INSTRUMENTAL SEISMICITY OF CENTRAL IDAHO

BY JAMES W. DEWEY

ABSTRACT

Hypocenters of regionally recorded earthquakes that occurred in central Idaho from 1944 through October 1985 have been recomputed with travel times calibrated by locally recorded aftershocks of the Borah Peak, Idaho, earthquake of 1983. The effect of the relocation is to define more sharply the sizes and relative positions of seismic source zones in central Idaho and to move epicenters systematically south, often by more than 10 km, from their previously cataloged positions. The distribution of epicenters of the Borah Peak main shock and early aftershocks suggests that the fault segment that ruptured in the main shock was approximately a parallelogram with one pair of sides parallel to the zone of surface fault scarps associated with the earthquake and with the other pair of sides parallel to the slip vector of the earthquake. Such a rupture shape would be expected on geometrical grounds if the 1983 rupture zone were terminated on the north and south by intersection with adjacent segments of the Lost River fault that have the same slip vector as the 1983 rupture. Epicenters of earthquakes occurring before 1983 define a seismic zone, the White Cloud Peaks zone, that is approximately parallel to the Borah Peak aftershock zone but situated from 30 to 40 km to the west. The relocated epicenters may also be interpreted as defining a north-northeast trending seismic zone near Seafoam and a north-northeast trending seismic zone that is situated north and west of Challis, here called the Twin Peaks-Myers Cove zone. The Seafoam zone includes the epicenter of the largest instrumentally recorded central Idaho earthquake prior to the Borah Peak earthquake, the magnitude 6.1 shock of 12 July 1944. The region within 25 km of the epicenter of the Borah Peak main shock was quiescent for at least two decades before the main shock for magnitudes $[m_b(L_p)]$ of 3.5 and greater.

INTRODUCTION

Following the Borah Peak earthquake of 28 October 1983 (dates of earthquakes are denoted as year.month.day in figures), research groups from the U.S. Geological Survey and several universities installed portable seismographs in the seismosismal region and recorded strong aftershocks that were also recorded teleseismically (Boatwright, 1985; Richins et al., 1985). I have used arrival times from the locally and teleseismically recorded aftershocks to calibrate the location of the hypocenters of the Borah Peak main shock and of other earthquakes from central Idaho and vicinity (Figure 1) that were instrumentally recorded to epicentral distances of at least 5°. The earliest such shock occurred in 1944, and the period covered by this study ends in October 1985. Prior to the local registration of the 1983 aftershocks, absolute positions of well-recorded central Idaho earthquakes would have had to be considered uncertain by 10 or 20 km because of lateral variations of seismic wave velocity in the earth's mantle beneath the Western United States (Herrin and Taggart, 1962).

METHODS OF RELocATING HYPOCENTERS AND RECOMPUTING MAGNITUDES

I used as the general location method a two-step procedure based on the method of joint epicenter determination (JED). The general method is described by Dewey (1983); in detail, the earthquakes were divided up into four groups on the basis of

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Fig. 1. The most reliably located epicenters (those with 90 per cent confidence ellipse semi-axes shorter than 15 km) for the period 1944 to 31 October 1985. WCP = White Cloud Peaks zone; S = Seafoam zone; TPMC = Twin Peaks-Myers Cove zone. The line striking at azimuth 28° is parallel to the horizontal projection of the slip vector of the Boreh Peak main shock. Late Cenozoic faults are taken from the compilation of Witkind (1975). LR = Lost River fault; L = Lemhi fault; B = Beaverhead fault; "u" and "d" indicate, respectively, the upthrown and downthrown blocks of these three faults.

their previous epicentral positions and their dates of occurrence, and each group was treated slightly differently. The four groups, and the ways in which they were analyzed, are discussed in subsequent paragraphs in this section.

For all four groups, the first step of the location procedure consisted of processing up to 15 of the most widely recorded earthquakes in each group by the method of JED. The JED provided station adjustments to the travel-time tables and estimated variances of the observations for use in constructing weighting functions. Focal depths were fixed in this first step, in order to prevent the joint computation of location parameters and station adjustments from becoming unstable in the event that a focal depth of one of the earthquakes were computed to be negative (Dewey, 1983). In the second step of the location procedure, I used a single-event location method with the JED-computed station adjustments and variances to relocate all earthquakes in each group (not just the 15 used in the JED computation), and I usually computed both focal depth and epicenter. If the free-depth hypocenter was computed to lie above the earth's surface or if the free-depth computation did not converge, I recomputed the epicenter with depth fixed at 10 km. The epicenters
plotted in the figures were determined in the second step. In addition to first-arriving $P$ waves from stations located out to epicentral distances of 86°, later phases ($P_g$, $S$, $L_g$) were used in the location process. $P$-wave and $S$-wave travel-time tables were constructed from velocity model T7 of Burdick and Helmberger (1978); $P_g$ and $L_g$ velocities were taken to be 6.0 and 3.5 km/sec, respectively (Sheriff and Stickney, 1984).

The first group of earthquakes comprised shocks of the 1983 Borah Peak sequence. Rather than use a calibration event (Dewey, 1979) to constrain the JED computation, I assumed that travel times to local stations out to distances of 0.6° were unbiased and as predicted by the Burdick and Helmberger (1978) velocity model. Station adjustments were computed for stations at epicentral distances of more than 0.6°. In the JED computation, focal depths of Borah Peak aftershocks occurring after 29 October were fixed to values determined from locally recorded data by HYPO71 using a local velocity model similar to that used by Richins and others (1985) (S. Goter, personal communication). Focal depths of several large aftershocks occurring on 28 and 29 October were fixed in the JED computation to depths implied by $pP$-wave arrival times at the telemeter station PMR (all station abbreviations are as given by Poppe et al., 1978).

Earthquakes occurring in the study area west of longitude 113.5°W from 1963 through 27 October 1983 were treated as the second group in the location procedure. Definition of the second group was necessitated by space limitations in my JED code, which would have unduly restricted the number of station adjustments that could be computed had I treated the Borah Peak aftershocks and the pre-1983 earthquakes simultaneously. There were 24 stations that recorded many of the second group of earthquakes and that also recorded the 1983 Borah Peak earthquakes. In the JED computation for the second group of earthquakes, adjustments at these stations were fixed to the values computed for the Borah Peak sequence. The 24 stations thereby became “calibration stations” with respect to which station adjustments were computed for 76 other stations that recorded many of the second group of earthquakes but that did not record the Borah Peak aftershock sequence. In this fashion, the locations of the pre-1983 earthquakes were calibrated with respect to the Borah Peak sequence. There may be an uncertainty of several kilometers in the position of the second group of earthquakes with respect to the Borah Peak group, due to departures from the assumption that station adjustments for the 24 calibration stations are constant for all source regions in central Idaho.

For the purpose of computing station adjustments, the focal depths of the second group of earthquakes were fixed at 10 km in the JED computation. In the event that the assumed 10-km focal depth were systematically too large or too shallow, the focal depths of hypocenters computed by the single-event location program would also be systematically too deep or too shallow (Dewey, 1983). To obtain independent estimates of focal depth, I tried computing focal depths, rather than fixing them, at the same time that I was computing the station adjustments: instead of using JED to compute the station adjustments, I used joint hypocenter determination. The median of depths thus computed was 10 km, the deepest focal depth computed was 18 km, and the shallowest was computed to lie above the surface. The precision of the focal depth computation is low for most of the hypocenters computed in the joint hypocenter determination of the group 2 events, but the results of the joint hypocenter determination give support to my choice of 10 km as the depth to which events are fixed in the joint epicenter computation of station adjustments.
Instrumentally recorded earthquakes occurring in the study region west of longitude 113.5°W from 1944 through 1962 constituted the third group of shocks. The third group differs from the second group by the time period during which its earthquakes occurred; the group was defined in order that the epicentral confidence ellipses of the pre-1963 events reflect the relatively high variances of the earlier arrival-time data, rather than the variances of the 1963 to 1983 data set. Half of the stations used for the third group had been used in the first or second groups; these stations were used as calibration stations for the third group, with their station adjustments taken to be those computed for group 1 or group 2. Focal depths for earthquakes in this group were fixed to 10 km throughout the location procedure.

The fourth group of earthquakes consisted of shocks located east of longitude 113.5°W and was separated from the other groups because of my concern that locations of earthquakes in this region could be affected by a substantially different source bias than earthquakes in the Borah Peak aftershock zone. The epicenters are halfway between the Borah Peak source and the source of the Yellowstone Park earthquake of 30 June 1975, the location of which is also known to high accuracy as a result of aftershock studies (Pitt et al., 1979). Epicenters of earthquakes in the fourth group that were calibrated by the Yellowstone Park earthquake lay 5 to 10 km west of the corresponding epicenters calibrated by the Borah Peak aftershocks, probably because of variations of upper mantle velocities in the Yellowstone region. The epicenters for the region east of 113.5°W were finally computed with respect to 6 January 1965 (Table 1) as a calibration event, with the epicenter of this shock fixed to a position mid-way between the 8-km-apart epicenters computed with,

### Table 1

**Catalog of Central Idaho Earthquakes with M = 6.0 or Larger, 1944 to 1962, or with m = 4.5 or Larger, 1963 to October 1985**

<table>
<thead>
<tr>
<th>Date (d-m-y)</th>
<th>Time (UTC)</th>
<th>Latitude (°N)</th>
<th>Longitude (°E)</th>
<th>Depth (km)</th>
<th>Magnitude</th>
<th>90% Confidence Ellipse*</th>
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</thead>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Trend† Semi-Major Semi-Minor</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(km) (km)</td>
</tr>
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<td>193020.7</td>
<td>44.412</td>
<td>−115.063</td>
<td>10.0‡</td>
<td>6.1 PAS</td>
<td>81.1 14.8 10.2</td>
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<td>14-02-1945</td>
<td>030111.3</td>
<td>44.607</td>
<td>−115.087</td>
<td>10.0‡</td>
<td>6.0 PAS</td>
<td>85.8 14.8 10.9</td>
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<td>27-01-1963</td>
<td>152443.8</td>
<td>44.190</td>
<td>−114.528</td>
<td>11.4</td>
<td>4.8 m(L)</td>
<td>84.1 6.9 5.6</td>
</tr>
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<td>11-09-1963</td>
<td>2 843.7</td>
<td>44.177</td>
<td>−114.615</td>
<td>8.1</td>
<td>4.8 m(L)</td>
<td>107.2 5.1 3.5</td>
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<tr>
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<td>44.181</td>
<td>−114.621</td>
<td>9.2</td>
<td>4.7 m(L)</td>
<td>95.6 5.3 4.3</td>
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<tr>
<td>06-01-1965</td>
<td>2 120.7</td>
<td>44.772</td>
<td>−112.746</td>
<td>10.0‡</td>
<td>5.0 m(L)</td>
<td>77.3 7.7 5.5</td>
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<td>44.058</td>
<td>−114.444</td>
<td>18.2</td>
<td>4.9 m(L)</td>
<td>67.8 6.4 3.7</td>
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<td>29-10-1978</td>
<td>134645.6</td>
<td>44.866</td>
<td>−114.243</td>
<td>11.9</td>
<td>4.7 m(L)</td>
<td>69.8 4.3 3.0</td>
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<td>28-10-1983</td>
<td>14 6 6.5</td>
<td>43.974</td>
<td>−113.916</td>
<td>14.0</td>
<td>7.3 M,GS</td>
<td>−171.0 3.8 3.0</td>
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<td>5.4 m,GS</td>
<td>66.4 2.9 2.0</td>
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<td>44.241</td>
<td>−114.109</td>
<td>10.7</td>
<td>5.5 m,GS</td>
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<tr>
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<td>−114.086</td>
<td>6.6</td>
<td>4.5 m,GS</td>
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<td>44.072</td>
<td>−114.403</td>
<td>10.0‡</td>
<td>4.5 m,GS</td>
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<td>94630.3</td>
<td>44.374</td>
<td>−114.062</td>
<td>13.0</td>
<td>5.0 m,GS</td>
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<td>08-09-1984</td>
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<td>−114.128</td>
<td>9.7</td>
<td>5.0 m,GS</td>
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<td>06-02-1985</td>
<td>193419.4</td>
<td>44.486</td>
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<td>9.7</td>
<td>4.7 m,GS</td>
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<td>17-03-1985</td>
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<td>44.472</td>
<td>−114.220</td>
<td>10.0‡</td>
<td>4.5 m,GS</td>
<td>77.5 4.1 2.9</td>
</tr>
</tbody>
</table>

* Confidence ellipse is on epicentral coordinates and is computed by the method of Evernden (1969).
† Trend is that of the semi-major axis and is measured in degrees clockwise from the north.
‡ Indicates that depth was fixed in the computation.
respectively, the Borah Peak and the Yellowstone Park station adjustments. Focal depths were fixed to 10 km in the JED computation of the station adjustments.

The arrival times obtained within 0.6° of the Borah Peak aftershocks are those recorded by temporary seismographs installed in the seismotectonic region by the U.S. Geological Survey, University of Utah, Boise State University, and the Idaho National Engineering Laboratory (Boatwright, 1985; Richins et al., 1985). Arrival times at more distant stations are mostly those reported in international seismological bulletins such as the bulletins of the International Seismological Centre, the bulletins of the Bureau Central International Seismologique, and the Earthquake Data Reports of the U.S. Geological Survey. For earthquakes occurring in 1963 to 1982, I supplemented the previously published arrival time data with data I read from nearby stations of the World Wide Standardized Seismograph Network and the Canadian national network.

Most of the relocated earthquakes had been assigned mb magnitudes in Preliminary Determination of Epicenters (PDE) listings, now published by the U.S. Geological Survey and formerly published by agencies of the U.S. Department of Commerce. Seismologists at the U.S. Geological Survey have recognized for some time that mb values for shallow-focus earthquakes that are based solely on regionally recorded P-wave amplitudes may systematically overestimate the sizes of the earthquakes (see also Evernden, 1967). Since the mid-1970’s, P-wave amplitudes recorded at distances of less than 15° have usually not been used in the computation of PDE mb for shallow-focus earthquakes (W. Person, personal communication), but such data were routinely used to assign mb to many of the 1960’s and early-1970’s earthquakes considered in this study.

I assigned mb(L9) magnitudes (Nuttli, 1973) to earthquakes occurring from 1963 to the Borah Peak main shock, using L9 amplitudes measured on stations of the World Wide Standardized Seismograph Network and stations of the Canadian national network. Because of lateral variations in attenuation of L9 waves propagating from central Idaho, different values of the anelastic attenuation parameter (γ) were used for L9 waves recorded at different stations. Values of γ were interpreted from contour maps of Espinosa (1981) and Singh and Herrmann (1983) and then adjusted slightly in order that magnitudes from different stations agree with each other for most earthquakes. For MSO, PNT, and SES (Poppe et al., 1978), γ was taken as 0.07/°; for EDM, 0.2/°; for BOZ and DUG, 0.3/°; and for GOL, 0.4/°. I found it necessary to use two different values of γ for L9 waves recorded at LON in order to avoid systematic inconsistencies between mb(L9) computed for LON and mb(L9) computed for other stations. For earthquakes west of 113.5°W, I used γ = 0.4 at LON. For earthquakes east of 113.5°W, I used γ = 0.2 at LON.

The newly assigned mb(L9) magnitudes are similar to the PDE mb for the larger central Idaho shocks that occurred from 1963 until the Borah Peak earthquake. The PDE mb are systematically larger than my mb(L9) for shocks of mb(L9) = 4.0, and the discrepancy increases with decreasing mb(L9). This is consistent with the computed PDE mb having relied more on regional data for progressively smaller shocks and becoming more biased in consequence. For 10 shocks of mb(L9) 4.1 and larger, the mean difference between mb(PDE) and mb(L9) is −0.01 ± 0.09. For 126 shocks of mb(L9) below 4.0, the mean difference between mb(PDE) and mb(L9) was 0.90 ± 0.13.

Hypocenters of the larger earthquakes relocated in this study are given in Table 1. I will provide a complete listing of all relocated shocks upon request.
Effect of Relocating Hypocenters

Figure 2 shows the consequences of relocating the most widely recorded members of a group of earthquakes that occurred in the White Cloud Peaks region of central Idaho, west of the Borah Peak aftershock zone, in 1963 to 1973. The effect of the relocation was to move the shocks systematically to the south and to show that the earthquakes occurred in a narrower source region than would have been inferred from the previously accepted epicenters of the shocks. The southward shift in the recomputed epicenters with respect to the previous epicenters is probably due to removing the bias that results from upper mantle velocities to the south of Idaho being slower than upper mantle velocities to the north of Idaho (Herrin and Taggart, 1962; Dewey et al., 1972; Trimble and Smith, 1976). The reduction in scatter of the epicenters is due partly to correcting for lateral variations in velocity and partly to the improvement of the quantity and quality of the data used to locate the shocks.

The difference between my hypocenters and those routinely computed by the U.S. Geological Survey are generally smaller for the Borah Peak sequence than for the earthquakes shown in Figure 2. My main shock epicenter is 10 km south of the routine U.S. Geological Survey main shock epicenter. Most of the revised epicenters of aftershocks are south of the corresponding routine U.S. Geological Survey epicenters, by distances of less than 10 km. The lower bias in the routine U.S. Geological Survey locations of the 1983 shocks, compared to that for the 1963 to 1973.

Fig. 2. Comparison of hypocenters determined in this study (JED) with the corresponding routinely determined epicenters (PDE) for the White Cloud Peaks zone. Earthquakes plotted are those that occurred in 1963 to 1973 and whose relocated epicenters had 90 per cent confidence ellipses with semi-axes smaller than 10 km.
1973 shocks, is probably due to a larger number of seismographic stations in 1983 that were within several degrees of the epicenters.

Richins et al. (1985) have also determined epicenters of the Borah Peak main shock and aftershocks using station adjustments that were calibrated by locally recorded Borah Peak aftershocks. In principle, the epicenters resulting from the two studies would be expected to differ slightly. We used different location algorithms, arrival times from quite different sets of stations, and different velocity models. However, our epicenters for the Borah Peak main shock are very close (within 1.5 km) to each other. Most other earthquakes of the sequence likewise have epicenters determined by our two studies that lie within several kilometers of each other, and it would appear that the use in both studies of calibrated station adjustments outweighs the differences in location algorithms, velocity models, and data sets. The most notable exceptions to the general similarity of epicenters in our two studies are for the teleseismically recorded aftershocks of 2329 UTC and 2339 UTC on 29 October, for which our epicenters differ by nearly 7 km. The set of epicenters located by Richins et al. (1985) is more complete than my own because it includes a number of aftershocks that were not reported from stations at epicentral distances of more than 5° and, hence, did not meet this study's criterion for being relocated.

**Configuration of the Early Borah Peak Aftershock Zone as a Consequence of Oblique Slip on a Single Planar Fault**

The locations of the Borah Peak main shock and early teleseismically recorded aftershocks are within or near the main shock fault inferred by Ward and Barrientos (1986) from inversion of geodetic data with their Variable Slip Planar source model (Figure 3). The epicenters of early teleseismically recorded aftershocks to a large earthquake are frequently assumed to provide a fuzzy “map” of the main shock rupture plane. This assumption would have been sound in the case of the Borah Peak earthquake, using aftershocks occurring within the first 2 days or (with a slight decrease in resolution) within the first 10 days. Later aftershocks, most of which occurred more than 1 month after the Borah Peak main shock, extended the aftershock zone well north of the geodetically determined main shock rupture (Figure 3; Zollweg and Richins, 1985).

The position of the Borah Peak main shock epicenter with respect to the southern end of the zone of associated surface fault scarp is not in the direction of dip on the fault plane (azimuth = 250°; henceforth called “downdip”), but is instead well south of the downdip projection of the surface fault scarp (Figures 3 and 4). Furthermore, the configuration of rupture at depth inferred from the distribution of early aftershocks or from geodetic data (Ward and Barrientos, 1986) is not downdip of the surface fault trace, but is instead located in a direction that is approximately downsip (azimuth = 208°) of the surface fault traces (Figures 3 and 4). Map projections of slip vectors plotted in Figure 3 are for the main shock, and the aftershocks of 1951 UTC, 28 October, and 2329 UTC, 29 October. The slip vectors plotted in Figure 3 are the surface projections of rays extending from the hypocenter upsip to the ground surface. The fact that the rays all intersect the surface several kilometers southwest of the surface fault traces could be due to some combination of small errors (several kilometers) in the hypocenters, small errors (10°) in the orientation of the focal mechanisms, and slight nonplanarity of the fault between the hypocenters and the free surface.

There is a set of conditions that would require that the main shock rupture plane
be a parallelogram which has one pair of sides parallel to the surface trace of the Lost River fault and the other pair of sides plunging parallel to the main shock slip vector. The conditions may plausibly have been approximately satisfied in the case of the Borah Peak earthquake, so that the shape of the rupture would be approximately that of the parallelogram expected under ideal conditions. The ideal parallelogram is shown in Figure 4 and would be expected on geometrical grounds if: (1) the entire Lost River fault zone were composed of a number of planar segments with different orientations; (2) the Borah Peak earthquake involved rupture, not necessarily uniform, of one entire segment; and (3) when fault movement occurs on an adjacent segment of the Lost River fault, this movement has the same slip vector.
as 1983 motion on the Borah Peak segment. Condition 1 has been postulated for the Lost River fault on geomorphological evidence (Scott et al., 1985). Condition 2 is equivalent to the hypothesis of Schwartz and Crone (1985) that the Borah Peak earthquake was a characteristic earthquake (Schwartz and Coppersmith, 1984) for the section of the Lost River fault west of Borah Peak. Condition 3 enables slippage to occur in the future on all segments of the Lost River fault without slippage on one segment truncating an adjacent segment and thereby locking it (Jackson and McKenzie, 1983). Equivalently, condition 3 would permit displacement on all segments without requiring the occurrence of subsidiary faulting in the hanging wall or footwall of the Lost River fault (King and Yielding, 1984). Condition 3 determines the orientation of the plunging sides of the parallelogram-shaped fault surface; from elementary geometry, two nonparallel planes containing a common line (the slip vector in this case) will intersect at that line.
Seismic Zones in Central Idaho

North-northwest trending seismic zones. The 1983 Borah Peak earthquake occurred on the north-northwest trending Lost River fault. The family of Cenozoic normal faults trending parallel to the Lost River fault extends to the northeast to the region of seismicity centered near 44.8°N, 112.8°W (Figure 1). Several of the north-northwest trending Cenozoic faults in this system were essentially aseismic during the period of study. Since the Lost River fault was also aseismic along most of its length during the two decades prior to the main shock (see section below entitled “Characteristics of Regional Seismicity in the Two Decades Preceding the Borah Peak Earthquake”), the lack of recent earthquake activity on other Cenozoic faults is no assurance that those faults will continue to remain quiescent.

The 70-km-long zone of epicenters that is approximately parallel to the Borah Peak aftershock zone, but displaced from it by 30 to 40 km to the southwest (Figure 1), occurs in a region in which major Late Cenozoic fault had not been identified as of the early 1970’s (Witkind, 1975). The zone is here called the White Cloud Peaks zone, after a nearby mountain crest (Figure 2). Seismicity in the White Cloud Peaks zone was most intense during 1963 to 1967 and occurred in episodes that were localized in both space and time (Figure 5). For the shock of 11 September 1963, 0208 UTC, $m_b$($L_g$) = 4.8, the surface-wave radiation pattern implies predominantly normal faulting in response to a northeast-trending axis of least compressive stress (Patton, 1985); this focal mechanism is also consistent with most $P$-wave first

![Figure 5](image-url)
motions reported for the event by Smith and Sbar (1974). Focal depths for earthquakes in the zone are not well determined from arrival time data, due to the absence of stations in the epicentral region; the most reliably determined focal depths are similar to the upper crustal depths of the Borah Peak sequence but are uncertain by 10 km at a 90 per cent level of confidence. Patton (1985) found that the surface wave data of the earthquake he studied implied a focal depth of about 3 km.

The White Cloud Peaks zone is one of several Western United States source zones that: (1) are elongated parallel to major normal faults; (2) are located several tens of kilometers from the major faults; (3) have focal mechanisms implying a tectonic stress field similar to that responsible for the major faults; but, (4) are not themselves located on geologically mapped Late Cenozoic faults. California’s southern Sierra Nevada seismic lineation (Jones and Dollar, 1986), 30 km west of the Sierran frontal-fault system, is another such zone. Segments of Utah’s Wasatch fault are paralleled by zones of small and moderate earthquakes both to the west and to the east (Arabasz et al., 1980; Smith and Bruhn, 1984).

Jones and Dollar (1986) emphasize the importance of the spacing between the southern Sierra Nevada seismic lineation and the Sierran frontal-fault system, which is equal to the average spacing between major faults in the Basin and Range to the east, as evidence that the southern Sierra Nevada lineation corresponds to a major developing normal fault in the Sierra Nevada. The distance between the White Cloud Peaks zone and the Borah Peak aftershock zone is similar to the distances between the Lost River, Lemhi, and Beaverhead faults to the east (Figure 1), and may therefore be evidence that the White Cloud Peaks zone also corresponds to a developing first-order fault similar to the faults further east.

Zandt and Owens (1980) and Smith and Bruhn (1984) propose, by contrast, that some zones of small and moderate earthquakes in the Wasatch Front reflect second-order responses of the earth’s crust to strain accumulation or release on the Wasatch fault proper. Similarly, activity in the White Cloud Peaks zone may partly reflect conditions on the Lost River fault. A proposed mechanical relationship between White Cloud Peaks seismicity and the Lost River fault would have to account, most importantly, for the fact that the White Cloud Peaks zone was active within the final 20 yr of a period of more than 4000 yr of strain accumulation on the Lost River fault (Scott et al., 1985).

Possible north-northeast trending seismic zones. The earthquakes of 12 July 1944, $M(PAS) = 6.1$, and 14 February 1945, $M(PAS) = 6.0$, were the largest instrumentally recorded earthquakes in central Idaho prior to the Borah Peak earthquake of 1983. The epicenters of these shocks, together with epicenters of small shocks occurring in 1963 to 1983, may be viewed as defining the north-northeast trending zone, here called the Seafoam zone, that extends from $44.35^\circ$N, $115.15^\circ$W to $44.80^\circ$N, $115.00^\circ$W (Figure 6). There were rather detailed reports of intensity for the 1944 earthquake (Bodle, 1946) that indicate that the mezoseismal area of the earthquake lay in the region between the epicenters of the 1944 and 1945 shocks. These intensity data, and the relative positions and dates of the earthquakes, suggest that the 1944 earthquake ruptured toward the epicenter of the 1945 earthquake and that the 1945 earthquake occurred near the northern extremity of the 1944 fault as a delayed aftershock.

Although the relative position of the 1944 and 1945 earthquakes are well-determined by arrival-time data, the absolute position of the pair of events is not known because of the lack of an initial station in the region.
to travel-time discrepancies of about 5 sec at stations in the crucial eastern azimuth. Depending on how the observations from the east are weighted, the computed epicenters may vary from the plotted positions (Figure 6) to positions that are west of the plotted positions by as much as 40 km. As the epicenters and origin times change, they are always consistent with about 80 per cent of the data and inconsistent with another 20 per cent. The 90 per cent confidence ellipses, which are constructed from the linearized equations of condition that are used in hypocenter determination algorithms (Flinn, 1965), grossly underestimate the size of the area in which the 1944 and 1945 epicenters could be moved, as a pair, without significantly increasing the variance of the residuals. The epicenters shown in Figure 6 are those that are most consistent with the intensity data for the 1944 earthquake, and they are slightly more consistent with the arrival-time data than solutions further to the west. They are therefore preferred.

Another north-northeast trending seismic zone in central Idaho may be interpreted from epicenters extending from 44.55°N, 114.55°W to 45.00°N, 114.15°W (Figure 1). The zone is here called the Twin Peaks-Myers Cove zone, after geo-
graphic landmarks with which Smith et al. (1985) associated two microearthquake sources in the zone. The trend of the Twin Peaks-Myers Cove zone is nearly parallel to the horizontal projection of the slip vector of the Borah Peak earthquake (Figure 1). One might speculate that the zone is a region of transcurrent faulting between the extensional terrane to the southeast, in which the Borah Peak earthquake occurred, and the relatively undeformed region to the west-northwest. On the other hand, the seismicity of the Twin Peaks section of the zone is spatially associated with a caldera (Smith et al., 1985), and Zollweg and Richins (1985) interpret first motions for the earthquake of 24 March in the Twin Peaks-Myers Cove zone as indicating normal faulting similar to that of the Borah Peak earthquake. These last results suggest that the Twin Peaks-Myers Cove seismic zone does not mark a single through-going fault.

**Characteristics of Regional Seismicity in the Two Decades Preceding the Borah Peak Earthquake**

A plot of magnitude versus cumulative frequency (Figure 7) suggests that the set of regionally and teleseismically recorded shocks that I have relocated is nearly complete above magnitude \( m_b(L_g) \) 3.5 for the period from 1963 until the Borah

![Graph](image-url)

*Fig. 7. Magnitude \( m_b(L_g) \)-frequency relation for central Idaho excluding earthquakes east of longitude 113.5°W for the period 1963 to 27 October 1983. Line with slope \( b = -1 \) has been fit through the data by inspection.*
Peak earthquake. All shocks of magnitude 3.5 and above that I have relocated for the period from 1963 through 27 October 1983 have epicentral confidence ellipses smaller than 15 km and are therefore plotted in Figure 1.

No regionally recorded earthquakes of magnitude \([m_b(L_9)]\) 3.5 or larger were located within 25 km of the Borah Peak main shock in the period from January 1963 until the occurrence of the main shock. None of the incomplete sample of shocks smaller than magnitude 3.5 had minimum variance epicenters within 15 km of the Borah Peak main shock, although one such earthquake has a confidence ellipse on the epicentral coordinates that extends to the epicenter of the main shock (Figure 8). Other studies show that the vicinity of the Borah Peak hypocenter was aseismic down to magnitudes below 3.5 during sizeable periods before the main shock. King and Doyle (1982) found no shocks of magnitude 2 or greater within about 15 km of the Borah Peak epicenter for the period from October 1972 to June 1982; they found one shock of magnitude between 1 and 2 in the vicinity of the

![Diagram of earthquake epicenters](image_url)

**Fig. 8.** All regionally recorded epicenters that could be located with a precision of 50 km or better for the period 1963 to 27 October 1983. Star and hatched area are as in Figure 5. WCP = White Cloud Peaks zone.
future main shock epicenter. Richins et al. (1985) found no foreshocks of magnitude 2 or greater within 50 km of the surface rupture in the 2 months before the main shock.

Large young normal faults occur at many locations in the Cordillera of the Western United States. Most of these faults have been quiescent during the several decades for which instrumental seismicity data are available. With the occurrence of the Borah Peak earthquake on the Lost River fault, we have an example of a large normal fault that remained inaudible to regional seismographic stations right up to the occurrence of a major earthquake. By implication, other large normal faults may produce major earthquakes without first entering a period of increased small to moderate earthquake activity.

In view of the prominence of activity in the White Cloud Peaks zone in the two decades before the Borah Peak earthquake (Figures 1 and 5), one must wonder if some characteristic of this seismicity could have been recognized as a long-term regional precursor to the 1983 earthquake. Based on long-term seismicity precursors postulated in other source regions world-wide (e.g., Kanamori, 1981; Reyners, 1981), either the burst of activity in 1963 to 1967 or the relative quiescence of the White Cloud Peaks zone in 1973 to 1983 (Figure 9) might have been precursory phenomena.

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**Figure 9.** All regionally recorded epicenters that could be located with a precision of 50 km or better for the period 27 October 1973 to 27 October 1983. Star and hatched area are as in Figure 5. “WCP” is centered on the region of most intense seismicity before 1973 in the White Cloud Peaks zone.
Unfortunately, instrumental coverage adequate to routinely detect and locate shocks of magnitude 4 in central Idaho had only existed for several years prior to the beginning of the 1963 to 1967 White Cloud Peaks activity. The unusualness of the activity of 1963 to 1967 or of the quiescence of 1973 to 1983 therefore cannot be evaluated by comparison with activity during a long period preceding the possible precursors.

Conclusions

The 1983 Borah Peak earthquake occurred on a major normal fault that had been recognized from geologic evidence as being an active fault but that had been quiescent at least since 1963. The occurrence of the earthquake justifies the concern with which geologists have viewed major young, but historically quiescent, faults elsewhere in the Western United States.

The locations of the Borah Peak main shock and early teleseismically recorded aftershocks can be interpreted quite well in terms of slippage on a single, parallelogram-shaped, fault segment of which one side coincides approximately with the surface fault traces and whose nonhorizontal sides are parallel to the slip vector of the main shock focal mechanism. Such a fault plane would occur if the Borah Peak earthquake involved rupture of an entire planar segment of the Lost River fault, if that segment were bounded to the north and south by intersection with other planar segments of the Lost River fault, and if the lines of intersection were so oriented that slippage on one fault segment would not lock the adjacent segments.

The epicenters relocated in this study have defined an elongated zone of earthquake activity, the White Cloud Peaks zone, that is parallel to the Borah Peak aftershock zone but situated from 30 to 40 km to the west, in a region where major surface faults have not been mapped. The seismological characteristics of the White Cloud Peaks zone and its position with respect to major Holocene normal faults suggest that the zone is similar to the southern Sierra Nevada seismic lineation of Jones and Dollar (1986) or to zones of small earthquakes that parallel segments of Utah's Wasatch fault. Proposals put forth to explain the other zones may be applicable also to the White Cloud Peaks zone; the zone may correspond to an incipient normal fault or to a second-order effect of crustal deformation caused by strain accumulation and release on the Lost River fault. The record of small and moderate earthquakes in central Idaho is not long enough to evaluate the possibility that some characteristic of White Cloud Peaks seismicity may have been precursory to the Borah Peak earthquake.

The relocated epicenters suggest the existence of two north-northeast trending zones, the Seafoam zone and the Twin Peaks-Myers Cove zone. These zones are located north and west of the northwest-trending Borah Peak and White Cloud Peaks zones. The magnitude 6.1 earthquake of 12 July 1944 and the magnitude 6.0 earthquake of 14 February 1945 occurred in the Seafoam zone.

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U.S. GEOLOGICAL SURVEY
P.O. BOX 25046
DENVER FEDERAL CENTER
DENVER, COLORADO 80225

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