Washington Regional Seismograph Network Operations
1434-92-A-0963 R.S. Crosson, S.D. Malone and A.I. Qamar, P.I.s

1993

R.S. Crosson, S.D. Malone, A.I. Qamar and R.S. Ludwin
Geophysics Program
University of Washington
Seattle, WA 98195
(206) 543-8020
e-mail: bob, steve, tony, or ruth@geophys.washington.edu
Oct. 1, 1992 - Sept. 30, 1993

The University of Washington operates 94 stations west of 120°W under this agreement. Details on seismic activity and network operations are included in our Quarterly bulletins.

Between Oct. 1, 1992 and Sept. 30, 1993, the Washington Regional Seismograph Network processed 3,126 events, including earthquakes or blasts within the network (2,425), regional earthquakes (156), and teleseisms (545). West of 120.5° a total of 1,572 earthquakes were located. Of these, 373 were near Mount St. Helens, which has not erupted since 1986. Thirty-two earthquakes were reported felt during this period, most of them in Oregon, where two significant earthquake sequences occurred.

On March 25 at 13:34 GMT, A damaging M_L 5.7 (M_c 5.6) earthquake occurred about 20 km SE of Woodburn, OR near the town of Scotts Mills. Damage was reported in the Polk, Washington, Clackamas, Marion, and Yamhill counties of Oregon, including cracking of the Oregon state capitol rotunda. The shock was reported to be felt from Seattle, WA to Roseburg, OR.

Beginning on September 21, an unusual sequence of earthquakes occurred near Klamath Falls, OR. It included two events (M_c 5.9 and 6.0) on September 21 that are among the largest earthquakes to have occurred in Oregon in this century (the felt area of the 1936 Oregon/Washington border earthquake was larger). Two deaths, one due to a rockfall triggered by the earthquake, and another from a heart attack were attributed to the earthquakes and damage was severe in the Klamath County Courthouse. Over 600 aftershocks followed these mainshocks in Sept. and Oct., and aftershock activity is continuing in Nov.

Washington Regional Seismograph Network Operations
1434-92-A-0963 R.S. Crosson, S.D. Malone and A.I. Qamar, P.I.s

R.S. Crosson, S.D. Malone, A.I. Qamar and R.S. Ludwin
Geophysics Program
University of Washington
Seattle, WA 98195
(206) 543-8020
e-mail: bob, steve, tony, or ruth@geophys.washington.edu
Oct. 1, 1992 - Sept. 30, 1993

Investigations

Operation of the Washington Regional Seismograph Network (WRSN) and preliminary analysis of earthquakes in Washington and Northern Oregon continue under these contracts. Quarterly bulletins which provide operational details and descriptions of seismic activity in Washington and Northern Oregon are available from 1984 through the third quarter of 1991. Final published catalogs are available from 1970, when the network began operation, though 1986.

The University of Washington operates 94 stations west of 120°W under this agreement. This report includes a brief summary of significant seismic activity. Additional details are included in our Quarterly bulletins.

Network Operations and Outreach

Station WPO, in west Portland, OR, was reinstalled (on 4/15/93) at the same site where it previously operated between 1986 and 1988. WPO replaced station WP2, which operated from late 1988 through Oct. '92. A new station (RCM) using a 1.72 Hz Ranger seismometer was installed at Camp Muir on Mt. Rainier in September in order to allow us to more accurately locate earthquakes and icequakes on the volcanic cone. Camp Muir was selected because it is high on the mountain and can be readily accessed. Because of earthquake activity in the Klamath Falls, OR area, four new stations were installed in early October by the USGS and telemetered to the UW. These stations are HAM (Hamaker Mt.), LAB (Little Aspen Butte), VSP (Spence Mtn.), and VRC (Rainbow Creek). LAB is a three-component short-period station with an additional high-gain vertical component. A station map and a discussion of new broadband instrumentation is included in the summary for agreement 1434-92-G-2195.

For significant local events, our automatic processing includes an alarm that initiates electronic mail or faxes to local emergency response agencies, operators of adjacent seismograph networks, and the National Earthquake Information Center in Colorado. When the event has been fully processed, updated final information on it is also faxed or e-mailed. A taped message on our voice mail system (206) 543-7010 gives information on felt earthquakes in the last few days within our network, and a longer general message is available on earthquakes in the Pacific Northwest. In addition, locations of recent significant earthquakes can be obtained via modem by dialing (206)685-0889 and logging in as "quake" with password "quake", or via ethernet using the UNIX utility "finger quake@geophys.washington.edu".

Summary cards for all earthquakes located by the WRSN since 1969 are available via anonymous ftp on "geophys.washington.edu" in the pub/seis_net subdirectory. In addition, special sub-directories; pub/kfalls and pub/woodburn; include locations, focal mechanisms, and local station lists for the Klamath Falls and Scotts Mills, Oregon earthquake sequences.

We answer from 5-40 questions per day on Pacific Northwest seismicity and seismic hazards, and give about a half-dozen lab tours or presentations each month for a wide variety of age groups; students from elementary through post-graduate, retirees, science teachers, emergency educators, etc. Requests for information increased after the Scotts Mills and Klamath Falls earthquakes in Oregon in March and September, respectively.

Seismicity

Two damaging earthquake sequences occurred in Oregon during this reporting period. Both were unusual because they occurred in areas where damaging seismicity was unknown historically. These sequences, near Scotts Mills (beginning in March, 1993) and Klamath Falls (beginning is September, 1993), are discussed below.

The Washington Regional Seismograph Network processed 3,126 events between Oct. 1, 1992 and Sept. 30, 1993. Of these 2,425 were earthquakes or blasts within the network and the remaining events were either regional earthquakes (156), teleseisms (545), or events too small to be located.

Figure 1 shows earthquakes (M_c ≥2.0) located in Washington and Oregon during this reporting period. Excluding blasts, probable blasts, and earthquakes outside the U. W. network, a total of 1,572 earthquakes west of 120.5°W were located between Oct. 1, 1992 and Sept 30, 1993. Of these, 373 were located near Mount St. Helens, which has not erupted since October of 1986. East of 120.5°W, 174 earthquakes were located.

During this reporting period there were 32 earthquakes reported felt west of the Cascades, and 1 reported felt east of the Cascades.

The Scotts Mills, Oregon Earthquake Sequence

A damaging M_L 5.7 (M_c 5.6) earthquake occurred about 20 km SE of Woodburn, OR on March 25 at 13:34 GMT. The closest town to this earthquake was Scotts Mills, OR and is known as the **Scotts Mills sequence** . Figure 2 shows a map view and two cross sections of the best-located earthquakes from the Scotts Mills sequence. These earthquakes were relocated by Thomas et. al. (1993) using additional readings from portable stations deployed by the USGS following the mainshock. The earthquakes are at depths of 7-15 km, and lie in a plane which strikes N75W and dips steeply to the NNE. The focal mechanism of the main shock (also shown in Fig. 2) is compatible with this interpretation.

Damage was reported in the Polk, Washington, Clackamas, Marion, and Yamhill counties of Oregon. Notable damage (according to the Portland Oregonian) included: cracking of the Oregon state capitol rotunda and shifting of the "Oregon Pioneer" statue on the rotunda tower in Salem; extensive damage to St. Mary's Catholic Church in Mount Angel ($4 million to $6 million). where bricks fell from 200 foot tower and walls separated from the roof; a 6 inch drop of the roadway on the Yamhill River bridge River on Oregon 18 near Dayton because of the failure of rocker bearings; damage to the Molalla Union High School south campus ($2 million) where bricks covering gables at the south end of the building fell, blocking the door; and structural damage to the Forest Grove Fire Hall in Washington County and to the Salud Medical Center in Woodburn. The USGS Preliminary Determination of Epicenters (12-93) lists Modified Mercalli Intensities for many communities, and a preliminary intensity map appeared in an article entitled "March 25, 1993, Scotts Mills earthquake - western Oregon's wake-up call" by Madin, Priest, Mabey, Malone, Yelin and Meier; Oregon Geology, Vol. 55, No. 3 (May, 1993). The mainshock was felt widely around Portland and to the south of Portland, and was reported (in the Oregonian) to be felt from Seattle, WA to Roseburg OR.

The Klamath Falls, Oregon Earthquake Sequence

Beginning on September 21, a highly unusual sequence of earthquakes occurred near Klamath Falls, Oregon in an area which normally has no detectable seismicity. The 1993 Klamath Falls earthquake sequence includes two events (M_c 5.9 and 6.0) on September 21 that are among the largest earthquakes to have occurred in Oregon in this century (the felt area of the 1936 Oregon/Washington border earthquake was larger). This sequence included a felt foreshock, the two mainshocks, and many aftershocks. The initial foreshock, M_c 3.9, was felt in the Klamath Falls area at 03:16:55 GMT; followed twelve minutes later by the M_c 5.9 earthquake at 03:28:55 GMT. Sixteen aftershocks in the M_c 2.4-3.8 range (including two felt M_c 3.8 earthquakes at 04:16 and 04:34 GMT) were then recorded prior to the second mainshock (M_c 6.0) at 15:45 GMT. A total of

106 earthquakes M_c 1.7 and larger located in the area by the end of September, and aftershock activity continued in October. A preliminary report on this sequence was published in Oregon Geology (Wiley et al., 1993).

Figure 3 is an epicentral plot showing the best-located earthquakes in the Klamath Falls area. Because the Klamath Falls area lies between the areas covered by the WRSN and CALNET, A.I. Qamar (UW) and K. Meagher (USGS) have recomputed locations by combining WRSN and CALNET data and using data from portable instruments placed in the epicentral region the day after the main shock. They used a velocity model based on the Modoc Plateau (Zucca et al., 1986, JGR, V. 9, pp. 7359-7382). Station corrections were determined using travel-time residuals from three well-located aftershocks for which arrival-time readings were available from close-in portable stations.

The earthquake hypocenters occurred in several groups that were initially isolated from one another. For example, the M_c 6.0 earthquake occurred in a cluster 5 km northwest of the cluster that included the earlier M_c 5.9 earthquake. Fault plane solutions indicate that both main shocks were normal faulting on north to northwest trending faults; one interpretation is that both earthquakes lie on different segments of the same fault zone. Two days after the main shocks another fault zone became active near the western shore of Klamath Lake in an area that is 8 km east of the primary fault zone. Unlike the primary fault zone which had earthquakes with foci up to 12 km deep, the earthquakes along the western shore of Klamath Lake were very shallow.

Geologically, the Klamath Falls area lies at the westernmost extent of the Basin and Range geomorphic province, and the current activity is along the western margin of the Klamath Graben; in a down-dropped area bounded by normal faults. Focal mechanisms of both main shocks correspond to normal faulting along northwest striking faults. In 1968 another basin and range sequence occurred in southern Oregon in the Warner Valley near Adel, OR. Reports from geologists who examined the Klamath Falls area after the earthquakes indicate that although cracking due to settling of unconsolidated material was observed, no evidence of primary ground rupture was found.

Two deaths, one due to a rockfall triggered by the earthquake, and another from a heart attack were attributed to the earthquakes. Damage was severe in the Klamath County Courthouse, a hybrid building with several additions. Other notable damage included cracking of a highway bridge over a canal on state Rt. 140 (probably due to settling), broken or cracked parapets in brick buildings, fourteen broken display windows at "Yesterday's Plaza" antique mall, and damage to the Oregon Institute of Technology student union building (a modern building with an eccentric floor plan). Many homes were also damaged, particularly masonry chimneys and veneer. This earthquake was located in a rural area where historic seismic activity was unknown. Based on geologic similarity to areas to the east and south where seismic activity has occurred, Klamath County was in the very earliest stages of developing emergency plans for earthquakes. Plans for rural areas must consider problems such as dispersed population, sparse emergency resources, and a lack of trained personnel to conduct building inspections. Aftershock activity has continued into October.

Reports and Articles

Benson, R., C.D. Lindholm, R.S. Ludwin, and A.I. Qamar, 1992, A Method for Identifying Explosions Contaminating Earthquake catalogs: Application to the Washington Regional Earthquake Catalog, Seis. Res. Lett., V. 63, No. 4, pp. 533-540.

Jonientz-Trisler, C. B. Myers, and J. Power, (in press), Seismic identification of gas-and-ash explosions at Mount St. Helens: capabilities, limitations, and regional application, in *Proceeding Volume, First International Symposium on Volcanic Ash and Aviation Safety,* USGS Bulletin 2047.

Ludwin, R.S., A.I. Qamar, S.D. Malone, C. Jonientz-Trisler, R.S. Crosson, R. Benson, and S. Moran (in press), Earthquake Hypocenters in Washington and Northern Oregon, 1987-1989 and the Washington Regional Seismograph Network; Operations and Data Processing, Washington State Dept. of Natural Resources, Information Circular 89, 45 p.

Univ. of Wash. Geophysics Program, 1993, Quarterly Network Report 92-D on Seismicity of Washington and Northern Oregon

Univ. of Wash. Geophysics Program, 1993, Quarterly Network Report 93-A on Seismicity of Washington and Northern Oregon

Univ. of Wash. Geophysics Program, 1993, Quarterly Network Report 93-B on Seismicity of Washington and Northern Oregon

Univ. of Wash. Geophysics Program, 1993, Quarterly Network Report 93-C on Seismicity of Washington and Western Oregon

Wiley, T.J., D.R. Sherrod, D.K. Keefer, A. Qamar, R.L. Schuster, J.W. Dewey, M.A. Mabey, G.L. Black, and R.E. Wells, 1993, Klamath Falls earthquakes, Sept. 20, 1993 -- Including the strongest quake ever measured in Oregon, Oregon Geology, V. 55, No. 6, pp. 127-134.

Abstracts

Ludwin, R.S., S.D. Malone, A.I. Qamar, and R.S. Crosson, 1993 (in press), Operation of the Washington Regional Seismograph Network, ESSSA meeting, Oct. 1993

Malone, S.D., R. Buland, B. Presgrave, W. Ellsworth, A. Michael, T. Ahern, 1993, Rapid exchange of seismic data between international, national and regional networks using the InterNet, EOS, Vol. 74, No. 16, p. 216.

Qamar, A.I., and K.L. Meagher , 1993, The 1993 Klamath Falls, Oregon Earthquake Sequence, Special Session, Fall 1993 AGU meeting

Thomas, G.C., R.S. Crosson, S. Dewberry, J. Pullen, T. Yelin, R. Norris, W.T. Bice, D. Carver, M. Meremonte, D. Overturf, D. Worley, E. Sembera, and T. MacDonald, 1993, The 25 March, 1993 Scotts Mills, Oregon earthquake: aftershock analysis from combined permanent and temporary digital stations, V. 74, N. 43, p. 201

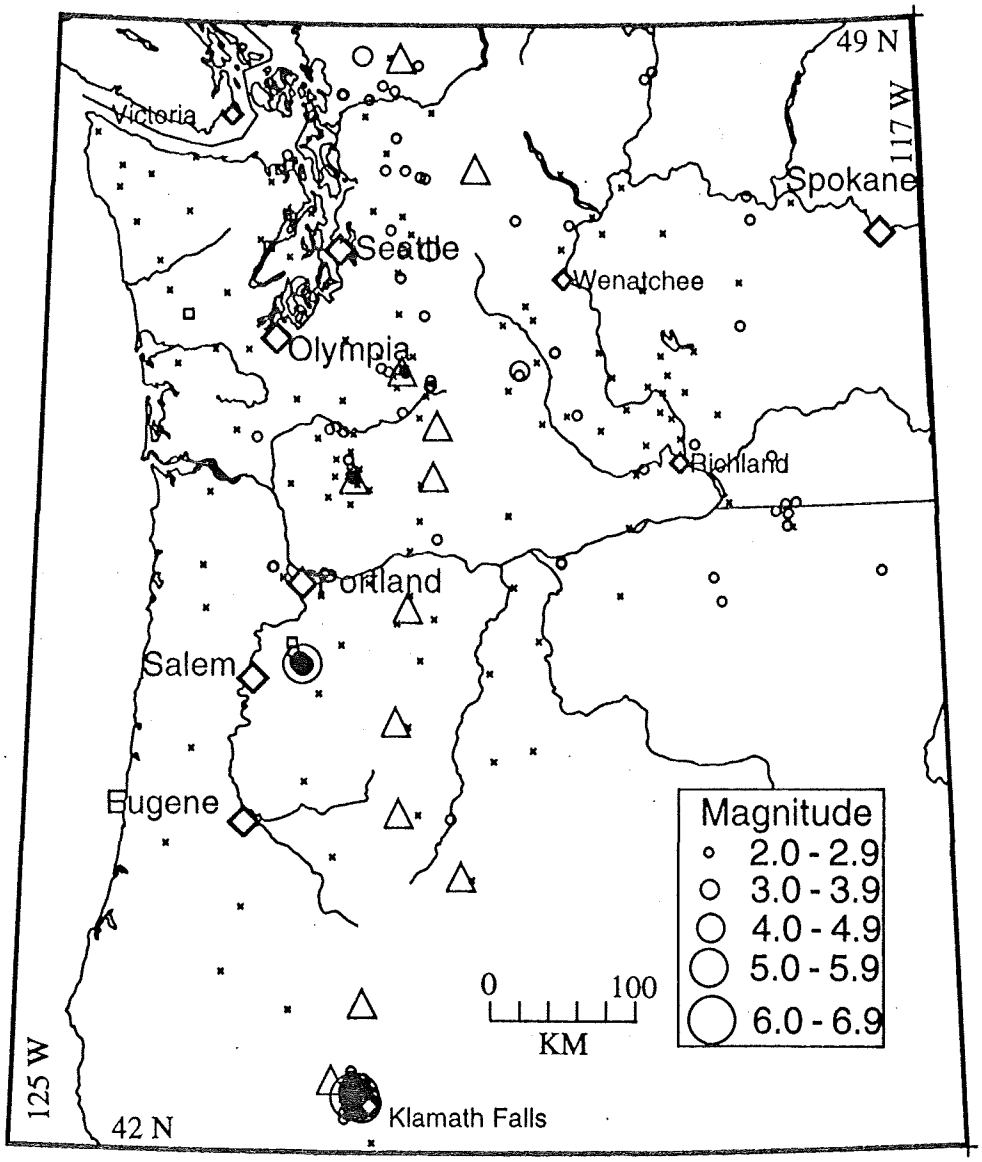
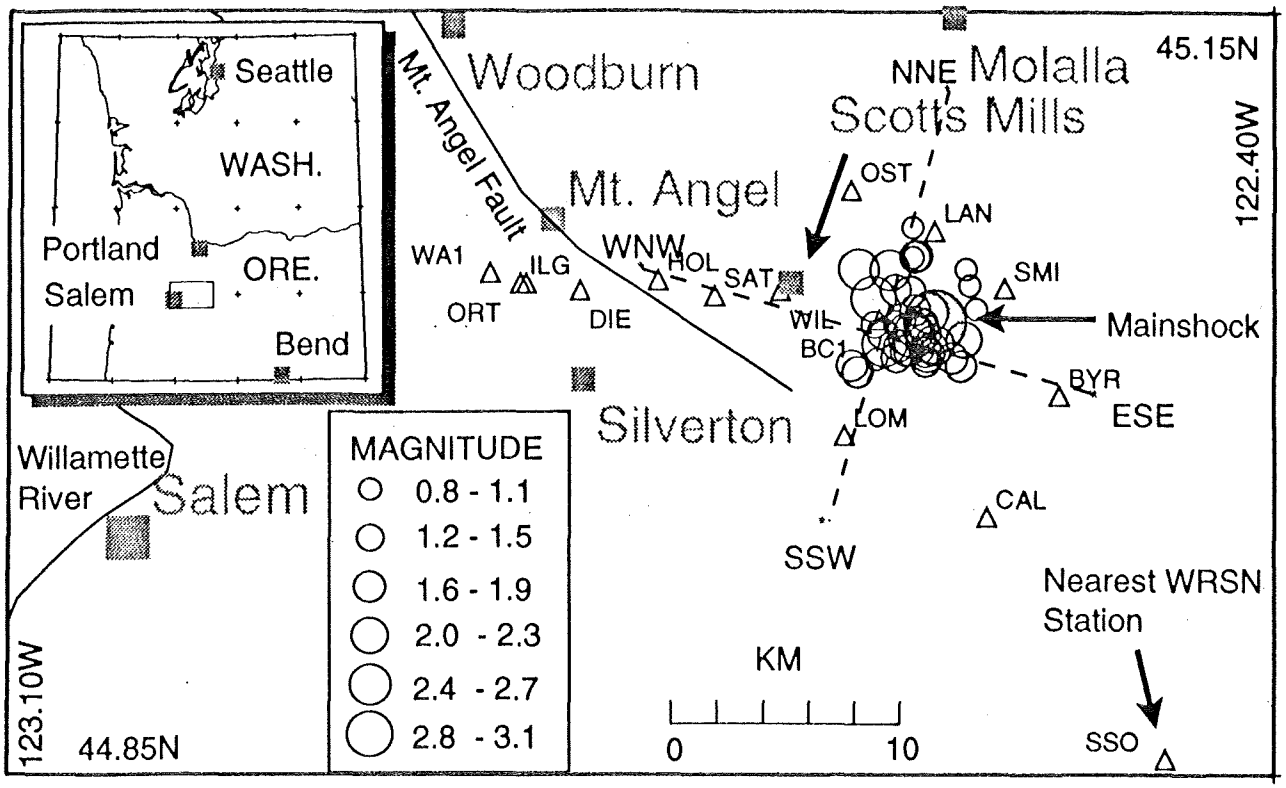
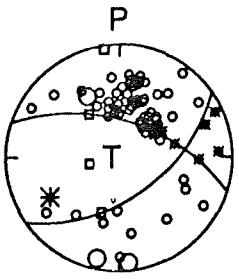


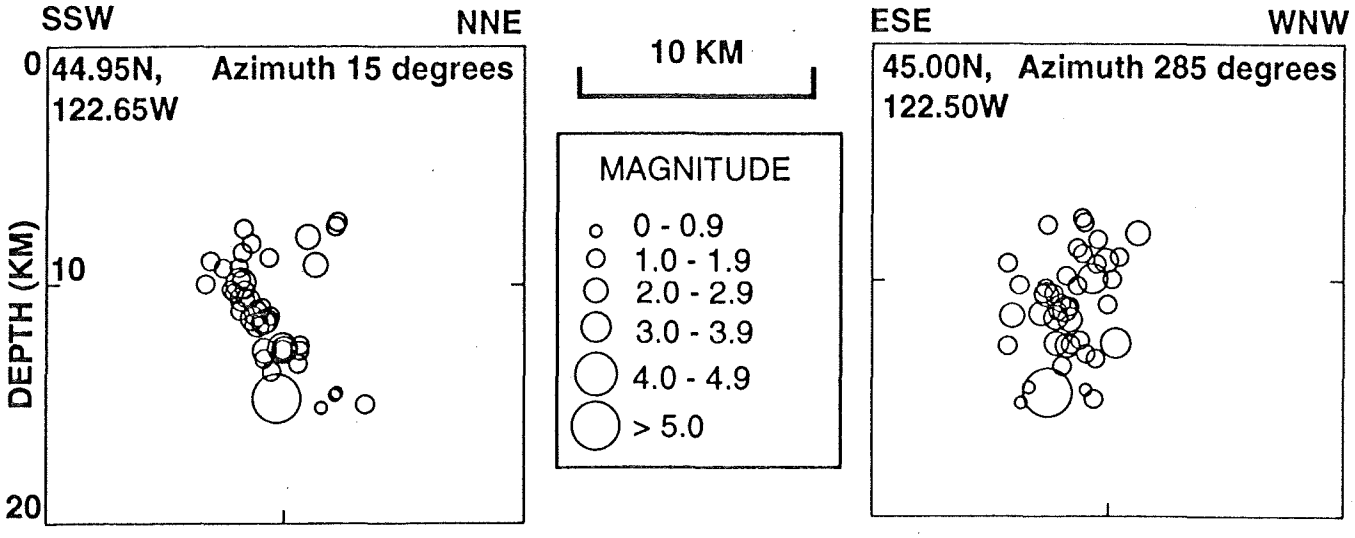
Figure 1. Earthquakes larger than magnitude 2.0 between Oct. 1, 1992 and Sept. 30, 1993. Locations of a few cities are shown as white-filled diamonds. Earthquakes are indicated by filled symbols, where the round symbols represent earthquakes at depths shallower than 30 km, and squares represent earthquakes at 30 km or deeper. Small "x" symbols indicate locations of seismometers operated by the WRSN at the end of Sept. 1993 and shaded triangles show the position of Cascade Volcanos. See the report on 1434-92-G-2195 for more information on stations.





Earthquake Mechanism 3/25/93 13:25 UT (1:1 Ratio of Strike-slip to Reverse motion)

Figure 2. Map view and cross sections of best-located earthquakes (shown as circles) from the Scotts Mills sequence (3/25/93 mainshock M_c 5.6); located with a modified version of our Puget Sound velocity model, $M_c \geq 0.9$, ≥ 6 P arrivals, ≥ 3 stations with both P and S readings, and azimuthal gap < 180°. Positions of temporary stations operated by the USGS are shown by triangles. Cross-section orientations are shown on the map by dashed lines; azimuths and end-point coordinates are indicated on the sections. The main shock focal mechanism shock is shown as a lower-hemisphere, equal area projection - see Fig. 3 for key to focal mechanisms.



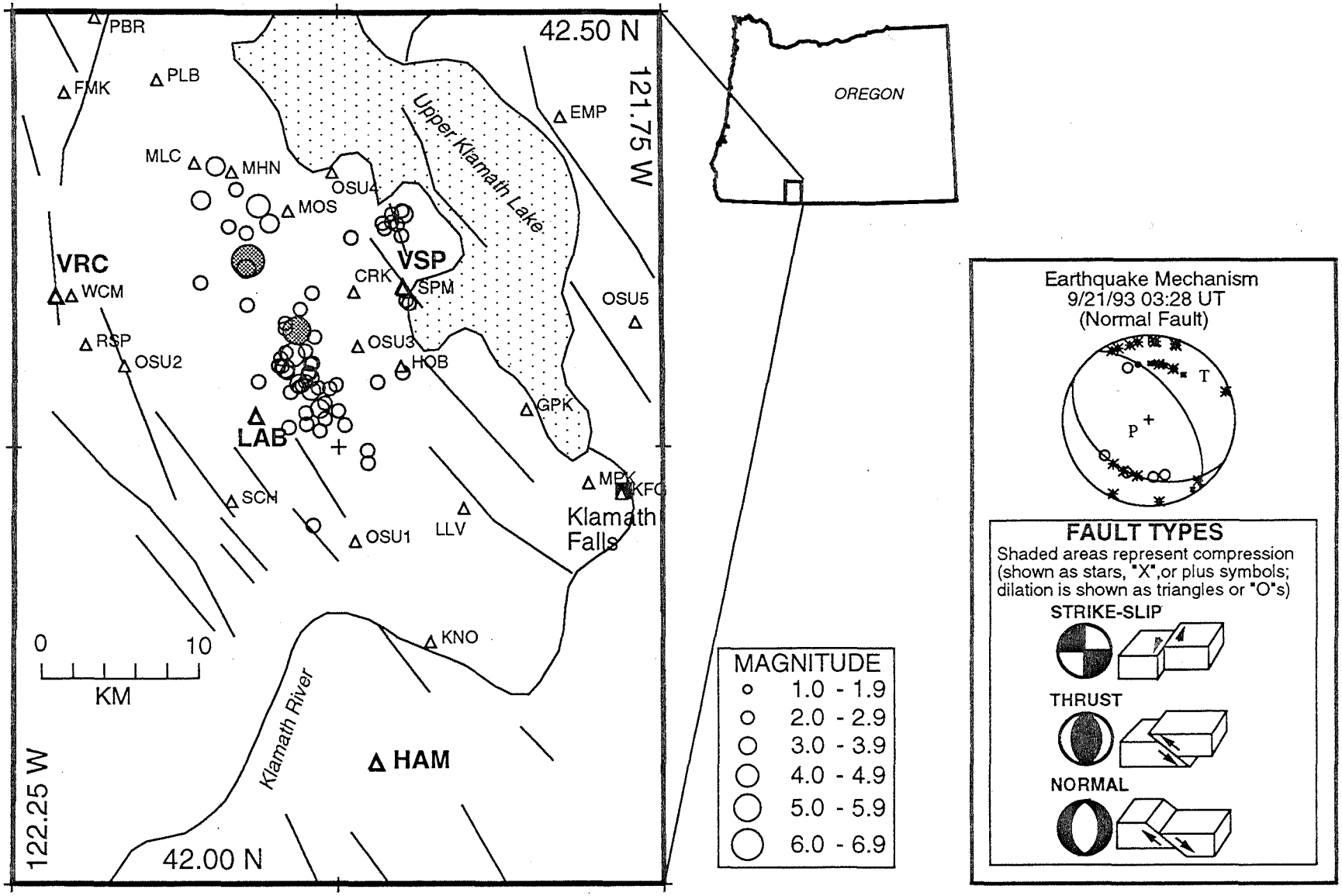


Figure 3. Best locations for earthquakes in the Klamath Falls, OR area; third quarter, 1993. The two largest earthquakes (shaded circles) were on 9/21/93 at 03:28 (M = 5.9) and 04:45 (M=6.0) UT. All locations contain arrival times from both CALNET (USGS,Menlo Park) and WRSN (UW, Seattle). Seismograph stations are shown as triangles. Most stations were portables deployed after the mainshocks. Permanent stations VSP, VRC, LAB and HAM (bold) were installed by the USGS in early Oct. Readings from portable stations are used for some aftershocks. Faults shown are from the dissertation of Silvio Pezzopane, U. of Oregon. The normal focal mechanism (lower hemispere, equal area) for the first mainshock was determined from combined UW and CALNET polarities. The mechanism of the second mainshock is similar.