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## Earthquake Hazard Investigations in the Pacific Northwest

14-08-0001-G1390

1987

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### Investigations

The objectives of this research are to provide fundamental data and interpretations for earthquake hazard investigations. Currently, we are focusing on seismicity, structure, and tectonic questions related to the possibility of a major subduction earthquake on the Juan de Fuca - North American plate boundary. Specific tasks which we have worked on in this contract period are:

1. Tomographic inversion of travel times to determine three-dimensional earth structure.
2. Locations, focal mechanisms and occurrence characteristics of crustal and subcrustal earthquakes beneath western Washington and their relationship to subduction processes.
3. Investigation of offshore earthquakes.
4. Creating an improved catalog of Northwest earthquake locations, magnitudes and dates.

### Results

1. A study of crustal velocity in western Washington is being done using tomographic techniques. The study area is divided into a grid of blocks, and travel times from the U. W. network data base are compared to travel-times computed from a starting velocity model. Pseudo three-dimensional inversion is carried out using 2-D methods in horizontal layers. Programs are now being developed for full three-dimensional inversion of a large volume of the earth's crust.

2. Focal mechanisms have been determined for about 275 earthquakes in western Washington. We are implementing FPFIT, a program written by P. Reasenber and D. Oppenheimer of the USGS (OF-85-739) which automatically determines focal mechanisms given polarity information. This program also provides an estimate of mechanism quality. The objective of this study is to determine the most probable regional tectonic stress in western Washington. Examination of 121 focal mechanisms in the Puget Sound area indicates that systematic differences exist between shallow and deep earthquakes in the Puget Sound region; many more normal mechanisms occur in the deep suite than in the shallow; while thrust events are more common in the shallow suite. The shallow and deep suites also show significantly different distributions of P and T axes. P axes for shallow events are clustered around the North-South direction, while P axes for deep earthquakes scatter in a broad girdle roughly about the E-W equatorial plane. Results are being prepared for publication by Ma Li and others.

By combining high quality hypocenter locations with localized structure from broad band teleseismic P waveform inversion, we have constructed a preliminary structure model of the subducted Juan de Fuca slab beneath Washington. The slab is bent into an eastward plunging arch

beneath Puget Sound in which the axis of the arch dips at about 10-12° whereas the "normal" slab dip on both sides of the arch appears to dip at 15-20°. This structure may help explain the localization of slab seismicity beneath Puget Sound and provide a basis for developing a consistent tectonic model for the region.

3. A study of offshore earthquakes occurring in the vicinity of the Juan de Fuca plate was undertaken to examine the possibility that internal deformation of the JDF plate may be in evidence. We found that many offshore earthquakes could be accurately located if both  $P_n$  and  $S_n$  phases were detected. Although we were able to locate events at least a half magnitude unit lower than the PDE catalog, out of over 135 earthquakes with good locations, only two could be possibly within the plate interior. The remainder were on the Blanco Fracture Zone or at the north end of the JDF plate. We conclude that there is little or no direct evidence of internal deformation of the JDF plate.

4. In cooperation with the USGS, we are preparing a revised catalog of earthquake times, locations, and magnitudes. A national map, and regional seismicity articles are being prepared for the multi-volume "Decade of North American Geology" to be published by the Geological Society of America. Our responsibility is for the catalog and article covering Washington and Oregon. The DNAG catalog for the Pacific Northwest is a compilation of data collected from many sources; we are reviewing the literature to select preferred locations. Previous catalogs for the Pacific Northwest are seriously flawed, and the DNAG catalog represents a significant improvement which allows us to place historical seismicity within the context of seismicity observed with the current network. Seismologists from both the USGS and the U.W. are contributing to both the catalog and an overview article covering seismicity in the Pacific Northwest.

#### Articles

Ludwin, R. S., S.D. Malone, R.S. Crosson, 1987 (in press), Washington Earthquakes 1983, National Earthquake Information Service.

Ludwin, R. S., S.D. Malone, R.S. Crosson, 1987 (in press), Washington Earthquakes 1984, National Earthquake Information Service.

Ludwin, R. S., S.D. Malone, R.S. Crosson, 1987 (in preparation), Washington Earthquakes 1985, National Earthquake Information Service.

Ludwin, R. S., L.L. Nason, A.I. Qamar, R.S. Crosson, C.S. Weaver, S.D. Malone, W.C. Grant, T.S. Yelin, J.E. Zollweg, 1987 (in preparation), Seismicity in the Pacific Northwest, in Decade of North American Geology, published by Geol. Soc. Am.

Crosson, R.S., 1986, Comment on 'Geodetic Strain Measurements in Washington' by J.C. Savage, M. Lisowski, and W.H. Prescott, JGR, V. 91, No. B7, pp. 7555-7557.

#### Reports:

Crosson, R. S., 1986, Seismological Setting of the Puget Sound Region, in USGS proceedings of Conference XXXIII, ed. W.W. Hays and P.L. Gori, U.S.G.S. OFR 86-253.

Qamar, Anthony, Anne Rathbun, Ruth Ludwin, Robert S. Crosson, and Stephen D. Malone, 1986, Earthquake Hypocenters in Washington and Northern Oregon - 1980; Washington State Department of Natural Resources, Division of Geology and Earth Resources, Information Circular 82

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Qamar, Anthony, Ruth Ludwin, Robert S. Crosson, and Stephen D. Malone, 1987 (in press), Earthquake Hypocenters in Washington and Northern Oregon - 1981; Washington State Department of Natural Resources, Division of Geology and Earth Resources.

Earthquake Hypocenters in Washington and Northern Oregon; 1982-1986, 1987 (in preparation), University of Washington Geophysics Program

Univ. of Wash. Geophysics Program, 1986, Quarterly Network Report 86-C on Seismicity of Washington and Northern Oregon

Univ. of Wash. Geophysics Program, 1986, Quarterly Network Report 86-D on Seismicity of Washington and Northern Oregon

Earthquake Hazard Research in the Pacific Northwest, 1987, Contract 14-08-0001-G1080 Final Technical Report 1987.

### Abstracts

Ludwin, R. S., L.L. Nason, A.I. Qamar, R.S. Crosson, C.S. Weaver, S.D. Malone, W.C. Grant, T.S. Yelin, 1986 Seismicity in the Northwestern U.S., EOS, V. 67, No. 44, p. 1084.

Crosson, R. S. and E.L. Crosson, 1986, Preliminary Analysis of Juan de Fuca Plate Seismicity using the Washington Regional Seismograph Network, EOS, V. 67, No. 44, p. 1084.

Ma, Li, and R.S. Ludwin, 1987, Can Focal Mechanisms be used to Separate Subduction Zone from Intra-plate Earthquakes in Washington?, EOS, V. 68, No. 3.

J. Lees, 1987, Tomographic Inversion for Lateral Velocity Variations in western Washington, EOS, V. 68, No. 3.

Sent 4/29/87

**Regional Seismic Monitoring in Western Washington**

14-08-0001-A0266

1987

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**Investigations**

Operation of the western Washington regional seismograph network and routine preliminary analysis of earthquakes in western Washington are carried out under this contract. Quarterly catalogs of seismic activity in Washington and Northern Oregon are available for 1984 through 1986, and the first two quarters of 1987. These catalogs are funded jointly by this contract and others. The University of Washington operates approximately 80 stations west of 120.5°W. Twenty eight are funded under this contract.

Data are provided for USGS contract 14-08-0001-G1390 and other research programs. Efforts under this contract are closely related to and overlap objectives under contract G1390, also summarized in this volume. Publications are listed in the G1390 summary. This summary covers a six month period from October 1, 1986 through March 31, 1987. During this period the U.W. seismic network located 727 events west of 120.5°W. 434 of these were located at Mount St. Helens and were associated with the extrusion of a new lava lobe between October 4 and October 27. Excluding Mt. St. Helens, 293 earthquakes were located west of 120.5° W, compared to 315 and 309 in the preceding two six-month periods. During the six months covered by this summary, the largest earthquake located in western Washington was a  $M_c$  3.2, which occurred on October 12th, at 67 km depth, about 40 km northeast of Longview Washington. The preliminary focal mechanism suggests normal faulting with extension in a NE-SW direction. Only one other earthquake this deep has been located in southwestern Washington (a magnitude 3.3 in April 1984).

Malone

## Significant Earthquakes in Washington and northern Oregon, 1987

1987

By R. S. Ludwin, A. I. Qamar, R. S. Crosson, and S. D. Malone

During 1987, the Washington Regional Seismograph Network (WRSN) operated by the University of Washington included more than 100 telemetered seismic stations in Washington and northern Oregon. Station coordinates and a description of data acquisition and processing procedures are given in Qamar et al. (1987). No damaging earthquakes occurred in Washington or Oregon during 1987. The largest earthquake within our network had a magnitude of 4.3, and was located at a depth of ~20 km on December 2nd near Yakima.

During 1987, 969 earthquakes were located by the Washington Regional Seismographic Network within Washington, northern Oregon, and southern British Columbia in the area shown in Figure 1. Fig. 1 shows epicenters of earthquakes which were reported felt or had coda-length magnitudes ( $M_C$ ) greater than or equal to 2.7. During 1987, 21 earthquakes were felt in the area of Fig. 1, and 7 additional events had magnitudes greater than or equal to  $M_C$  2.7 but were not reported felt. Earthquakes reported felt are indicated by filled symbols. Of all earthquakes located by the U. W. network in 1987 22% were located in the vicinity of Mt. St. Helens, 32% west of the Cascade range in Washington, and outside of the Mt. St. Helens area, 20% in Washington within the Cascade range, 20% in Washington east of the Cascade range, and 6% in Oregon. The geographic extent of these regions is shown on Fig. 1 by dashed lines.

The largest earthquakes in Washington and Oregon were a pair of moderate sized earthquakes,  $M_C$  4.1 and 4.3, at depths of about 18 km, that occurred two hours apart on December 2 (07:12 and 09:02 UCT). Their location was 16 km northwest of Yakima in eastern Washington, and they were followed by seven aftershocks in the next two days, three of which were  $M_C$  1.0 or larger. A  $M_C$  3.0 earthquake (not reported felt) at similar depth occurred on June 11 about 10 km to the north.

Elsewhere east of the Cascades, a magnitude 2.6 event with a near surface depth was reported felt on February 28 near the eastern end of Lake Chelan, and on December 20 three events (all shallower than 20 km); magnitudes 1.2, 1.1, and 2.7; were felt at Sims Corner,

Washington, halfway between Entiat and Grand Coulee,

The largest earthquake in western Washington was on June 19, when a felt earthquake of  $M_C$  3.9 occurred offshore, a short distance southwest of Aberdeen, at a depth of nearly 40 km. This is the largest deep ( $\geq 30$  km) earthquake known in this area, although about 12 deep earthquakes have been located within 50 km of the June 19 event since 1980.

Elsewhere in western Washington, three minor earthquakes were reported felt in northwestern Washington, near Darrington on March 17th, March 19, and April 5; all were shallower than 5 km ( $M_C$  2.8, 2.1, and 2.8). More intense activity occurred in the Darrington area during 1985 and 1986. On September 16, a  $M_C$  3.3 earthquake occurred at a depth of about 12 km in southern British Columbia, and was felt in Blaine, Washington. Also in B.C., a  $M_C$  2.7 earthquake at  $\sim 25$  km depth was felt on Dec. 19 on the Saanich Peninsula of Vancouver Island (reported by the Pacific Geoscience Centre). On the Olympic Peninsula, two felt earthquakes,  $M_C$  2.7 and 2.8, at about 20 km depth on August 6 and Sept. 20 (06:55 UCT) located near Port Townsend. Although another  $M_C$  2.8 earthquake on Sept. 20 (08:53 UCT) occurred about 20 km southwest of Port Townsend at a depth of 55 km, it was not reported felt. Two small earthquakes that occurred on the Kitsap Peninsula about 10 km northwest of Bremerton at depths of  $\sim 20$  km were felt on on April 28 ( $M_C$  2.8) and June 18 ( $M_C$  2.4). Another  $M_C$  2.4 earthquake on Jan. 2 at the same location as the June event was not reported felt. In southwestern Washington, about 10 km north of Vancouver Washington, two felt earthquakes,  $M_C$  2.3 and 2.6, at depths of  $\sim 20$  km occurred on May 16 and October 2.

In Oregon two clusters of earthquakes occurred east of the Deschutes Valley. The first cluster, from August 8 through 24, included 21 earthquakes  $M_C$  1.0 or larger. The largest,  $M_C$  2.4, was felt on August 9. The WRSN computed depth for this event is poorly constrained, and we consider 12 km to be a reasonable depth estimate. In 1976, a  $M_L$  4.8 earthquake occurred at this same location. A  $M_C$  2.8 earthquake on June 30, located about 20 km south of the August activity, was not reported felt. The second cluster, from Sept. 4 through 29, was about 60 km east of the August activity and included two felt earthquakes  $M_C$  3.1 and  $M_C$  2.7 on Sept. 8 and

29, as well as 4 other earthquakes larger than  $M_C$  1.0; all were shallower than 5 km.

### References

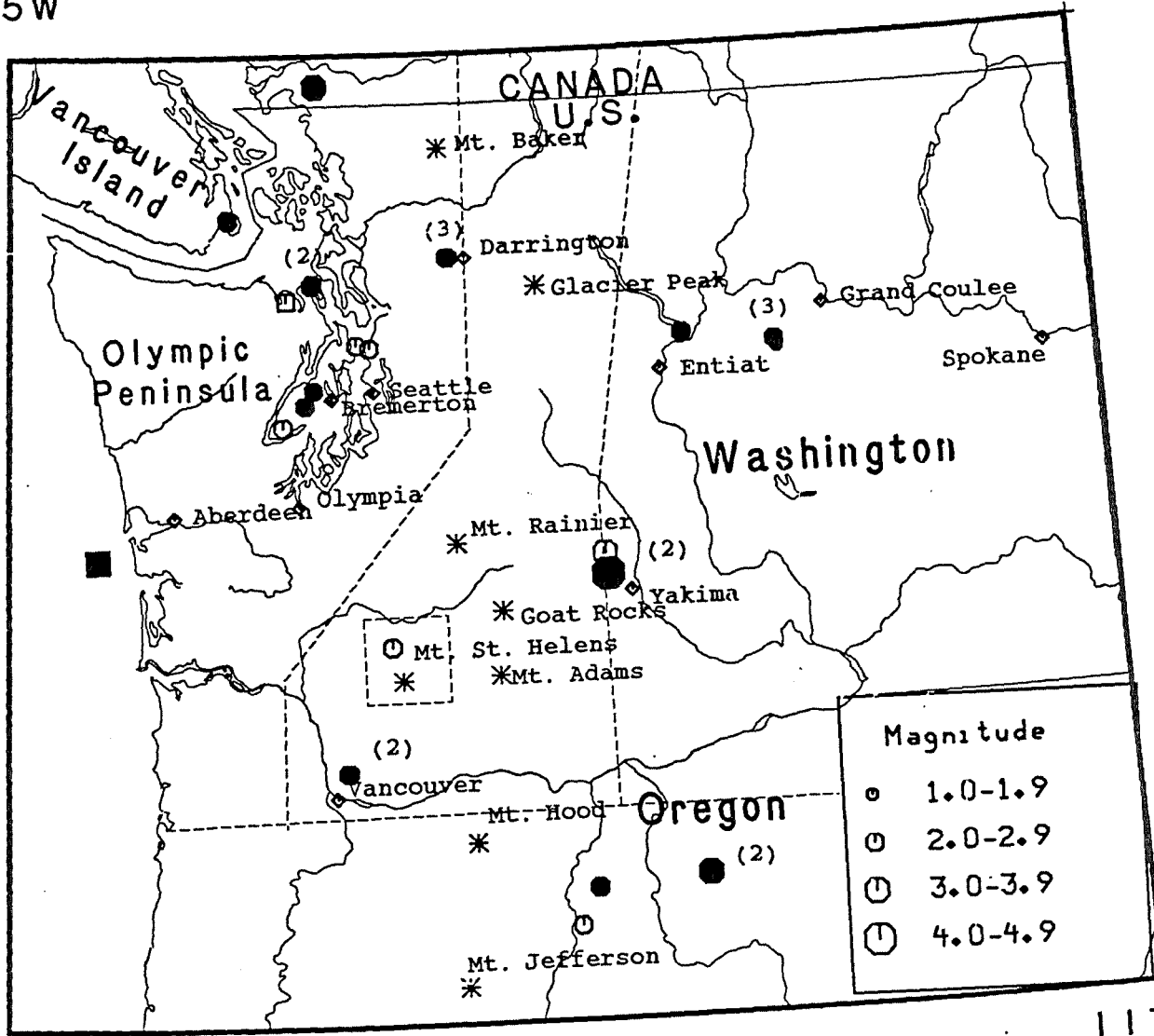
Qamar, Anthony, Ruth Ludwin, Robert S. Crosson, and Stephen D. Malone, 1987, Earthquake Hypocenters in Washington and Northern Oregon - 1982-1986, Washington Division of Geology and Earth Resources Information Circular 84.

**Figure 1.** Felt earthquakes in Washington and northern Oregon during 1987 plus earthquakes with coda-length magnitudes greater than or equal to 2.7 which were not felt. Earthquakes reported felt in Washington and northern Oregon during 1987 are shown as solid symbols, in some cases several earthquakes occur nearly in the same spot and the number of felt earthquakes is indicated in parenthesis. Open symbols show all other earthquakes having magnitudes greater than or equal to 2.7. Round symbols represent events with depths shallower than 30 km, while square symbols indicate event depths of 30 km or more. Cascade volcanos are shown as asterisks.



125W

49.25N



Magnitude	
○	1.0-1.9
⊙	2.0-2.9
⊖	3.0-3.9
⊕	4.0-4.9

44.5N

117W

0 200 KM

WASHINGTON - 1987 Earthquakes felt or larger than  $M_c$  2.7

DAY	TIME	LAT	LON	DEPTH	M	NS/NP	GAP	RMS	Q	MOD	TYP
87/01/15	17:58:13.18	47 49.71	122 26.58	19.55	2.7	20/29	0	0.15	AA	P3	
87/02/28	14:56:10.54	47 49.99	120 02.89	0.54	2.6	25/31	0	0.27	BA	N3	F
87/03/17	16:34:54.58	48 15.36	121 45.66	3.28\$	2.8	27/35	0	0.38	CC	P3	F
87/03/19	18:40:30.44	48 15.18	121 45.13	3.75\$	2.1	17/25	0	0.32	CC	P3	F
87/04/05	01:06:44.73	48 15.36	121 44.74	1.69	2.8	18/18	0	0.28	BC	P3	F
87/04/28	06:42:46.51	47 36.61	122 45.80	20.37	2.8	32/40	0	0.20	BA	P3	F
87/05/16	09:08:35.68	45 44.00	122 35.17	21.11	2.3	33/36	0	0.14	AB	C3	F
87/06/11	19:50:16.98	46 46.65	120 41.64	17.23	3.0	33/42	0	0.35	CA	E3	
87/06/18	10:15:59.77	47 32.29	122 49.57	18.73	2.4	32/39	0	0.15	BA	P3	F
87/06/19	05:47:41.66	46 47.65	124 21.04	37.95	3.9	37/43	0	0.24	BD	P3	F
87/06/26	14:42:38.88	47 48.79	122 20.97	14.95	2.7	31/45	0	0.24	BB	P3	
87/06/30	02:04:26.95	44 57.87	120 59.57	9.27	2.8	22/24	0	0.35	CC	O0	
87/07/25	10:10:18.48	47 25.99	122 59.45	15.60*	2.7	43/48	0	0.17	BB	P3	
87/08/06	21:12:42.55	48 07.80	122 45.83	22.44*	2.7	19/22	0	0.14	AA	P3	F
87/08/09	03:32:09.96	45 08.67	120 51.62	27.97*	2.4	31/37	0	0.31	CD	O0	F
87/09/08	05:02:15.66	45 11.47	120 04.32	13.01	3.1	37/37	0	0.51	DC	O0	F
87/09/11	13:13:10.93	46 21.19	122 15.07	12.46	2.8	42/45	0	0.16	BA	S3	
87/09/16	20:10:42.25	49 05.72	122 42.00	12.34	3.3	23/37	0	0.24	BB	P3	F
87/09/20	06:55:52.44	48 08.37	122 45.27	21.47	2.8	22/27	0	0.20	BB	P3	F
87/09/20	08:53:13.20	48 03.38	122 57.11	55.42	2.8	29/34	0	0.23	BA	P3	
87/09/29	16:20:26.48	45 10.57	120 03.67	20.09	2.7	24/25	0	0.35	CD	O0	F
87/10/02	02:33:01.50	45 44.06	122 34.86	18.93	2.6	42/47	0	0.19	BB	C3	F
87/12/02	07:12:57.46	46 40.49	120 41.03	18.20	4.1	37/40	0	0.26	BA	E3	F
87/12/02	09:02:24.27	46 40.75	120 40.39	17.80	4.3	38/39	0	0.37	CA	E3	F
87/12/19	20:30:17.85	48 27.67	123 22.50	23.89	2.7	27/38	0	0.26	BA	P3	F
87/12/20	07:14:40.58	47 46.09	119 21.67	0.64	1.2	6/10	0	0.36	CC	N3	F
87/12/20	07:28:51.85	47 44.44	119 21.18	16.67	1.1	6/08	0	0.24	BC	N3	F
87/12/20	07:38:25.13	47 46.56	119 22.02	0.03*	2.7	19/21	0	0.31	CB	N3	F

### 1987 FELT REPORTS; WRSN

AF8702281455 70.54 47N4999 120W 289 0.54 2.6 25/031 89 3 0.27 0.4BA N3

Located in north-central Washington:  
Felt in Chelan, "Paul" (509)654-1930

AF8703171634 54.58 48N1536 121W4566 3.28\$ 2.8 27/035 59 14 0.38 1.0CC P3

AF8703171639 21.89 48N1589 121W4595 3.38 1.1 7/011 139 14 0.08 0.7AC P3

Located in NW Washington, Darrington area:

Shari Brewer (206)436-1771 "came in a roll; like 2 heights in the roll, lasted ~30 secs, shook whole house. Heard rumbling but no boom" (she lives near the Whitehorse store).

Sharon Felder (206)436-1883 " lots of rumbling after a big boom". Neighbor felt 2nd shock ~5 minutes later (located at end of Swede Heaven Road about 5 miles W. of Darrington).

Local school staff "heard rumbling".

Theresa Holme "felt boom, whole house shook, daughter looking out window saw earth ripple"

(located directly across from Whitehorse Mtn., ~1 mile from Whitehorse store).

AF8703191840 30.44 48N1518 121W4513 3.75\$ 2.1 17/025 61 14 0.32 11.5CC P3

Located in NW Washington, Darrington area:

Felt by Sharon Palmer and Shari Brewer - shook house, seemed smaller than before (one quarter size of the last one (3/17/87?)). Shari says Ken Anderson (206) 436-1462 knows of an old earthquake that closed mines in the area.

Albert Palmer felt the floor shift but heard nothing.

AF8704050106 44.73 48N1536 121W4474 1.69 2.8 18/018 61 15 0.28 2.0BC P3

Located in NW Washington, Darrington area:

Shari Brewer (Whitehorse area) shook house a couple of times "good" rattled windows, daughter felt one this morning at about 4:27 AM PDT (did not trigger the UW recording system) "in between" earthquakes of 3/17/87 and 3/19/87 in force.

AF8704280642 46.51 47N3661 122W4580 20.37 2.8 32/040 28 7 0.20 0.7BA P3

Located in western Washington, Kitsap Peninsula:

Dennis Shannon from a radio station called to verify one report of felt earthquake near the Belfair area; caller reported a "pretty good shake"

Mission Lake; closer to Belfair "really loud noise, windows rattled"

"Sam" Anderson - Bremerton energy coordinator - was up past midnight but felt nothing. Also, they recorded no calls from Bremerton.

AF8705160908 35.68 45N4400 122W3517 21.11 2.3 33/036 82 31 0.14 1.3AB C3  
Located in southwestern Washington:  
Felt by someone in Orchards (NE Vancouver, WA) who reported this quake to  
Pat Pringle at the Cascade Volcano Observatory

AF8706181015 59.77 47N3229 122W4957 18.73 2.4 32/039 42 3 0.15 0.5BA P3  
Located in western Washington, Kitsap Peninsula:  
Felt by Barbara Archer (206)886-0268 at the north end of Sawyer Lake,  
near Maple Valley. A hot water tank on the ground floor shook, the house  
shook, dogs barking woke her prior to the event.  
She felt and heard something like an explosion, then a rumbling.  
Her neighbor said it sounded like a truck rolling by.

AF8706190547 41.66 46N4765 124W2104 37.95 3.9 37/043 221 45 0.24 0.7BD P3  
Located offshore western Washington:  
Felt in Tokeland, South Bay and Raymond

AF8708062112 42.55 48N 780 122W4583 22.44\* 2.7 19/022 83 20 0.14 0.1AA P3  
Located near northeastern tip of Olympic Peninsula:  
Felt on Whidbey Island

AF8708090332 9.96 45N 867 120W5162 27.97\* 2.4 31/037 194 41 0.31 0.1CD O0  
Located in north-Central Oregon:  
R. Couch of OSU reports that this earthquake was felt in Deschutes Valley,

AF8709080502 15.66 45N1147 120W 432 13.01 3.1 37/037 140 35 0.51 3.1DC O0  
Located in north-Central Oregon:  
We heard indirectly that this earthquake was felt in  
the Condon, Oregon area; but it was not reported to the UW.

AF8709162010 42.25 49N 572 122W4200 12.34 3.3 23/037 76 21 0.24 1.8BB P3  
Located in Canada:  
Felt in Blaine, Washington

AF8709200655 52.44 48N 837 122W4527 21.47 2.8 22/027 83 21 0.20 1.2BB P3  
Located near northeastern tip of Olympic Peninsula:  
Felt by two people in Port Townsend. Reported by John Peterson at Ft.  
Warden State Park (206)385-4730 in Port Townsend "shook house, rattled windows".

AF8709291620 26.48 45N1057 120W 367 20.09 2.7 24/025 181 36 0.35 1.6CD O0

Located in north-Central Oregon:

We heard indirectly that this earthquake was felt in the Condon, Oregon area; but it was not reported to the UW.

AF8710020232 61.50 45N4406 122W3486 18.93 2.6 42/047 60 24 0.19 1.3BB C3

Located in southwestern Washington:

Felt in Vancouver, Washington.

AF8712020712 57.46 46N4049 120W4103 18.20 4.1 37/040 40 9 0.26 0.7BA E3

Located in central Washington:

The director of Yakima Emergency Services reported earthquake; he received a few calls from Naches area. Also reported felt by Isabelle Lynn, owner of the DoubleK Mountain Ranch in Goose Prairie, WA 98929.

Tim? Klaes? Naches area 682-1812

AF8712020902 24.27 46N4075 120W4039 17.80 4.3 38/039 35 8 0.37 1.0CA E3

Located in central Washington:

Reported felt by Isabelle Lynn, owner of the DoubleK Mountain Ranch in Goose Prairie, WA 98929.

Judy Setzer 793-2798 from Goldbar/Goose Prairie felt the earthquake in a mobil home, which swayed with vibration for ~ 1 minute, her roommate heard roaring.

Dick Whitehurst (509)376-4687 from the Hanford area operates a strong motion instrument which triggered on this earthquake

A man from Wenatchee reported being awakened by this quake.

Joanne Santerre (206) 825-2140 from Enumclaw called and said her neighbor's pipes disconnected and she thought she felt this EQ.

AF8712192030 17.85 48N2767 123W2250 23.89 2.7 27/038 51 6 0.26 0.9BA P3

Located on Saanich Peninsula, British Columbia

Felt in Victoria, British Columbia - reported by Canadian GS

AF8712200714 40.58 47N4609 119W2167 0.64 1.2 6/010 118 7 0.36 0.7CC N3

Located in north-central Washington:

Felt near Sims Corner, WA

AF8712200728 51.85 47N4444 119W2118 16.67 1.1 6/008 120 5 0.24 1.0BC N3

Located in north-central Washington:

Felt near Sims Corner, WA

AF8712200738 25.13 47N4656 119W2202 0.03\* 2.7 19/021 84 8 0.31 0.3CB N3

Located in north-central Washington:

Felt near Sims Corner, WA