Earthquake Hazard Investigations in the Pacific Northwest 1990

14-08-0001-G1803

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Investigations

The objective of this research is to investigate earthquake hazards in western Washington, including the possibility of a large subduction-style earthquake between the North American and Juan de Fuca plates. Improvement in our understanding of earthquake hazards is based on better understanding of the regional structure and tectonics. Current investigations by our research group focus on the configuration of the subducting Juan de Fuca plate, differences in characteristics of seismicity between the overlying North American and the subducting Juan de Fuca plates, kinematic modeling of deformation of the Juan de Fuca slab, and modeling of lateral velocity variations in the shallow crust. Accomplishments this quarter include final publication of the 3-D crustal velocity model for Puget Sound resulting from tomographic inversion of earthquake travel times, submission of an article describing a technique for incorporating gravity data as a constraint in the tomographic inversion of earthquake travel times for crustal structure, and publication of a paper on an automatic method for more accurate determination of teleseismic relative phase arrival times. We are continuing development of non-linear inversion techniques for use in the inversion of teleseismic travel times for deep structure of the Cascadia Subduction Zone. Research during this contract period concentrated on the following topics:

1. Investigation of anomalous phase arrivals from sub-crustal earthquakes.

2. Modeling of 3-D kinematic flow of the subducted slab.

Results

1. Anomalous Phase Arrivals

We are completing an investigation of the lower crust and uppermost mantle of western Washington using anomalous high amplitude phase arrivals at stations on the Olympic Peninsula from subcrustal earthquakes. These phases are observed at distances of 100-200 km for subcrustal earthquakes at south-east azimuths, and have apparent velocities of 5.8-6.2 km/s. We interpret these arrivals as resulting from energy trapped within the low-velocity subducting oceanic crust. We used 2-D raytracing to model these phase amplitudes and arrival times.

From observed P_n arrivals we find that, along a NW-SE azimuth, the subducting plate has an apparent dip of 8-11°. The observed 5.8-6.2 km/s velocity of the low velocity oceanic crust is somewhat lower than that observed in a similar study of Southwestern Japan, where subducting crust velocities of 6.8-7.0 km/s at around 40 km depth were obtained. The lower velocity observed in the subducting crust below western Washington may be related to a layer of metasediments being subducted within the basaltic crust as described by Cochrane et. al (1988, PAGEOPH, V.128, pp. 767-800), with the observed apparent velocities of the anomalous phases being an average of the two low velocity layers.

2. Slab Kinematics

Well-located subcrustal microseismicity recorded by the Washington Regional Seismograph Network (WRSN) since 1970 is concentrated in the Puget Sound Basin. The catalog of subcrustal earthquakes greater than magnitude 6 in Washington during the last century indicates an even more pronounced concentration of seismic moment release of events beneath the Puget Sound Basin; from Olympia, Washington to Victoria, British Columbia. Intra-slab moment release in this area is four orders of magnitude higher than to the north and south.

Wadati-Benioff zone seismicity dips 20° under central Vancouver Island, 10° across the Olympic Peninsula-Puget Sound area, and about 20° under Oregon, defining an arching slab geometry with the axis of the arch running east-west under Puget Sound. The arch coincides with the Olympic Mountains, a horseshoe-shaped, post-Eocene accretionary prism. This unusually wide and deep accretionary wedge extends 200 km from the deformation front, but is confined to less than 100 km along arc. To the north and south the prism is much smaller. All these observations seem to be related to the ~ 35° concave oceanward bend of the trench adjacent to the Olympic Peninsula. The subduction process forces an initially spherical shell of oceanic lithosphere to pass through the trench, whose curvature is backwards relative to most island arcs, and into the mantle. Even though the descending slab retains much of the strength it had as a tectonic plate, in-plane deformation is required to obtain the observed slab geometry. To explore the three-dimensional consequences of the concave oceanward trench, we have developed a numerical scheme to determine the kinematic flow field of a thin sheet of stiff fluid that enters the mantle along the trench at the known relative plate velocities, is constrained to remain on a given slab geometry, and minimizes various global norms of the in-plane strain rate tensor. Minimizing the integrated effective strain rate to the power [1+ 1/n] is equivalent to determining the flow field that minimizes the global dissipation power associated with internal deformation of the slab for a power rheology with power n. We constructed two basic models of the geometry based on constraints from subcrustal seismicity, receiver function analysis and marine seismic reflection data. We utilized a criteria of "least change of curvature" to interpolate at places where no direct geometric constraint is available. The 'constant dip' model has a uniform 20° dip along any cross section normal to the trench, while the 'arch' model has 20° dip under Vancouver Island and Oregon, but has a shallower 11° dip under the Olympic Peninsula and Puget Sound, adjacent to the bend in the trench. For all slab geometries and rheologies analyzed the calculated flow field is dominated by high values of along-strike compression concentrated landward of the bend in the trench. The region of high calculated strain rates is coincident with the region of high observed seismic activity. The largest in-plane strain rates are $10^{-16}s^{-1}$. The following effects have been examined in detail: (1). *Sphericity.* The compressional in-plane strain rates adjacent to the bend in the trench are a factor of two larger if the incoming lithosphere is a spherical shell than if it is planar. (2). *Arch.* The 'arch' model reduces the total dissipation power by a factor of 3 compared with the 'constant dip' model.

Fixing the dip to the north and south at 20°, we performed several calculations varying the dip along the arch axis and found that the minimum total integrated dissipation power occurs at a dip of 10-12°. Thus, the observed arch geometry matches the optimum slab configuration in the sense that it requires the least amount of in-plane deformation. (3.) *Non-linear rheology.* The experiments discussed above assume a linear Newtonian rheology, which is not likely to be appropriate for the cold core of a slab. We have extended the calculations to a power-law rheology with a power of n= 3.5 and n= 100000. The power law rheology has little effect on the pattern of strain rates, except to concentrate regions of peak strain rate, and to produce large areas of very small strain rates.

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