Earthquake Hazard Investigations in the Pacific Northwest

1989

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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. Research during this contract period concentrated on the following topics:

1. Final publication of 3-D crustal velocity models for Puget Sound and southwestern Washington resulting from tomographic inversion of earthquake travel times, and preparation of an article describing a technique for incorporating gravity data as a constraint in the tomographic inversion of earthquake travel times for crustal structure.

2. Development of non-linear inversion techniques for use in an inversion for deep crustal and shallow mantle velocity structure beneath Washington.

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

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

Results

1. 3-D structure in western Washington

Final result of our inversions of local earthquake travel-time data for three-dimensional crustal velocity structure have been published or are in press in the form of several journal articles. An additional article on the use of gravity data as a further constraint on the velocity model is being prepared by J. Lees and J. VanDecar.

2. Deep structure of the Cascadia subduction zone

In most subduction regions, the position of the subducting lithosphere is indicated by a Benioff zone. In the Cascadia subduction zone (CSZ), the lack of any well-defined Benioff zone east of the Puget Sound lowland leaves us without detailed knowledge of the plate position. We are studying the deep-crustal and upper-mantle velocity structure of the CSZ by using a large set of teleseismic arrival times which have been recorded on the Washington Regional Seismic Network (WRSN) to invert for velocity structure. Previous teleseismic inversions for velocity structure; Lin and Crosson (1973), Michaelson and Weaver (1986), and Rasmussen and Humphreys (1988); provided low resolution images of the regional velocity structure. The low resolution of these models was due at least in part to the use of (1) small and incomplete data sets, (2) inaccurate, visually chosen arrival times without dependable error estimates and (3) inappropriate linear inversion techniques. In order to obtain a high resolution, well constrained CSZ structure we must improve in each of these areas.

The WRSN has accumulated 9+ years of high-quality digital teleseismic data spanning a nearly complete range of azimuths and distances. To go along with the data set, we have developed a new technique for efficiently extracting both highly accurate relative arrival time and quantitative uncertainty estimates (for use in inversion weighting) from this data. The method combines a multi-channel cross-correlation procedure with adjustment by least squares. A paper on this techniques and its application to the WRSN data will appear shortly in the BSSA. Non-linearity in this inversion arises from the fact that the ray paths depend on the velocity structure. The linear assumption used in past studies significantly distorts ray paths in many parts of the model. This can be dealt with by performing iterative linear inversions, and ray tracing after each iteration to correct the ray paths. The combination of our higher quality data with down-weighting of relatively low quality data (using our quantitative uncertainty estimates) should help to produce a convergent solution.

3. Anomalous Phase Arrivals

Another line of investigation into the deep crustal and upper mantle velocity structure uses phase arrivals from subcrustal earthquakes within the Wadati-Benioff zone under western Washington. Deep structure affects both apparent phase velocities and wave forms. Apparent velocities from these Benioff zone earthquakes show azimuthal dependency at epicentral distance of 100-200 km, with apparent velocities ranging from 7.5 to 8.5 km/sec, with the highest velocities towards the west. This azimuthal dependency could be due to higher velocities in the oceanic lithosphere of the east-dipping subducting slab relative to the surrounding mantle material. Low apparent velocities towards the east in this distance range may give an upper bound of ~7.5 km/sec on the velocity of the wedge of mantle material between the crust and the downgoing slab, lower than the previous estimate of ~7.79 km/s (Zervas and Crosson, 1984). For stations east of the Cascades, at epicentral distances of 200-300 km from the Benioff zone, apparent velocities of 8.25-8.50 km/s are observed. Such high apparent velocities are consistent with the velocity model based on seismic refraction studies (Catchings and Mooney, 1988).

The analysis of subcrustal earthquake waveforms has focused on anomalous phases observed at stations on the Olympic Peninsula, where a high energy arrival is often observed after the initial P-wave, but before the S-wave. This anomalous phase has higher amplitude than the initial P wave, and is not observed on stations towards the east within the same epicentral range. The anomalous phase may represent energy trapped in the low velocity upper crustal layer of the subducting oceanic lithosphere. Such trapped phases have been observed in the subducting Philippine Sea Plate beneath SW Japan (Horai et al., 1985). The anomalous phase arrivals in western Washington show an apparent velocity of 6.0-6.5 km/s, whereas P-arrivals show apparent velocities of 8.2-8.4 km/s in the same western azimuths.

4. Slab Kinematics

As described is the last report, we are attempting to explain the observation that seismicity within the subducting Cascadia slab is concentrated beneath the Puget Sound Basin, along the axis of an apparent east-west trending arch in the slab geometry. The arch extends from an oceanward concave bend in the trench, under the Olympic Mountains, to the Puget Sound Basin. Preliminary calculations of kinematic slab flow suggested that the trench geometry forces along-arc compression in the slab beneath Puget sound, and that an arch in the geometry relieves some of the required inplane strain rate. During the past six months we have formalized the theoretical description of inplane strain rates for an arbitrary flow on an arbitrary surface [Creager and Boyd, 1989] and are nearly finished with a new algorithm to calculate the unique flow that globally minimizes the inplane deformation for an arbitrary surface with boundary conditions imposed on the flow at the trench. A critical part of this calculation is describing realistic slab geometries by smooth continuous surfaces with continuous gradients. We are trying both a taut spline approach and an expansion of the surface in orthogonal polynomials.

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Regional Seismic Monitoring in Western Washington

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Investigations

Operation of the western portion of the Washington Regional Seismograph Network (WRSN) and routine preliminary analysis of earthquakes in western Washington are carried out 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 second quarter of 1989. Final catalogs are available from 1970, when the network began operation, though 1986. The University of Washington operates approximately 80 stations west of 120.5°W, 28 of which are supported under A0622, and 40 under A0623. This report includes a brief summary of significant seismic activity. Additional details are included in our Quarterly bulletins.

Excluding blasts, probable blasts, and earthquakes outside the U. W. network, 808 earthquakes west of 120.5°W were located between April 1 and September 30, 1989. Of these, 395 were located near Mount St. Helens, which has not erupted since October of 1986. Twelve earthquakes were felt in western Washington during the period covered by this report. East of 120.5°W 76 earthquakes were located, one of which was felt.

Notable seismicity and related phenomena during this reporting period includes 3 unusual episodes at Mt. St. Helens in late August, which lasted as long as 45 minutes (as recorded on the crater station helicorder record). These episodes consisted of complex signals containing slightly elevated levels of shallow seismicity accompanied by high-frequency background noise. These sequences left no surface deposits, such as might be expected from steam and ash emissions, rockfalls, or mudflows. After each episode, seismicity rapidly returned to background levels.

During the summer of 1989 two new seismic stations were installed on the west and northeast sides of Mt. Rainier to improve our location resolution for earthquakes on the volcano, and to investigate lahars on the flanks of the mountain caused by glacial outburst floods. This proved to be fortuitous timing, since on August 16 a significant rockfall (more than 1 million cubic meters) occurred on Mt. Rainier originating at Russell Cliff, and traveling 4 km down the Winthrop Glacier. We were able to accurately locate the rockfall and alert the Park Service on a day when bad weather and poor visibility prevented visual observation. We also recorded a small lahar on one of the newly installed stations in late September. Elsewhere in western Washington on June 18th a notable deep earthquake, magnitude 4.4, was widely felt in the Puget Basin and was located at a depth of 45 km beneath the Kitsap Peninsula.

In Oregon, a cluster of activity near the summit of Mt. Hood in August and September included over a dozen shallow (depth less than 10 km) earthquakes larger than magnitude 1.0. Five of these were magnitude 2.0 or larger, with the largest being a magnitude 3.5 on September 15. A similar sequence occurred in September, 1978 (Weaver et al., 1982). In Portland, Oregon a magnitude 3.8 earthquake was felt on August 1. Its depth was about 15 km, and it was followed immediately by one aftershock.

East of 120.5°W, a very interesting magnitude 4.5 earthquake, at 15 km depth occurred on May 9th in the North Cascades about 40 km southwest of Okanogan and was felt in Omak, Washington. This is the largest earthquake we have located in this area since beginning instrumental recording in 1970. Very little seismicity is seen in the North Cascades, although it is believed to be the source region for the 1872 earthquake, the largest earthquake known to have occurred in Washington or Oregon.

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