**Earthquake Hazard Investigations
in the Pacific Northwest and southern Alaska using network data**

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Investigations

This research focuses on earthquake hazards in the Pacific Northwest, including large scale plate interactions, through the study of regional structure and tectonics. Current investigations by our research group include determining source scaling and moment estimation using coda amplitudes, completing work on subduction kinematics of the subducting plate, investigating P-wave multiplets arising from teleseismic arrivals reflected from the subducting plate, and refraction interpretation of earthquake travel times.

Source moment estimation and magnitude determination using S-coda amplitude:

We wish to provide accurate automated estimates of earthquake magnitude using regional or local (mainly vertical component) short-period data. The current technique for determining magnitudes from short-period data is to use S-wave coda duration. However machine algorithms to automatically assign coda durations are far from satisfactory due to variations in noise level and signal frequency.

We have developed a method to base magnitudes on coda amplitude rather than duration. Using standard coda amplitude models based on scattering theory (e.g. Aki and Chouet, 1975), we can relate the amplitudes back to the source spectrum and hence directly to moment. Magnitudes can then be derived directly from the moment estimates.

S-wave coda amplitudes from local earthquakes recorded by the regional network were used with the single-scattering coda model of Aki and Chouet (1975) to estimate source spectra in a narrow frequency band. We found an omega-square, constant stress drop scaling model provided the best fit to the source spectra estimate. Using an event with a known seismic moment, moment estimates for subsequent events can be determined.

We feel this method of moment estimation provides better source size estimates for locally recorded earthquakes than S-wave coda duration. The method is being prepared for routine testing on data from the WRSN (Washington Regional Seismograph Network).

Kinematic Modeling:

Several aspects of the surface geology of the Pacific Northwest, such as volcanism and crustal deformation, are related to mantle flow associated with subduction. Along-arc variations in the geology require a three- dimensional analysis of convection. In order to make a three-dimensional flow calculation both tractable and interpretable, we consider the limiting case that the subducting slab is very thin, and that its viscosity far exceeds that of the surrounding crust and mantle. With these assumptions, we have developed a non-linear finite-element optimization scheme to find the slab configuration with the least amount of membrane (in-plane) deformation rate while satisfying boundary conditions such as the known relative plate convergence rates, and partial geometric constraints obtained from Wadati-Benioff earthquake locations. Because of a concave-oceanward bend in the trench axis located seaward of the Olympic Mountains, the subducted Cascadia slab has a geometric space problem analogous to a table cloth hanging over the corner of a table. This induces along-arc compression within the slab surface which can be relieved by forming an arch or by an along-arc buckling structure. Our numerical experiments suggest that the arch-like structure, revealed from seismic observations, is a natural consequence of the subducted slab responding to the concave-oceanward bending of the trench. The locus of points where both the observed and theoretical slab dips are less than 10° is offshore everywhere except along the arch, beneath the Olympic Mountains. According to the Critical Taper Theory, the height of an accretionary wedge will grow landward until the slab dip exceeds about 10°. This provides a plausible explanation for the origin and geographic location of the Olympic Mountains accretionary prism. The concentration of seismicity beneath the Puget Sound area appears to be the result of bending the already arched slab. The computed deformation is dominated by N-S compression in the Puget Sound area and the peak compressional strain-rate is around $2\times10^{-16}s^{-1}$ which is comparable to the value estimated from seismic moment release rates of the last century. A manuscript describing the results will be submitted to JGR.

Like Cascadia, the trench off Alaska has concave-oceanward curvature. Given this geometry and the assumption that the slab is continuous, our calculations (Creager and Chiao, 1992) predict that the slab under central Alaska should have a shallow dip relative to the dip under the Aleutian Islands to the west and under the Wrangell Mountains to the east. Our models also predict along-arc compressive strain rates under Alaska and along-arc extensional strain rates under the central Aleutians. The observed subduction geometry and the orientations of seismic moment tensors are in close agreement with our models.

Preliminary Investigation of P multiples from Teleseisms

We are using teleseismic P waves incident on the subducted Juan de Fuca slab to investigate local dipping structure through multiple P reflections. The potential advantage of using this method for regional networks is that:

a) A single component vertical short period station can be used;

b) Vertical structure information can be obtained for a large number of network stations, allowing lateral variations in structure to be mapped; and

c) Signal stacking and other array processing techniques can be applied to leverage the structure information using large numbers of stations.

We first investigated the expected amplitudes of multiple reflections using standard ray tracing techniques. These results indicated that amplitudes were sufficient that stacking techniques could be used to increase the signal-to-noise ratio. However, because earthquakes have individual source-time functions the source signals must be deconvolved prior to stacking.

We found that source signals could be approximately estimated using network averaging, and each source was deconvolved using its average signal. We immediately found strong signal coherence in the deconvolved signals for similar source distances and back azimuths. We are currently working on modeling some particularly strong coherent phases on selected stations using dipping interface models.

Work is continuing on improving our methods of source estimation and deconvolution in order to reduce the "noise" in the deconvolved signals and improve the stacking results. In addition, we are continuing work on modeling identified phases.

Refraction Interpretation of Earthquake Travel Times

In an attempt to gain a better understanding of the crust and upper mantle transition across the Cascade Range, we are using techniques of refraction interpretation with earthquakes as sources. We have constructed a profile from the central Puget Sound region southwest of Seattle to a point near Walla Walla in eastern Washington. There are a number of moderate sized earthquakes along the profile and near each of its ends, which can be well located with network stations. We are using these events as "sources" by assuming their locations are known, but allowing their origin times to float to minimize residuals. The advantage of earthquakes over man-made sources is that sources located at depth provide more information on velocities at depth. This advantage is at least partially offset by the uncertainties of the source locations and origin time.

Our analysis is being done using the forward and inverse modeling program developed by Colin Zelt. Both reflections and refractions can be utilized with this method. Preliminary results suggest that we will be able to produce an improved model of the Cascadia transition structure.

Articles

Chiao, L.-Y., and K. C. Creager (in preparation) Geometry and lateral membrane rate of the subducting Cascadia slab, to be submitted to JGR

Dewberry, S.R. and R.S. Crosson, (in preparation), Source scaling and moment estimation for the Washington Regional Seismograph Network using coda amplitudes, to be submitted to BSSA.

Lees, J.M. and R.S. Crosson, (1991), Bayesian ART versus conjugate gradient methods in tomographic seismic imaging: An application at Mount St. Helens, Washington, in *Spatial Statistics and Imaging*, A. Possolo, editor, Inst. of Math. Statistics, Hayward, CA, V. 20, p. 186-208.

Ma, L., R.S. Crosson, and R.S. Ludwin, 1991, Focal Mechanisms of western Washington earthquakes and their relationship to regional tectonic stress, USGS Open File OF-91-441-D, will also be published in a USGS Professional Paper.

Ma, L., R.S. Crosson, and R.S. Ludwin, (submitted), Focal Mechanisms of western Washington earthquakes and their relationship to regional tectonic stress, in: USGS Professional Paper "Assessing and Reducing Earthquake Hazards in the Pacific Northwest")

Mundal, I., M. Ukawa, and R.S. Crosson, (in press), Normal and anomalous P phases from local earthquakes, and slab structure of the Cascadia Subduction zone, BSSA

VanDecar, J.C., R.S. Crosson and K.C. Creager, (in preparation), Travel-time inversion for subduction zone structure: I. The effect of three-dimensional ray tracing on resolution analysis, to be submitted to JGR.

Abstracts

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Dewberry, S.R. and R.S. Crosson, 1992, Source scaling and moments for the Washington Regional Seismic Network data using coda amplitudes, Seism. Res. Lett., V. 60, p. 71-72.

VanDecar, J.C., R.S. Crosson, and K.C. Creager, (in press), Teleseismic travel-time inversion for Cascadia subduction zone structure employing three-dimensional ray tracing (extended abstract), presented at the XXII General Assembly, European Seismological Commission, Barcelona, Spain, Fall, 1990.