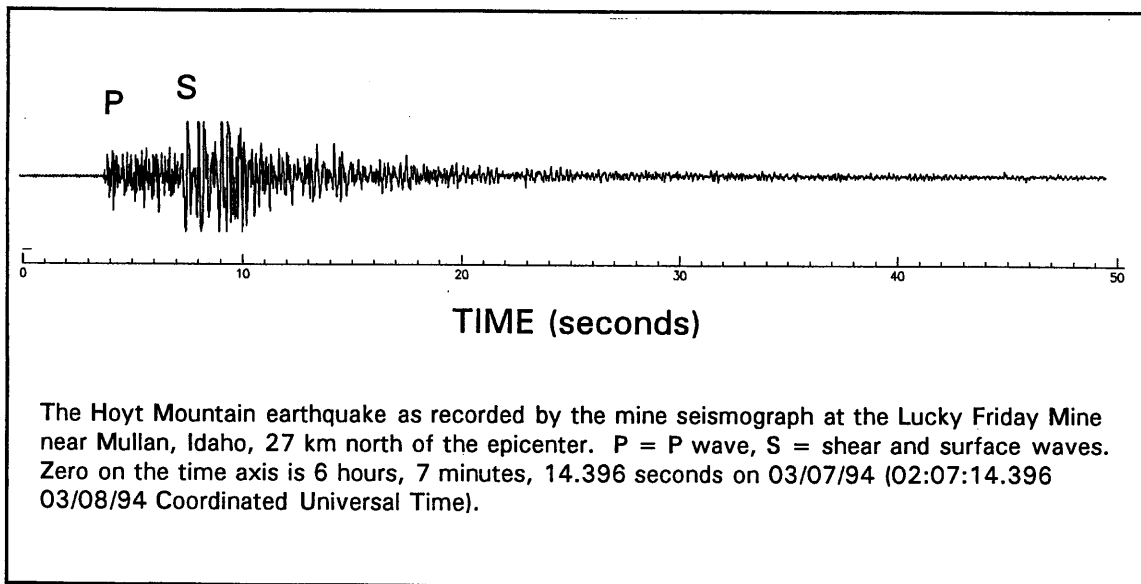


The Hoyt Mountain Earthquakes Shoshone County, Idaho March 7 and June 3, 1994

Kenneth F. Sprenke
Michael C. Stickney
Roy M. Breckenridge



Staff Report 94-4
September 1994

Idaho Geological Survey
University of Idaho
Moscow, Idaho 83844-3014

The Hoyt Mountain Earthquakes Shoshone County, Idaho March 7 and June 3, 1994

Kenneth F. Sprenke
Michael C. Stickney
Roy M. Breckenridge

*Staff reports present timely information for
public distribution. This publication may not
conform to the agency's usual standards.*

Staff Report 94-4
September 1994

Idaho Geological Survey
University of Idaho
Moscow, Idaho 83844-3014

Contents

<u>Abstract</u>	1
<u>Introduction</u>	2
Purpose	2
<u>Description of the event</u>	2
Significance	2
Epicenter Location	3
Shaking Intensity	4
Fault-Plane solution	4
Geologic Setting	5
<u>Discussion</u>	6
<u>Acknowledgments</u>	6
<u>References</u>	6
Table 1. Mercalli Intensity Scale	9
Table 2. Crustal Velocity Model	10
Figure 1. Seismicity map	11
Figure 2. Epicenter location	12
Figure 3. Hypocenter depth determination	13
Figure 4. Fault-plane solutions	14
Figure 5. Uplift areas in the Northwest	15
Figure 6. Epicenter locations	16
Figure 7. Regional geology map	17
Figure 8. Local geology map	19
Figure 9. Geological cross-section	20

The Hoyt Mountain Earthquakes Shoshone County, Idaho March 7 and June 3, 1994

Kenneth F. Sprenke¹, Michael C. Stickney², and Roy M. Breckenridge³

ABSTRACT

On March 7, at 6:07 pm PST (March 8, 2:07 am UTC), an earthquake, M3.5, occurred in the Coeur d'Alene Mountains of Shoshone County, Idaho, near Hoyt Mountain. On June 3, a M2.9 aftershock occurred at the same location at 7:58 pm PDT (June 4, 2:58 am UTC). This report summarizes the preliminary information that the Idaho Geological Survey has received from agencies investigating the earthquakes and to evaluate these data in relation to the state's seismicity and seismotectonics. The main shock, centered very close to Hoyt Mountain about 6 miles east-southeast of Avery was the largest earthquake in the northern Idaho region since the 1988 M4.1 Cooper Pass event, and one of only a few natural earthquakes in the region since the 1942 M4.6 Sandpoint event. The Hoyt Mountain shock reached a maximum intensity of V and was felt far east as Marble Creek and as far north as Wallace. There were no foreshocks, and no aftershocks until the M2.9 event almost three months later. Except for a lower magnitude, the aftershock was identical to the main shock in location and focal mechanism. The fault-plane solution indicates either (1) reverse slip (SW side up) on a near vertical northwest-striking plane, up to the southwest, or (2) low-angle thrust faulting on a plane striking north-northwest and dipping very gently northeast. The hypocenter of the earthquake was close to the west-northwest trending St. Joe fault which follows the St. Joe River; however, the fault-plane solution indicates that the failure was most likely on a northwest-trending auxiliary fault. Many such faults in the area are part of the Lewis and Clark line of fractures that extends from near Coeur d'Alene over 240 miles eastward to Helena, Montana, where damaging earthquakes occurred in 1935.

¹College of Mines and Earth Resources, University of Idaho, Moscow, Idaho 83844.

²Earthquake Studies Office, Montana Bureau of Mines and Geology, Butte, Montana 59701

³Idaho Geological Survey, Main Office at Moscow, University of Idaho, Moscow, Idaho 83844-3014.

INTRODUCTION

A small but significant earthquake occurred on March 7 at 6:07 PST (March 8, 2:07 pm UTC) in Shoshone County near Avery (Figure 1). The magnitude of the shock was determined to be 3.5 (3.4 by the Wood-Anderson equivalent seismometer at Butte, Montana, 3.6 by regional network data, and 2.9 by the U.S. Geological Survey-National Earthquake Information Center). The event was recorded by 60 regional seismographs in Washington, Montana, and Idaho. Because the event was within the North Idaho Seismic Network, an unusually good epicentral location, depth estimate, and fault-plane solution were determined for an event of this small size. The network is operated by the University of Idaho to monitor rockburst activity in the mines of the nearby Coeur d'Alene Mining District.

Nearly three months later, on June 3 at 7:58 pm PDT (June 4, 2:58 am UTC), an aftershock of magnitude 2.9 occurred. The aftershock showed the same hypocentral location and focal mechanism as the main shock.

Purpose

This report summarizes the preliminary information that the Idaho Geological Survey has received from agencies investigating the earthquake sequence and to evaluate these data in relation to seismicity and seismotectonics of the state. Our primary sources of information on the earthquake were from seismographs operated by the University of Idaho, the U.S. Bureau of Mines, the U.S. Geological Survey-National Earthquake Information Center, the U.S. Bureau of Mines, the Montana Bureau of Mines and Geology, Boise State University, ASARCO Inc., and the Hecla Mining Company.

DESCRIPTION OF THE EVENT

Significance

The M3.5 main shock, though small by most seismology standards, is certainly significant in the historic seismicity of northern Idaho. No more than four documented natural earthquakes in northern Idaho have exceeded this magnitude in historic time (Figure 1). The most recent one was the M4.1 in 1988 on the Montana-Idaho border at Cooper Pass, 15 km northeast of Mullan. The largest one was the M4.6 Sandpoint event of 1942. The 1988 event was felt over 8,000 square kilometers with an intensity of IV at Saltese and Trout Creek, Montana, and at Mullan. The data recorded from this event provided valuable information on the

tectonic stress regime in northern Idaho (Sprenke and others, 1991). The 1942 Sandpoint event reached intensity VI. It caused plaster and chimneys to fall. The event was felt over 64,000 square kilometers and it halted railroad operations in the epicentral area. The magnitude of the Sandpoint event has recently been estimated from old instrumental records at about 4.6 (oral commun., Jim Zollweg). Other natural seismicity in northern Idaho includes a cluster of small events at and north of Bonners Ferry, and a few other poorly documented, scattered events in the Priest Lake, Sandpoint, and Coeur d'Alene areas (Figure 1). The seismicity in the Kellogg-Wallace area, with the exception of the Cooper Pass event, does not represent natural earthquakes, but rather rockbursts related to deep mining in the Silver Valley.

The Hoyt Mountain mainshock had no measurable foreshocks or early aftershocks. The same observation was noted with respect to the 1988 Cooper Pass event. Such behavior is atypical of seismic events elsewhere in the western Cordillera. The single late aftershock occurred almost three months after the main shock. Except for lower amplitude, the aftershock produced seismograms virtually identical to those of the main shock, indicating that it shared the same epicenter, hypocenter, and focal mechanism with the main shock.

Epicenter Location

The shocks occurred below the west slope of Hoyt Mountain, a peak (el. 4925 ft) in the Coeur d'Alene Mountains of the St. Joe National Forest (Figure 2). The main shock was strongly recorded by fourteen seismographs within 50 km of the epicenter including eleven of the North Idaho Seismic Network stations in the Silver Valley, the mine seismographs at the Lucky Friday and Galena mines, and University of Idaho stations at St. Maries and Elk River. The U.S. Geological Survey station at Newport, Washington, 147 km from the epicenter, reported a P arrival time that was 1.8 seconds late. The remaining 46 stations reporting the event were 186 to 440 kilometers from the epicenter. The aftershock was not recorded by as many distant stations but was recorded by several additional local stations that were inoperable during the main shock, the most important being the University of Idaho station on Dunn Peak, located only 10 km from the epicenter. The Dunn Peak record of the aftershock provided a valuable check on the quality of our main shock location, particularly the depth to the hypocenter.

The standard crustal velocity model for western Montana (Table 2) was used along with the program HYPO71 (Lee and Lahr, 1975) to locate the epicenter. Although the western Montana model may not perfectly describe the crustal structure of northern Idaho, it seems to allow reasonable estimates of hypocentral location for events in the region. As a test, we used this model along with local and regional

seismograph data to calculate the hypocenters of large recent rockbursts at two different mines in the Silver Valley. Our calculated hypocenters were within 0.8 km of the known source locations within the mines.

The epicenter of the shocks were on the west slope of Hoyt Mountain about 3 miles (5 km) south of Hoyt (Figure 3) within 0.8 km of 47°12.62'N, 115°56.31'W.

The initial result for the main shock indicated a hypocentral depth of 10.09 km. To evaluate the uniqueness and stability of the initial location, the hypocenter was relocated 25 times with the hypocentral depth fixed at one-km intervals from the surface downward. A plot of fixed depth versus root-mean-square (RMS) travel time residual--an indication of hypocenter solution error--shows the lowest residuals occur for depths from 10 to 13 km (Figure 3). The computed hypocentral depth of 10 to 13 km agrees favorably with well-determined focal depths elsewhere in the western Cordillera.

Shaking Intensity

The shock was felt strongly at Hoyt where houses shook, dishes rattled, a lamp walked on a table, and an outside basketball upright swayed (Becky Ware, oral commun., 1994). In Shoshone County, the event was felt as far east as Avery, as far north as Osburn, Silverton, and Wallace, and as far west as Marble Creek. There were no felt reports at Calder. The extent of shaking is indefinite because of the sparse population of Shoshone County to the east and south of Avery. There were no felt reports in Montana. The maximum Mercalli intensity of the main shock was V at Hoyt, which is within 3 miles of the epicenter. Newspaper accounts of the earthquake appeared in the March 8, 1994 edition of the Spokesman Review and later in the April 17, 1994, edition of the same newspaper in an article about "Earthquake Awareness and Preparedness Week" (Drumheller, 1994).

Fault-Plane Solution

The fault-plane solution for the shocks is shown in Figure 4. The most likely failure plane strikes northwest and dips 75° or more southwest; the slip direction is reversed with the southwest hanging-wall block up. The geometry of this solution is consistent with ancient northwest-trending normal faults in the area although the reactivated slip direction is opposite. The alternate solution involves thrusting on a gently eastward-dipping shallow plane. This latter solution does not seem geologically possible in the area; shallow dipping faults exist in the area, but they dip west.

The fault-plane solution T axis, which indicates the direction of maximum extension for the event, is northeast. This T axis orientation is consistent with that of the 1988 M4.1 event near Cooper Pass, and with studies of rockburst-related stresses in the nearby Coeur d'Alene mining district (Sprenke and others, 1991). On the other hand, the P axis, which is oriented southwest for the Hoyt Mountain earthquake and is inconsistent with the expected northwestward direction of maximum principal stress found in the Silver Valley. Thus, a different stress regime may be active in this area south of the Silver Valley. Figure 5 shows areas of present-day uplift and subsidence based on land surveys over the past century. The Hoyt Mountain event is on the northern edge of a rising area of central Idaho. The fault-plane solution with reverse slip on a near vertical plane (up to the southwest) would be consistent with this earthquake representing crustal adjustment along a pre-existing fault in the rising topography of central Idaho.

Geologic Setting

The Hoyt Mountain earthquake occurred within the Lewis and Clark Zone (LCZ), an area of major tectonic significance that extends over 400 km from Coeur d'Alene, Idaho to Helena, Montana (Figure 6). The LCZ has been geologically active since middle Proterozoic time and has undergone several tens of kilometers of right-lateral slip during late Cretaceous time (Wallace and others, 1990). Moderate levels of seismicity including the 1935 Helena, Montana, earthquake sequence (two events greater than M 6), and faults with late Quaternary displacement indicate that the eastern end of the LCZ near Helena, Montana, is tectonically active (Qamar and Stickney, 1983; Stickney, 1987; Stickney and Bartholomew, 1987). Witkind (1975) has compiled maps of suspected active faults at the western end of the LCZ in northern Idaho; however, the northeast-trending Jocko Valley fault, located 30 km north of Missoula, Montana, is the westernmost fault within the LCZ with clearly demonstrable late Quaternary surface offset.

The epicenter of the Hoyt Mountain earthquake was located near the surface expression of the St. Joe fault, a major west-northwest trending fault of the Lewis and Clark Zone. Witkind (1975) indicated that the St. Joe fault had possible Quaternary displacement in the vicinity of St. Maries where Miocene basalt flows were said to have been cut by the St. Joe fault. However, subsequent field investigations by the Idaho Geological Survey have failed to verify Witkind's suggestion. Numerous northwest trending faults splay off from the St. Joe fault; the Hoyt Mountain event was apparently on one of these.

Figures 7 and 8 show the location of the Hoyt Mountain earthquake plotted on geological maps of the region and the epicentral area, respectively. The epicenter lies within the Coeur d'Alene mountains which are structurally dominated by the St. Joe fault. However, the fault-plane solution argues against this west-northwest trending fault as the causative failure plane. A normal fault of unknown age which we call the Hoyt Mountain fault trends northwest up the west slope of Hoyt Mountain and extends through the epicentral zone of the main event. This fault, if re-activated as a reverse fault, is consistent with the fault-plane solution. Figure 9 shows a geological cross-section through the epicentral region and the location of the shock relative to the surface faults.

Surface rupture would be very unusual for an event the size of the Hoyt Mountain earthquake. Therefore, it is unlikely that geological evidence of ground breakage will be found in the area. However, geological evidence might exist for earlier Quaternary events on the same fault. The most reasonable places to look in the field would be the Hoyt Mountain fault trace and the St. Joe fault trace near Hoyt (Figure 2). Also worthy of detailed field checks in the general area would be the various air photo linears mapped by Venkatakrishnan (1983) and the Quaternary and Tertiary gravel terraces mapped by Harrison and others (1986).

DISCUSSION

The Hoyt Mountain earthquake, though inconsequential in fatalities or damage, reminds us that all of Idaho is exposed to a moderate level of seismic risk. As with most of the state's seismic events, it was only the remoteness of the epicenter from urban areas and critical facilities that averted more serious damage. The St. Joe River valley in the Avery area is surrounded by some of the steepest slopes in North America; it is not unreasonable to suggest that a moderate earthquake in the area could cause debris avalanches that might block the only highway access or might even temporarily dam the river, creating serious flood hazards both upstream and downstream. The probability of such events are small, but real, and government agencies should have plans prepared to handle such emergencies.

This earthquake also points out once again the need for a statewide seismic network and an earthquake study center in Idaho. The U.S. Geological Survey national network cannot provide sufficiently rapid or accurate epicenter locations for emergency response; in fact, the National Earthquake Information Center (USGS, 1994), listed this event incorrectly as having occurred in Montana! Furthermore, the U.S. Geological Survey seismograph station at Newport, Washington, the data from which is telemetered directly to Denver, reported a time that was late by 1.75 seconds

(compared to an average error of 0.28 second at most stations reporting), causing us to eliminate Newport from the epicentral location solution. Regional networks (Montana, Utah, Teton Dam, Idaho National Engineering Laboratory, North Idaho Seismic Network, Boise State University, Ricks College) do not have the mission or the funding to respond to events outside their immediate areas of responsibilities. No state agency in Idaho has the equipment, funding, or personnel to launch a field team to adequately investigate seismic occurrences.

ACKNOWLEDGMENTS

The authors wish to thank Jim Zollweg at Boise State University for alerting us about this earthquake within minutes after its occurrence. The following seismograph operators kindly provided data in a timely manner on the Hoyt Mountain earthquake: Boise State University, University of Montana, University of Washington, U.S. Geological Survey, U.S. Bureau of Mines, Galena Mine, and Lucky Friday Mine.

REFERENCES

- Breckenridge, R.M., and K.F. Sprenke, 1988, Completion report, seismic safety standards for Idaho schools: State of Idaho Bureau of Disaster Services, 42 p.
- Drumheller, S., 1994, Major quake could level Idaho schools: Spokesman Review, Spokane, Washington, p. A1.
- Harrison, J.E., A.B. Griggs, and J.D. Wells, 1986, Geologic and structure maps of the Wallace 1° x 2° Quadrangle, Montana and Idaho: U.S. Geological Survey Miscellaneous Investigations Series, Map 1-1500-A Sheet, scale 1:250,000.
- Hilt, A.P., R.M. Breckenridge, and K.F. Sprenke, 1994, Preliminary Neotectonic map of Idaho: Idaho Geological Survey Technical Report 94-1, 1:1,000,000.
- Lee, W.H.K., and J.C. Lahr, 1975, HYPO71 (revised): a computer program for determining hypocenter, magnitude, and first-motion pattern of earthquakes: U.S. Geological Survey Open-File Report 75-311, 113 p.
- Qamar, A.I., and M.C. Stickney, 1983, Montana earthquakes, 1869-1979; Historical seismicity and earthquake hazard: Montana Bureau of Mines and Geology Memoir 51, 80 p.

Skinner, B.J., and S.C. Porter, 1987, *Physical Geology* (1st ed.): New York, John Wiley and Sons, 750 p.

Sprenke, K.F., M.C. Stickney, D.A. Dodge, and W.R. Hammond, 1991, Seismicity and tectonic stress in the Coeur d'Alene mining district: *Bulletin of the Seismological Society of America*, vol. 81, p. 1145-1156.

Stickney, M.C., 1987, Quaternary geologic map of the Helena Valley, Montana: Montana Bureau of Mines and Geology Geologic Map 46, Scale 1:50,000.

Stickney, M.C., and M.J. Bartholomew, 1987, Seismicity and late Quaternary faulting of the northern Basin and Range Province, Montana and Idaho: *Bulletin of the Seismological Society of America*, vol. 77, p. 1602-1625.

Stickney, M.C., and K.F. Sprenke, 1993, Seismic events with implosional focal mechanisms in the Coeur d'Alene mining district, northern Idaho: *Journal of Geophysical Research*, vol. 98, p. 6523-6528.

Wallace, C.A., D.J. Lidke, and R.G. Schmidt, 1990, Faults of the central part of the Lewis and Clark line and fragmentation of the late Cretaceous foreland basin in west-central Montana and northern Idaho, *in* S.M. Roberts, ed., *Belt Supergroup: A guide to Proterozoic Rocks of Western Montana and Adjacent Areas*, Montana Bureau of Mines and Geology Special Publication 94, p. 245-257.

Witkind, I.J., 1975, Preliminary map showing known and suspected active faults in Idaho: U.S. Geological Survey Open-File Report 75-278, 71 p.

U.S. Geological Survey-National Earthquake Information Center, 1994, Preliminary Determination of Epicenters, March 31, 1994.

Venkatakrishnan, R., 1983, A remote sensing study of the structural evolution of the Coeur d'Alene mining district, Idaho: University of Idaho, Ph.D. Dissertation, Moscow, Idaho.

Zoback, M.D., and M.L. Zoback, 1991, Tectonic stress field of North America and relative plate motions, *in* D. Burton Slemmons, E.R. Engdahl, M.D. Zoback, and D. Blackwell, eds., *Neotectonics of North America: Geological Society of America Decade Map Volume*, p. 339-366.

Table 1. Modified Mercalli Intensity Scale (NOAA)

- I. Not felt except by a very few under especially favorable circumstances.
- II. Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.
- III. Felt quite noticeably indoors, especially on upper floors of buildings, but many people did not recognize it as an earthquake. Standing motor cars may rock slightly. Duration estimated.
- IV. During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed walls made cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
- V. Felt by nearly everyone; many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbance of trees, poles and other tall objects sometimes noticed. Pendulum clocks may stop.
- VI. Felt by all; many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.
- VII. Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motor cars.
- VIII. Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Disturbed persons driving motor cars.
- IX. Damage considerable in specially designed structures; well designed frame structures thrown out of plumb great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.
- X. Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundation, ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks of rivers, canals, etc.
- XI. Few if any (masonry), structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipe lines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.
- XII. Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into the air.

Table 2. Crustal Velocity Model

P Wave Velocity	Depth to Layer Top
(km/sec)	(km)
4.8	0.0
5.6	1.1
6.15	6.5
6.8	18.0
8.0	40.0

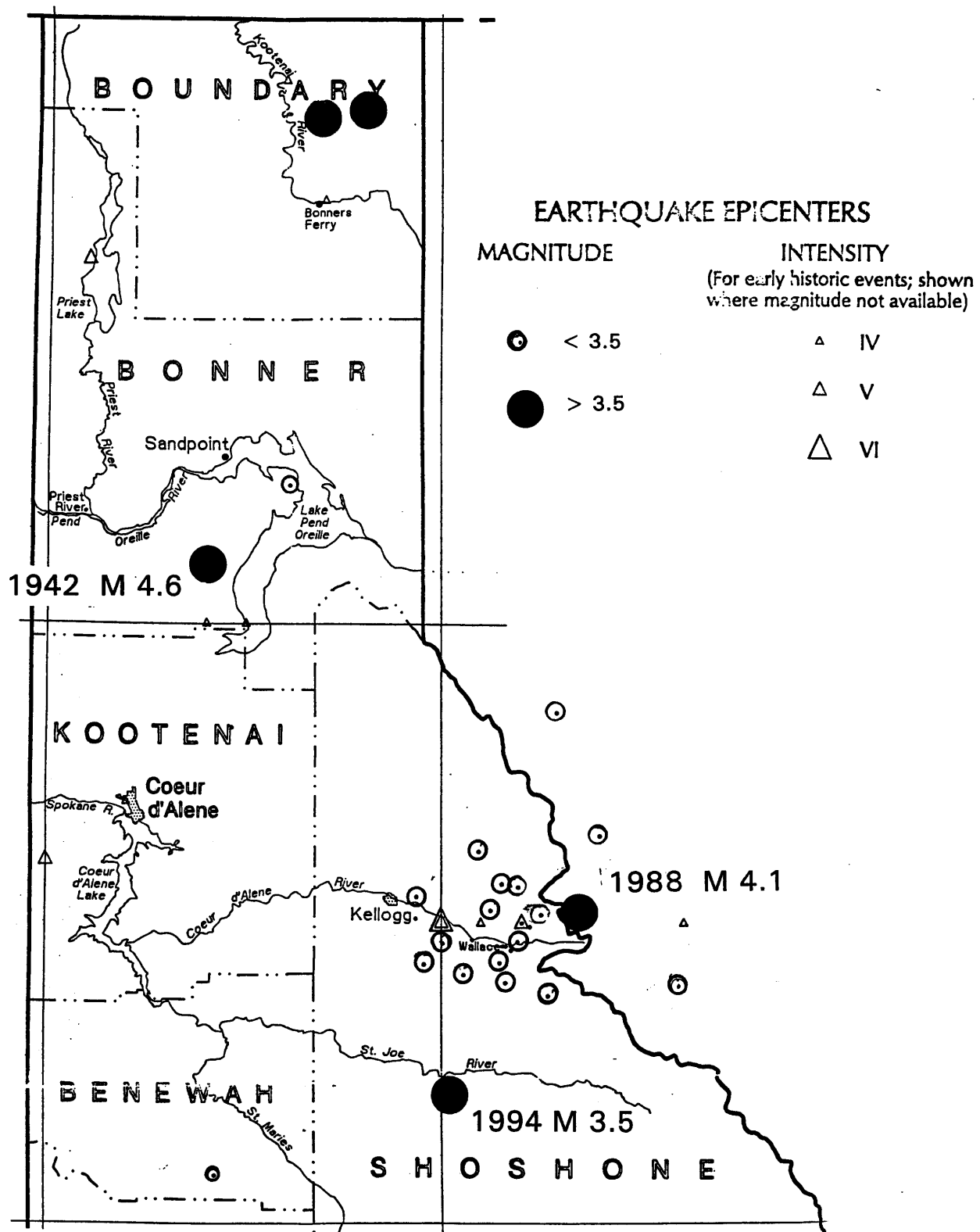


Figure 1. Location map of the 1994 M3.5 Hoyt Mountain earthquake and the other historic seismic events in northern Idaho. After Hilt and others, 1994.

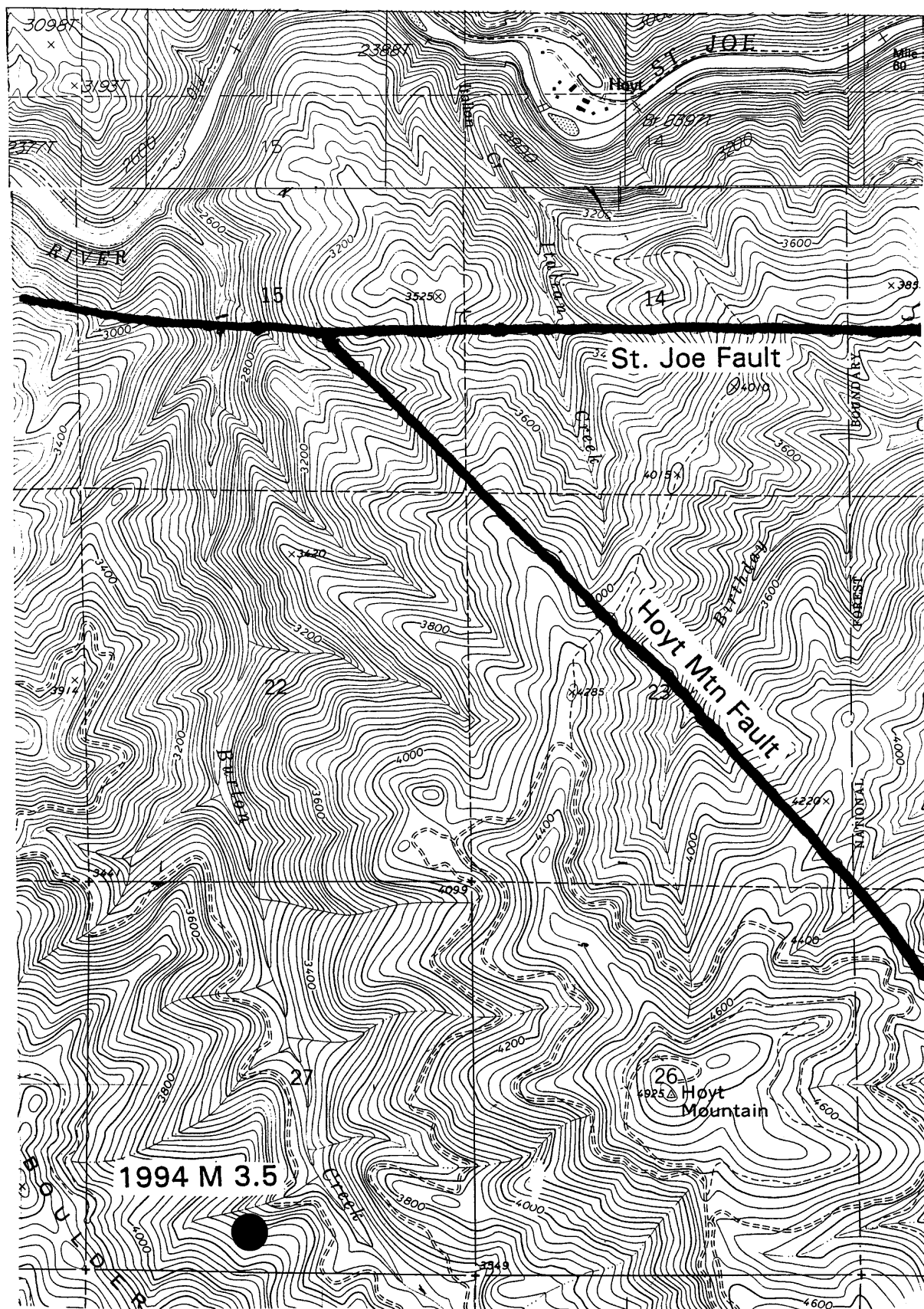


Figure 2. The epicenter of the Hoyt Mountain earthquakes.

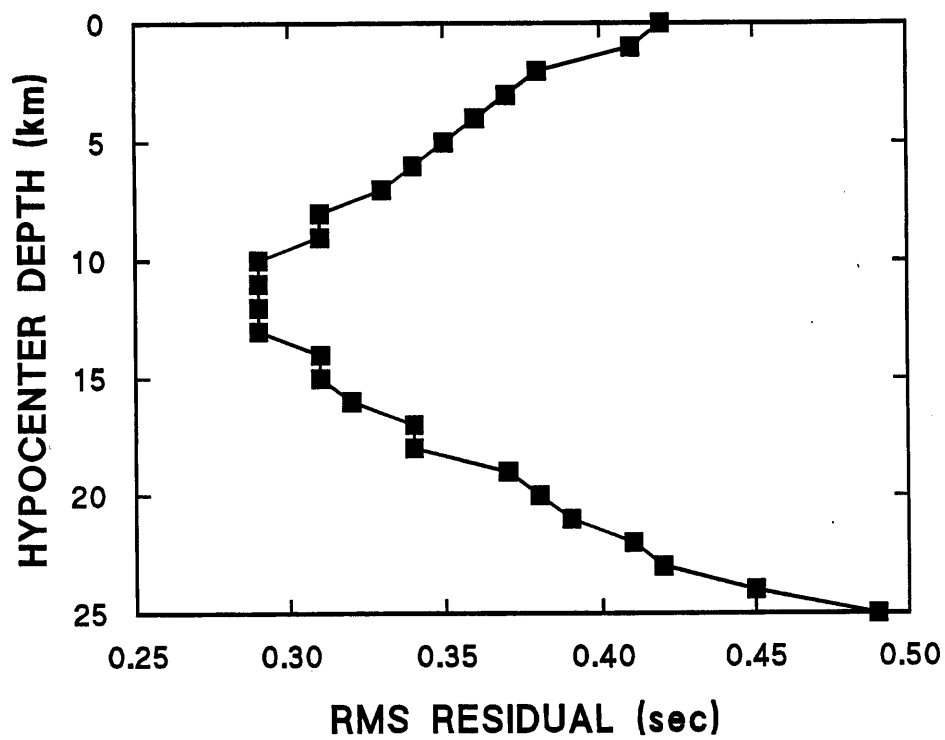


Figure 3. A plot of fixed hypocentral depth versus RMS residual travel time to 60 regional seismograph stations. The minimum RMS residual occurs for a hypocenter from 10 to 13 km deep.

940308 2 7 12.69 47-12.62 115-56.31 10.09 3.56 49 68 28.0 0.30 0.8 1.0 C
 65 10 110 .00 21 7.47 .56 .00 13 0 10

14

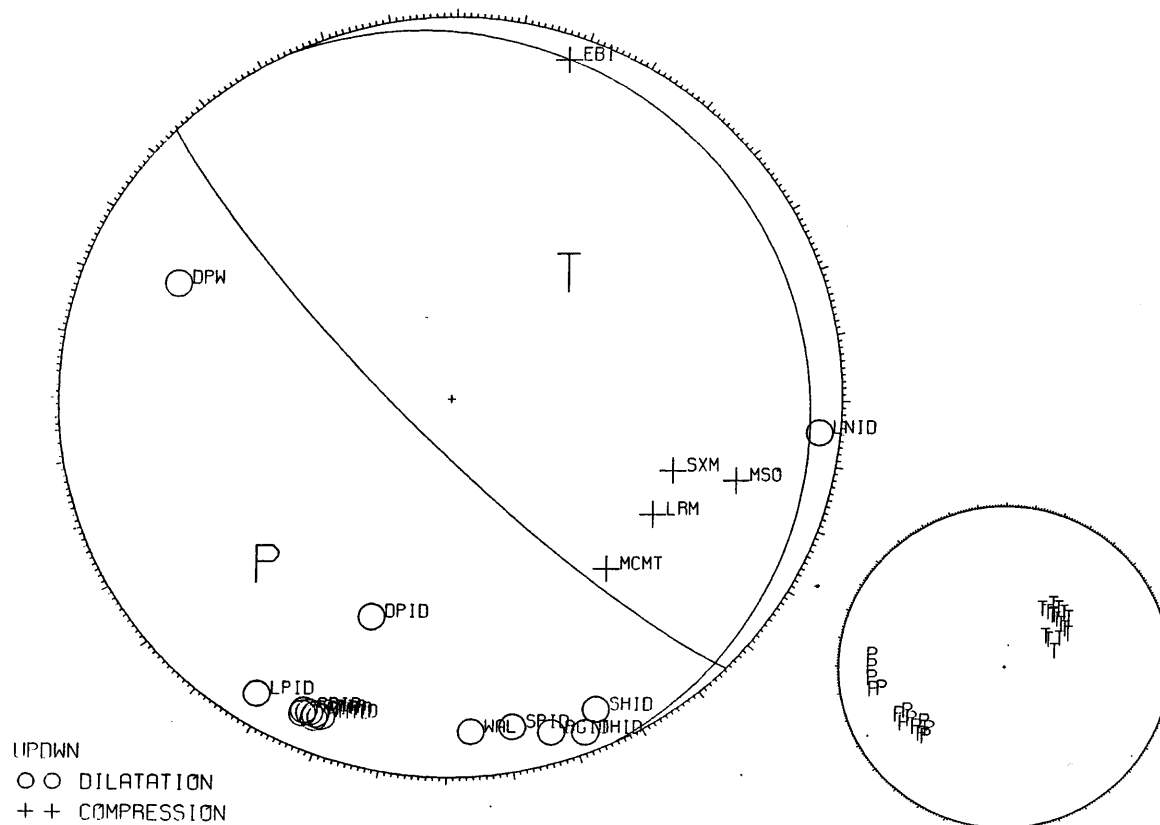


Figure 4. The fault-plane solution for the Hoyt Mountain earthquakes. The symbols P and T mark the orientation on equal-area stereo nets of possible directions of the P and T axes, respectively. The numbers at the top of each solution are the origin time, epicenter location, hypocenter depth and location error statistics; the numbers in the second line are the strike azimuth, dip angle, and rake of the fault plane solution followed by error statistics.

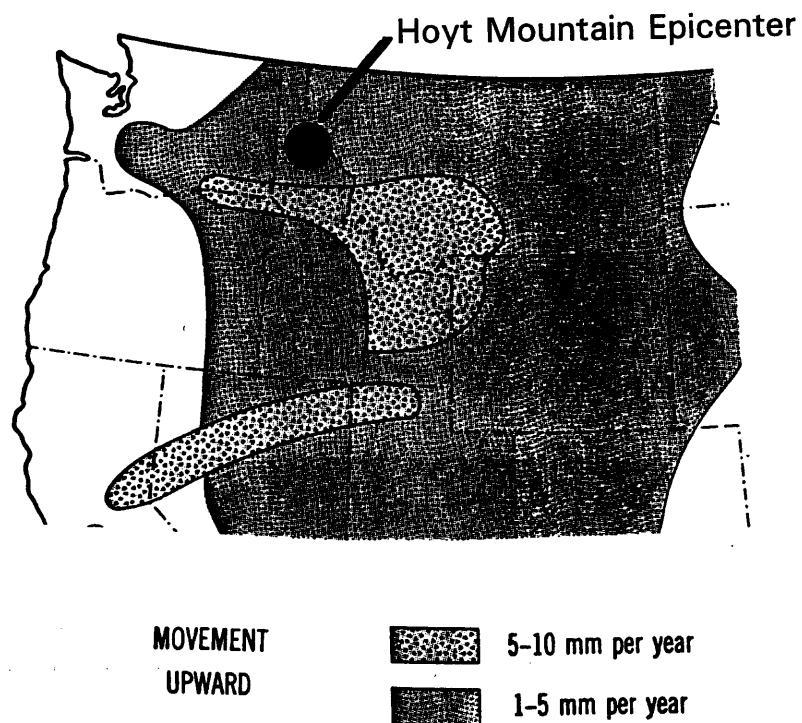


Figure 5. Measurements over the past century show that in large areas of the western United States the surface is slowly rising. The causes of these movements are not known with certainty. The Hoyt Mountain earthquake produced movement up to the southwest, consistent with continuing uplift in central Idaho. Based on Skinner and Porter (1987) using surveying data compiled by Hand in 1972.

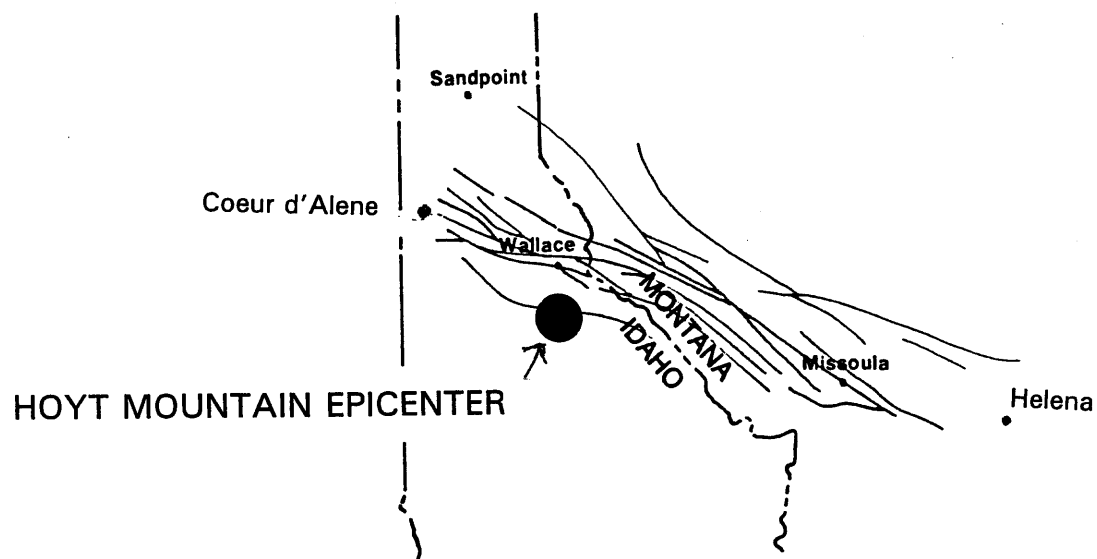


Figure 6. The location of the Hoyt Mountain earthquake at the southern boundary of the Lewis and Clark fault zone.

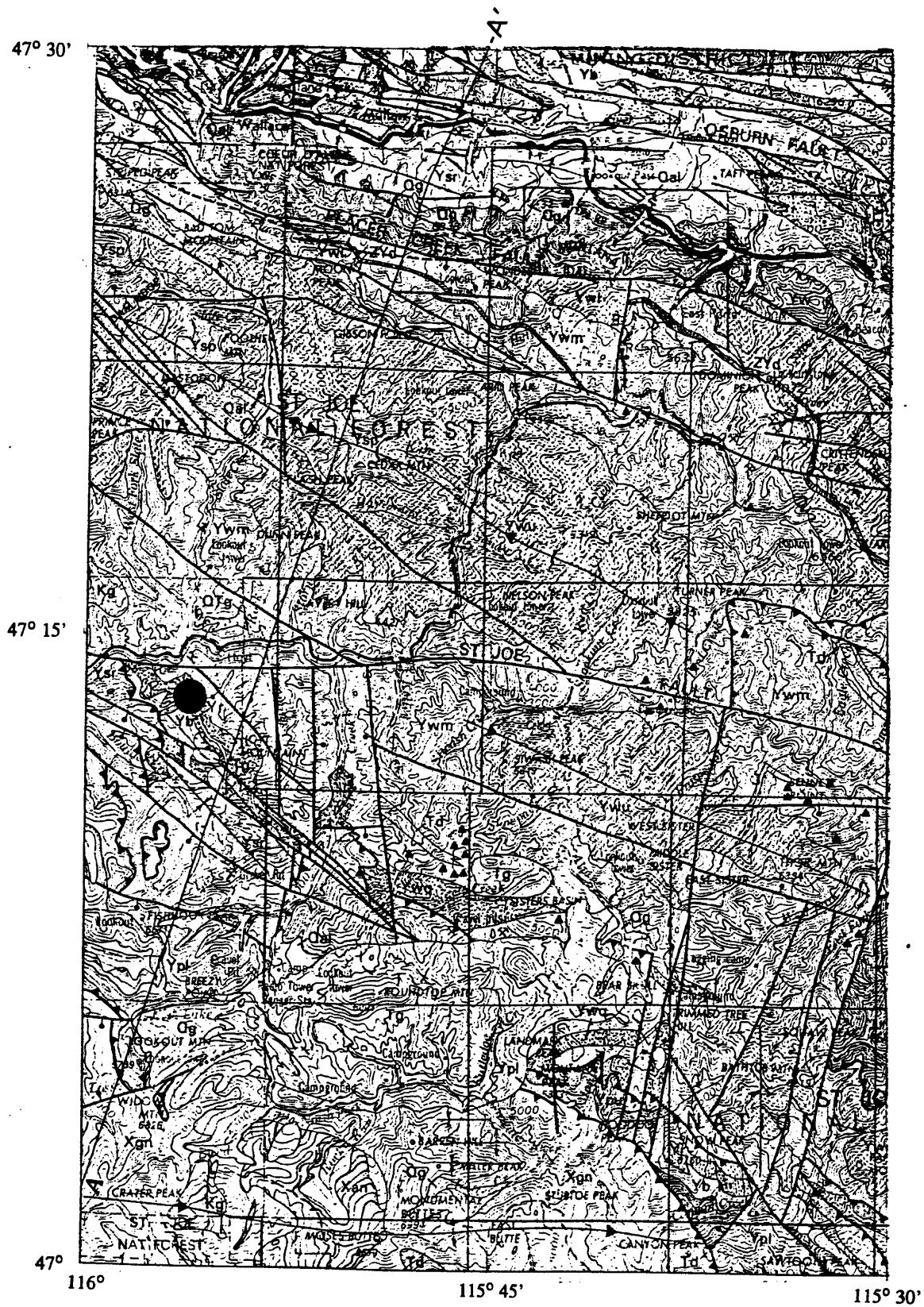


Figure 7. The approximate epicenter of the Hoyt Mountain earthquake (large dot) plotted on a geological map of the region. After Harrison and others, 1986. See next page for legend.

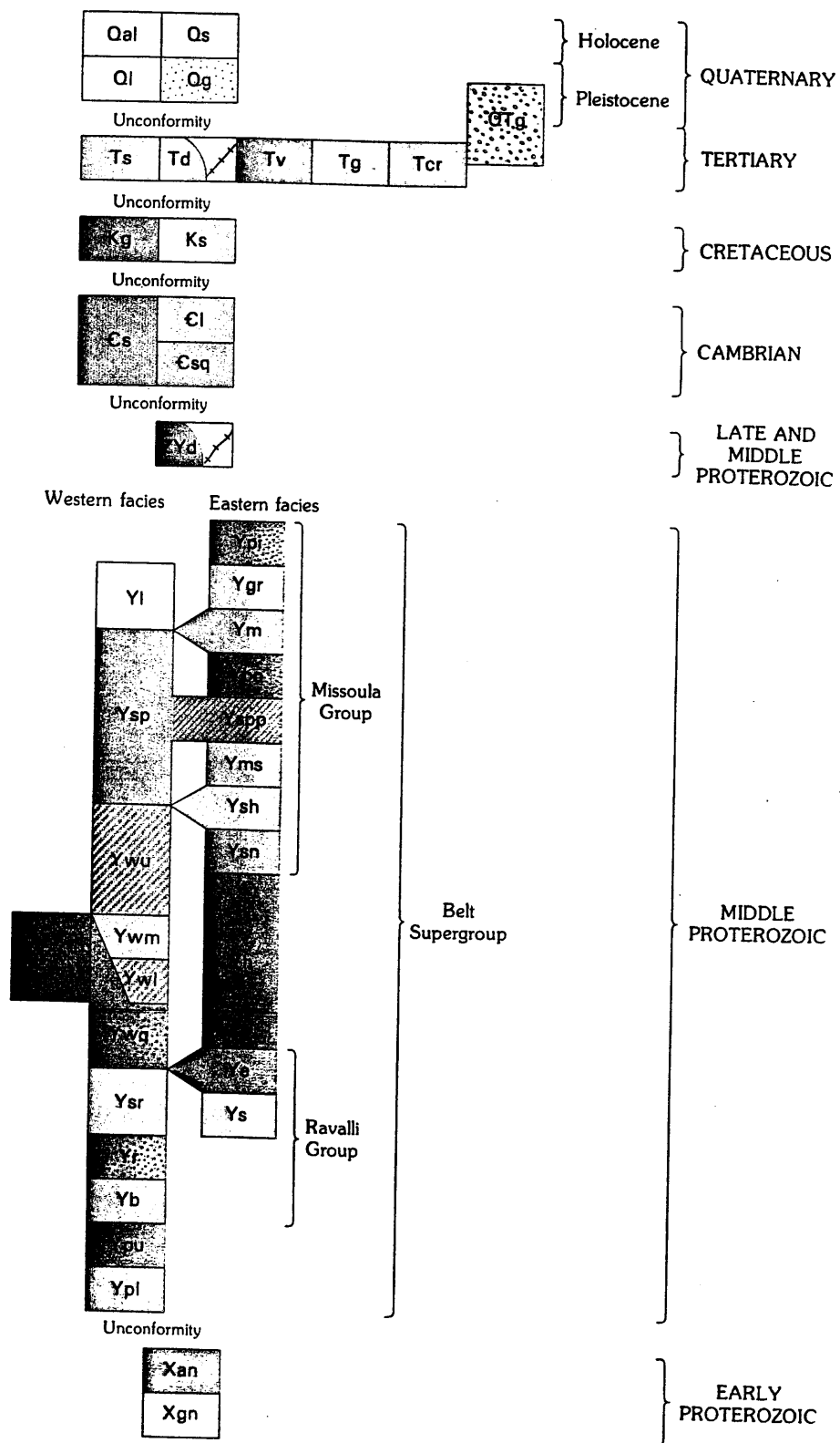


Figure 7 (cont.). Legend for geological map on previous page.

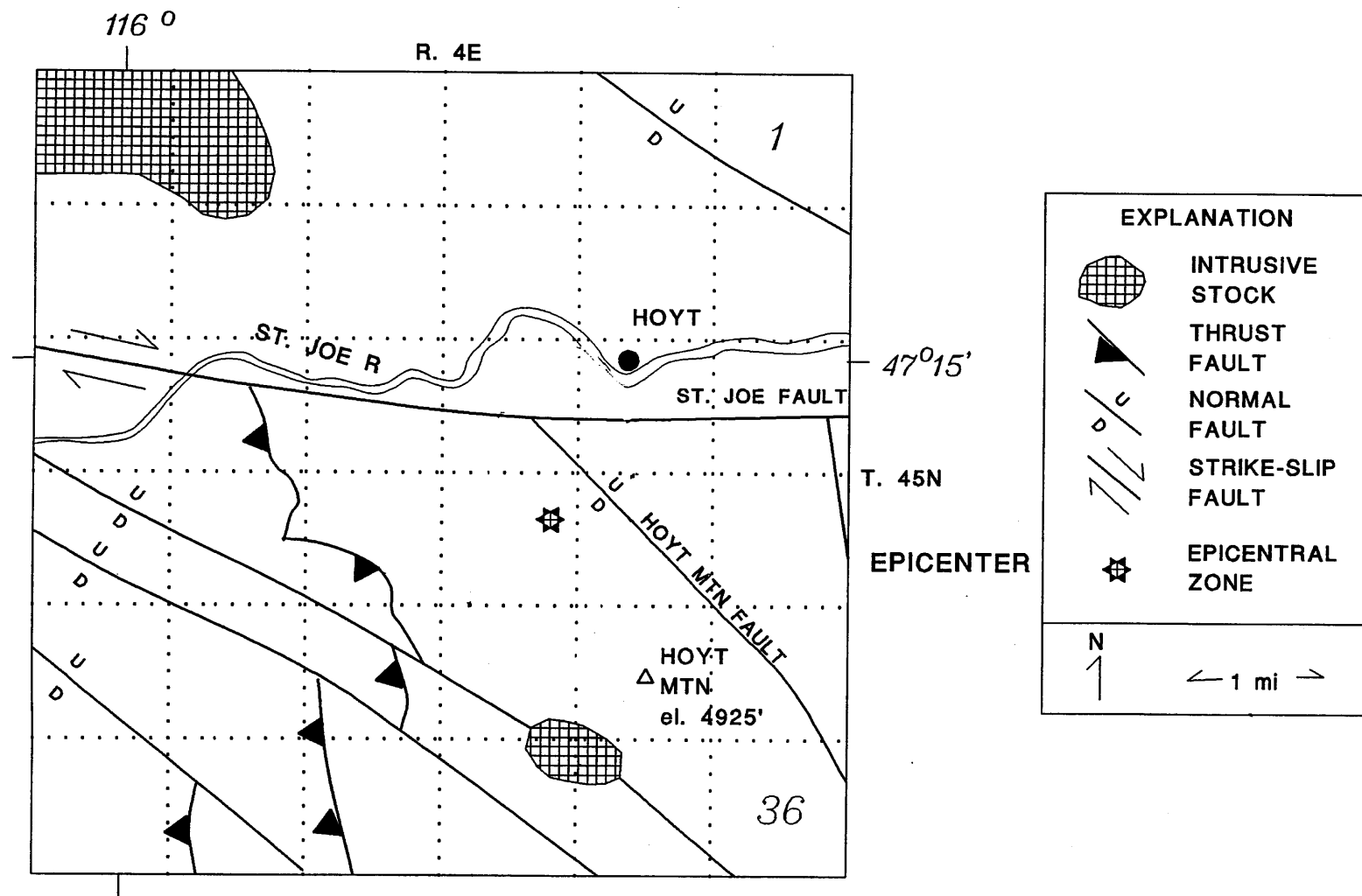


Figure 8. The geology in the immediate epicentral area of the Hoyt Mountain quake. Geologic data from Harrison and others (1986).

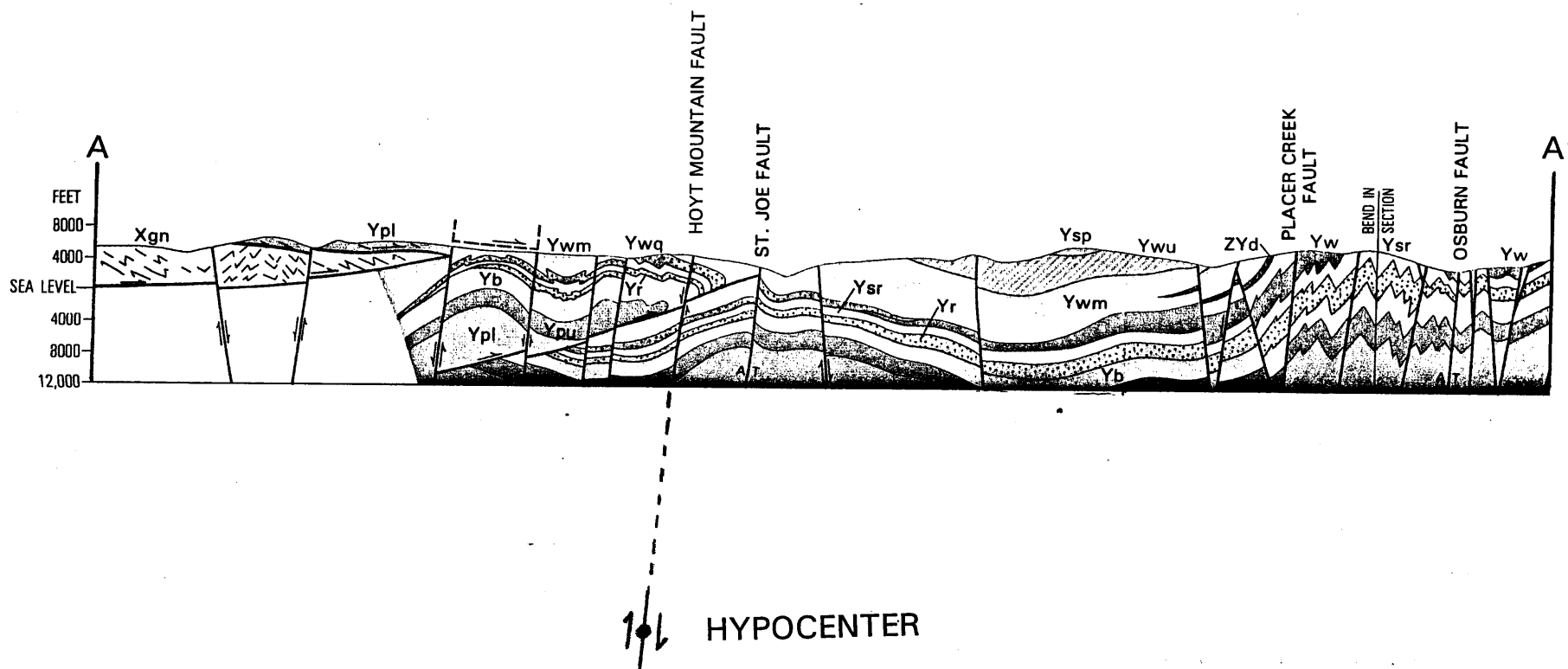


Figure 9. The Hoyt Mountain hypocenter, and probable fault movement plotted on a geological section through the region. The depth of the hypocenter was 13-16 km (42,500-52,500 ft). See Figure 7 for location of section and explanation of symbols.