FINAL REPORT: 1996

Name of Contractor:	**University of Washington**
Principal Investigator:	**S. D. Malone** **Geophysics Program** **Box 351650** **University of Washington** **Seattle, WA 98195-1650**
Government Technical Officer:	**Dr. John Sims** **MS 905** **U.S. Geological Survey** **12201 Sunrise Valley Drive** **Reston, VA 20192**
Short Title:	**Seismic Velocity Structure of the Greater Mount Rainier Area**
Program objective number:	**II-1 and II-2**
Effective Date of Grant:	**Feb. 1, 1995 - Oct. 31, 1996**
Amount of Grant, 1995-1996:	**$73,800**
Time Period Covered in Report:	**2/1/95 - 10/31/96**
Date Report Submitted:	**July 7, 1997**

Research supported by the
U.S. Geological Survey, Department of the Interior
under USGS award number 1434-95-G-2571

Final Report

1. Introduction

Evaluating earthquake hazards from crustal earthquakes in the greater Puget Sound region is complicated by the fact that very few potentially active faults are recognizable at the surface. Locating and characterizing potential fault zones is therefore largely dependent upon our ability to detect and evaluate structures below the earth's surface. Historic shallow earthquakes have mostly been located in and along the western edge of the Cascade Range. In southwestern Washington, many earthquakes occur in distinct clusters or zones of seismic activity (see Figure 1), suggesting the possibility that significant faults lie buried beneath surface.

The primary goal of this project was to generate an image of the 3-D P-wave velocity structure in a region of the southern Washington Cascade Range (which we refer to as the greater Mount Rainier area, or **GMR** (see Figure 1)), and to use this image to evaluate seismogenic potential in the area. We generated this image via seismic tomography, using a modified version of the methodology of Lees and Crosson (1990). Most of this work was carried out as a doctoral project titled "P-Wave Velocity Structure in the Greater Mount Rainier Area from Local Earthquake Tomography" by Seth Moran, who completed his thesis in 1997. The details of the tomographic methodology used in this project are described in Chapter II of Moran's dissertation.

A very important part of this work was the operation of a network of temporary seismograph stations between February 2nd, 1995, and June 16th, 1996. A total of 18 sites were occupied for 4 to 8 months each, and were placed so as to fill gaps in raypath coverage that we identified in the Pacific Northwest Seismograph Network catalog. Figure 3.6 in Moran (1997) shows these gaps, and Figure 3.10 shows the data recorded by the temporary stations. The data gap east of Mount Rainier has largely been filled by the data recorded during this experiment.

2. Project Goals

At the onset of this project, we had three goals. The first goal was to provide important additional constraints to current models of regional geologic structure, lithology, tectonics, and volcanism. The second goal was to examine and possibly map out boundaries of buried upper-crustal bodies detected by previous investigators, including the Southern Washington Cascades Conductor (SWCC) and the margins of the Crescent Formation and the pre-Tertiary margin of the North American continent. The third goal was to determine new hypocentral locations using the 3-D velocity model derived in the tomographic study, and to examine these locations in the context of our 3-D model to estimate seismogenic potential in various regions of the GMR.

3. Results

The results of our work more than satisified our goals as described above. We used a total of 75,000 P-wave arrival times from more than 3500 earthquakes to invert for P-wave velocities in a model parameterized by over 110,000 2.5 x 2.5-km constant velocity blocks, and we used Laplacian smoothing in 2-D to regularize the inversion. The results of this work are displayed in Plate 1 from Moran (1997), and are discussed in detail in Chapter IV. The most important results are also summarized here.

Geology

Our P-wave velocity model provides important constraints on the structure and lithology of the upper crust beneath the GMR. There is excellent general agreement between the upper 7 km of our model and surificial geology. Significant findings include:

- **Two low velocity anomalies that lie directly beneath the Morton and Carbon River-Skate Creek anticlines, extending from the surface to 10 km.** The P-wave velocities in these anomalies are consistent with experimentally-determined velocities of sandstones at pressures equivalent to these depths. Based on the velocity values and the close association of these anomaly patterns with mapped outcrops of Tertiary sediments, we interpret these anomalies to represent the underground extension of the Carbonado and McIntosh formations.

- **Low velocity anomalies that correlate with the positions of the Seattle, Tacoma, and Chehalis basins.** The anomaly patterns extend from the surface down to 7-10 km, which corresponds exactly with the base of these basins as determined by other investigators. The P-wave velocities are consistent with the poorly-to-loosely consolidated sediments found in these basins.

- **A broad high velocity anomaly extending from the surface to 10 km beneath and to the east of Mount Rainier.** This anomaly correlates almost exactly with the mapped positions of several Tertiary granodioritic bodies, including the the Tatoosh, White River, and Bumping Lake plutons. The velocities in this anomaly (~6.2 km/sec) closely match laboratory measurements of P-wave velocities in granodiorite.

- **A broad high-velocity anomaly at depths of 1-7 km located south of Olympia and east of Centralia.** This anomaly lies beneath the sedimentary cover of the Puget Lowlands. The velocities are quite fast (~6.5 km/sec), and are consistent with a body composed of altered basalts with minor amounts of gabbro and diabase. We interpret this feature to be a buried eruptive center of the Crescent formation.

- **A cylindrical low-velocity anomaly that extends from 4 to at least 14 km beneath Mount Rainier.** This anomaly is interpreted to be caused by heating of country rock in association with the cooling of bodies of magma in the conduit system beneath Rainier.

Seismotectonics

The association (or lack thereof) between seismicity patterns and structures in our P-wave velocity model has significant implications for seismic hazards and seismotectonics in the GMR. These include:

- **The association of the St. Helens seismic Zone (SHZ) with a narrow, north-south, 50-km long trough of lower velocities extending from near the surface to at least 14 km (Figure 2).** This is illustrated in Figure 2, which shows one horizontal slice through our model. Note that SHZ earthquakes occur within a north-south trending linear zone of cyan-colored blocks. This zone is an area of lower velocities, which we interpret to be a region of crustal weakness in which earthquakes preferentially occur. The association of the linear SHZ with this linear feature in our model supports the hypothesis that the SHZ represents a distinct fault or fault zone. Using a length of 50 km, the maximum expectable earthquake along this fault is between M 6.5 and 7.0.

• **The general lack of association of the Western Rainier Seismic Zone (WRSZ) with a single distinct feature in the velocity model (Figure 2).** Figure 2 shows the WRSZ occurring on the edge of a lower-velocity feature. Note, however, that earthquakes are occurring in both high (dark blue) and low (cyan) velocity material, and the seismicity is in general more diffuse than the SHZ. These observations, combined with data from focal mechanisms, support the hypothesis that the WRSZ does not represent a distinct fault or fault zone. Using the maximum width of the WRSZ, we estimate that the longest continuous fault on the WRSZ can be no more than 12 km, which would generate an earthquake no larger than a M 5.5. This estimate is an order of magnitude smaller than our estimate of the maximum earthquake for the SHZ.

• **The apparent association of the 1974 M 4.8 earthquake near Ohanapecosh with a northeast-trending lateral velocity contrast in the 3-D velocity model.** This suggests the possibility that this event occurred along a previously unidentified fault, which (based on the length of this lateral velocity contrast) could generate a M 6.4.

• **The general lack of a systematic relationship between velocity patterns and the inferred location of the Southern Washington Cascades Conductor (SWCC).** This lack of association indicates that there is no single velocity signature associated with the SWCC, and raises the possibility that it is not a distinct lithologic feature. If this is the case, then seismotectonic models in southwestern Washington may need to be revised.

• **The apparent correlation of a high velocity ridge with the southern boundary of the Olympic Wallowa Lineament (OWL).** Based on the additional correlation of these two features with a ridge of heat flows and an apparent change in the orientation of P- axes from focal mechanisms, we propose the addition of a fourth segment to the segmentation scheme of Guffanti and Weaver (1988) for the Washington and Oregon Cascades.

• **The apparent location of volcano-tectonic earthquakes at depths below the base of the edifice of Mount Rainier.** These new locations (made in our 3-D model) indicate that the volcano-tectonic earthquakes are probably not occurring in response to the disintegration of the edifice. We interpret these earthquakes instead to be occurring in response to thermal and/or volumetric forces related to the hydrothermal/magmatic system beneath Mount Rainier.

4. List of Publications

Moran, S. C., "Three-Dimensional P-Wave Velocity Structure in the Greater Mount Rainier Area from Local Earthquake Tomography", Ph.D. thesis, 170 pp., Univ. of Wash., Seattle, 1997.

Moran, S. C., J. M. Lees, and S. D. Malone, "Three-Dimensional P-Wave Velocity Structure in Southwestern Washington from Local Earthquake Tomography" (abstract), *EOS Trans. AGU, 77 (46),* Fall Meet. Suppl., p. F466, 1996.

Moran, S. C., J. M. Lees, and S. D. Malone, "P-Wave Tomography in Western Washington

Using Regional Network Recordings of Controlled Source Experiments: Results and Interpretations" (abstract), *GSA Abstracts with Programs, 28,* p. A-195, 1996.

Moran, S. C., J. M. Lees, and S. D. Malone, "P-wave Tomography at Mount Rainier, Washington: Preliminary Results" (abstract), *EOS Trans. AGU, 76 (46),* Fall Meet. Suppl., p. F644, 1995.

Moran, S. C., A. Qamar, and S. D. Malone, "Seismicity at Mount Rainier, Washington" (abstract), *IUGG Abstract Program,* p. A453, 1995.

Malone, S.D., and S.C. Moran, "Mount Rainier; Washington, USA: tectonics, seismicity, and hazards, *Volcanoes in Town,* page 49-52, IAVCEI conference on volcanic hazard in densely populated regions, Periodico di Mineralogia, Roma (extended abs), 1995.

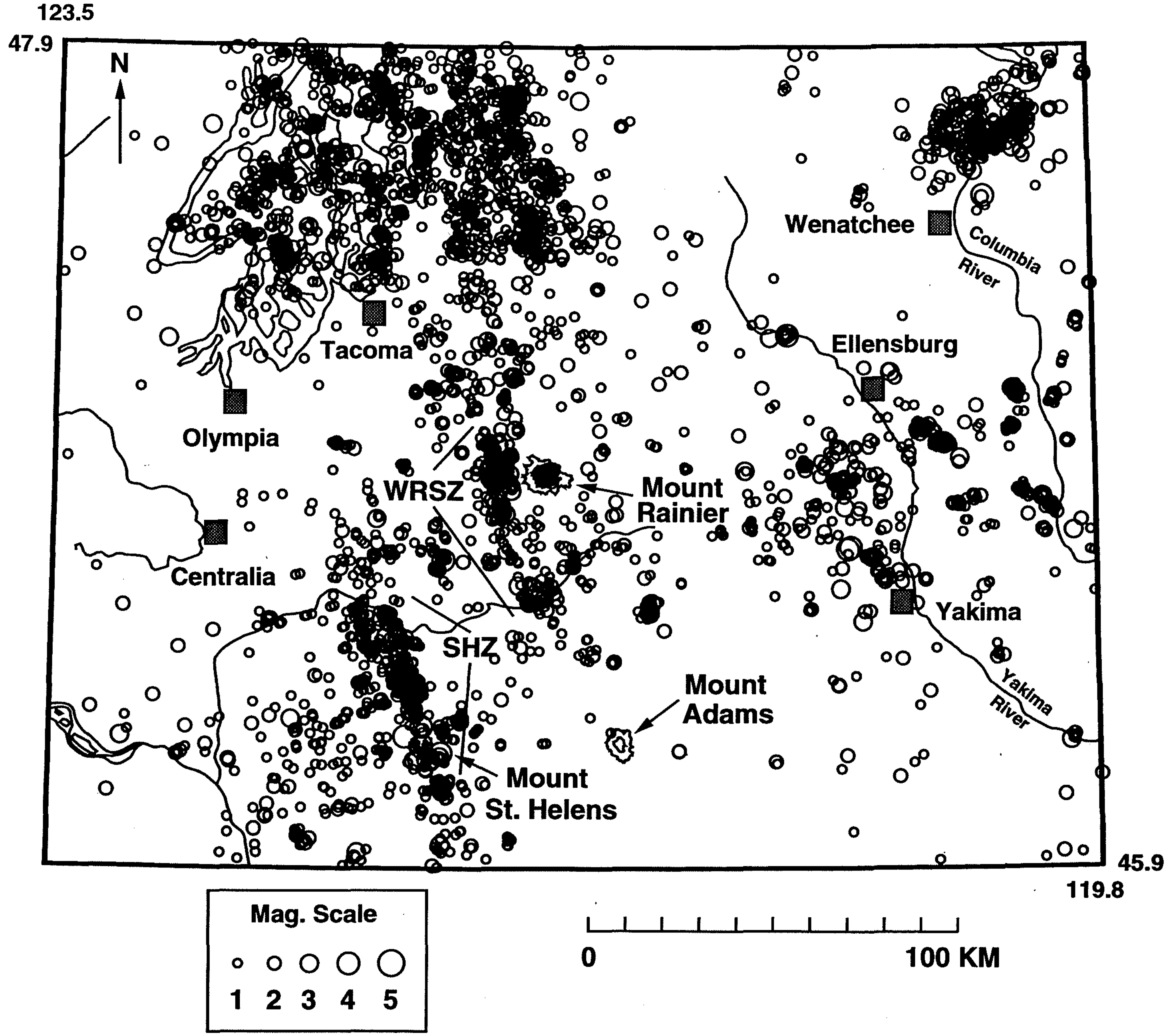

Figure 1. Map of all crustal (depths less than 35 km) earthquakes located within the Greater Mount Rainier area (GMR) between 1980 and 1996. These were the events we used to invert for 3-D P-wave velocity structure in the GMR.

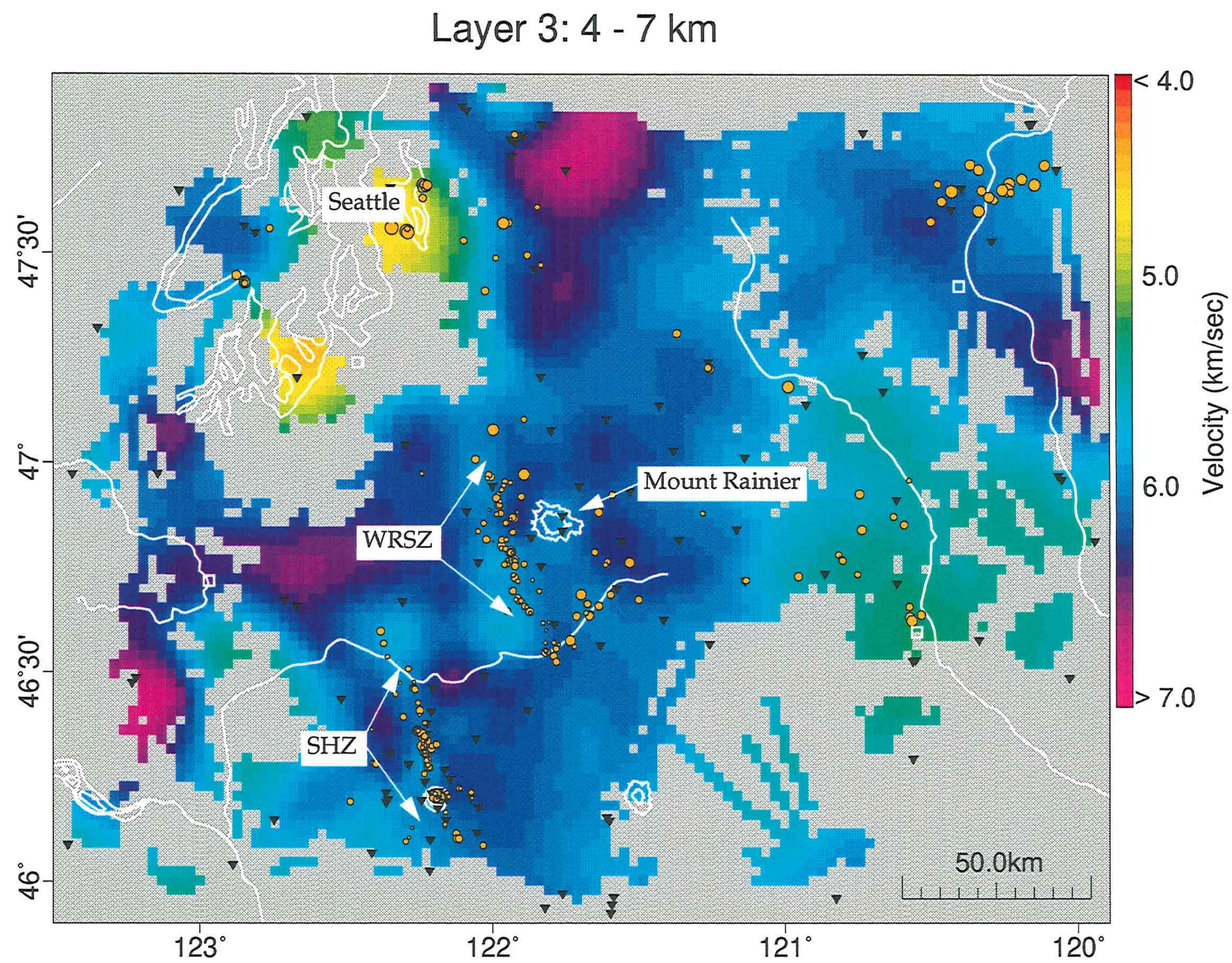

Figure 2. A horizontal slice (depth 4-7 km) through our 3-D model. Colors in each block correspond to seismic velocities determined using seismic tomography (color scheme for velocities is indicated in upper-right corner). Also plotted are earthquakes located at depths of 4-7 km. The locations of the St. Helens Seismic Zone (SHZ) and Western Rainier Seismic Zone (WRSZ) are also shown.