existing scarp at the foot of Borah Peak was as high and fresh as any other along the 100-mile-long Lost River fault and might therefore be the site of a future earthquake. Not only did that earthquake occur, but the new scarp created by the 1983 Borah Peak shock is identical to its predecessor; the scarp is now lifted to twice its former height.

The Lost River fault thus created two nearly identical earthquakes during the past two ruptures at Thousand Springs Valley. But are all ruptures of the fault at the valley similar to the 1983 event? Borah Peak now stands one and a half miles above the deepest deposits in the valley, although they are composed of the same rock and once stood at the same level. If each earthquake increased this separation between Borah Peak and the valley by six feet, then the Borah Peak shock must have struck 1,500 times since the birth of the fault about five million years ago. Scant evidence rarely restrains earth scientists from extending a twice-observed pattern a thousand times, particularly when the replication of the pattern is so exact.

What about other strands, or segments, of the Lost River fault and strands of different faults in the Great Basin: is each fault segment repeatedly revisited by its own characteristic earthquake? Here the data stream turns into a trickle. A repeating, moderate-sized earthquake is known to occur in the center of the San Andreas fault at Parkfield, California, but the occurrence of small earthquakes is nearly random. Associating each fault segment with a particular recurrent earthquake accordingly remains a tantalizing hypothesis in need of proof. If large earthquakes do recur in the same locality, then the magnitude and location of past shocks could be used to assess future large earthquakes in the Great Basin. Because the historical record is so brief, however, the archive of large earthquakes must be read from such landforms as fault scarps.



Aerial photographs taken twenty years apart show the same location of the Lost River fault. In th eleft photograph, taken after the 1983 earthquake, new scarps coincide with preexistingfault scarps created 10,000 years ago. In the right picture, made in 1963, the prehistoric scarps had been subject to degradation and weathering for thousands of years and were consequently smoother,softer, and more rounded than the new scarps.

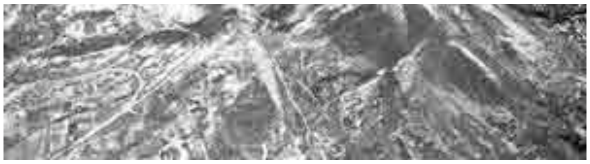
Two sound hypotheses of earthquake recurrence lead to diametrically opposing interpretations of what scarps bode for the future. In the first view, fault segments that lack scarps are deemed overdue for an earthquake and should be the next to go. If the rate of slip is uniform along the length of a fault, then the segments that have not yet ruptured must carry more of the load. Consider a piece of paper with a perforated line down the center and a small portion of the segments left uncut (and thus without fault scarps). When the two halves of the paper are pulled apart, the remaining segments will soon rip.

In the second view, the fault segments with the highest scarps are hosts to the greatest number of earthquakes. If the slip rate on the fault is greater at the center and diminishes to zero at the ends, earthquakes would occur more frequently in the center. Consider a piece of paper cut most of the way through; when the two sides are pulled gently apart, the center of the cut will separate the most (and thus produce the highest scarps). Along the best-studied faults in the Great Basin, the highest and freshest scarps are found along those segments near the center of the faults. Degradation of the scarp indi-cates that the most recent event on the Lost River fault occurred about 4,000 years ago just south of the 1983 rupture, whereas the ends of the fault have not ruptured for about 30,000 years. Thus, the evidence from Borah Peak lends new weight to the second view, suggesting that efforts to monitor faults in the Great Basin should be focused primarily, but not ex-clusively, on segments with the most im-posing scarps and the fastest rates of fault displacement.

Observations of scarp height and fresh-ness may therefore be plausibly transformed into forecasts of the location and magnitude of future earthquakes. Faults with prominent scarps are candidates for eventual repeat earthquakes. Both the Lost River fault in Idaho and the Wasatch fault in Utah separate into a string of twenty-mile-long fractures, each with a scarp produced by a separate prehistoric earthquake. The amount of fault slip can be gauged by the height of the prehistoric scarps, and the rupture length can be esti-mated by identifying scarps that extend continuously between bends or breaks in the fault. Earthquake magnitude is re-lated to the area of the rupture multiplied by the amount of slip on the fault. Because seismometers have recorded the larger shocks in the Great Basin originating at a depth of ten miles, only the fault length is needed to estimate the rupture area. Such a forecast is a major advance in attempts to lessen earthquake hazards, but it falls short of an earthquake prediction because the time lapse until the impending shock on each segment is missing.

Earthquake prediction is nowhere more difficult, and in few places more impor-tant, than in the Great Basin. Almost 90 percent of Utah's population lives within view of the scarps of the 230-mile-long Wasatch fault. Despite a search of news-papers and diaries kept by settlers, no large shocks seem to have been reported there since Brigham Young's arrival in 1847. Nor is an earthquake warning by monitoring for small foreshocks likely; none were detected near the eventual 1983 rupture at Borah Peak during two decades of monitoring before the main shock. Both the Lost River and Wasatch faults have been largely free of small shocks during the past twenty-five years of observation. Because it takes hundreds of years to strain the earth's crust enough to cause a segment of the Wasatch fault to rupture, the 140-year quiet does not mean that large earthquakes will not strike in the future. "Any locality on the fault line of a large mountain range, which has been exempt from earthquakes for a long time, is by so much nearer to the date of recurrence," said Gilbert in the nineteenth cen-tury. "It is useless to ask when this disaster will occur. Our occupation of the country has been too brief for us to learn how fast the Wasatch grows: and indeed, it is only by such disasters that we can learn."

Following the Borah Peak earthquake, some ground on the Lost River fault shattered (right). Faults themselves do not commonly open up, but if they do, the result



may be a dramatic crevice that never closes. The Wasatch fault in Utah, left, is the dark line running horizontally at the base of the mountains. The segment of the fault shown here, which last ruptured 1,000 years ago, is just south of Salt Lake City and goes through what is now a populated area. Based on the information they acquired at Borah Peak, geologists believe this part of the Wasatch fault is likely to experience a damaging earthquake sometime within the next several hundred years.

In the century since Gilbert opened our eyes to the rich prehistoric record pre-served in the faulted landscape of the Great Basin, the scarps have taught us something of "how fast the Wasatch grows." A decade of geologic investiga-tion at the Wasatch fault shows that it is slipping an inch every twenty-five years, and one of its six to eight strands ruptures every 450 years. The segments of the Wa-satch that appear most primed to rupture are those near Salt Lake City and Provo, Utah. With this insight, it is now incumbent upon us to ask "when this disaster will occur." Today, we can only say that the next rupture is less than five hundred years off. We will continue to sift through observations of the spectacular and tragic Borah Peak, Idaho, earthquake to see what clues might have alerted us to the imminent event. But if we cannot yet pre-dict when the next earthquake will occur, at least we know where it will strike and how strong it will be. It is therefore vital that we prepare for it now. And we must prepare not just for the fault rupture and for the ground shaking it generates but also for the possibility of a flood of water issuing from the ground.