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Precise Measurements Help Gauge Pacific Northwest's Earthquake Potential

M. Meghan Miller, Central Washington University, Ellensburg, Wash. USA; Herb Dragert, Geologica Survey of Canada, Pacific Geoscience Centre, Sidney, B.C., Canada;
Elliot Endo, Cascade Volcano Observatory, U. S. Geological Survey, Vancouver, Wash., USA;
Jeffrey T. Freymueller, University of Alaska, Fairbanks, AK USA;
Chris Goldfinger, Oregon State University, Corvallis, USA;
Harvey M. Kelsey, Humboldt State University, Arcata, Ca USA;
Eugene D. Humphreys, University of Oregon, Eugene, Ore., USA;
Daniel J. Johnson, Central Washington University, Ellensburg, Wash. USA;
Robert McCaffrey, Rensselaer Polytechnic Institute, Troy, N.Y. USA;
John S. Oldow, University of Idaho, Moscow, ID USA;
Anthony Qamar, University of Washington, Seattle, Wash. USA;
Charles M. Rubin, Central Washington University, Ellensburg, Wash. USA

Introduction

Except for the recent rumblings of a few moderate earthquakes and the eruption of Mt. St. Helen's, all has been relatively quiet on the Pacific Northwestern front. The Cascades region in the Pacific Northwest, a sporadically active earthquake and volcanic zone, still has great seismic potential [Atwat 1987], as comparisons with other subduction zones around the world have shown [Heaton and Kanamori, 1984]. Recent tsunami propagation models [Satake, 1996] and tree ring studies suggest that the last great Cascadia earthquake occurred in the winter of 1700 A.D. and had a magnitude of ~8.9. T North Cascades or Wenatchee earthquake followed in 1872. With an estimated magnitude greater than 7, it was the largest earthquake in the written history of Washington and Oregon. When will a great earthquake next hit this region, where is it most likely to occur, and what kind of hazard will it present populated areas? Relatively little is known about specific faults within the deforming continental plate margin, or about the recurrence and dynamics of great Cascadia earthquakes. But a permanent array of Global Positioning System (GPS) receivers in the United States and Canada (Figure 1), many of which were installed last year will help answer these questions by monitoring the subduction zone along the Cascadia margin and providing data for earthquake hazard assessment in the Pacific Northwest.

This geodetic network, operated by the Pacific Northwest Geodetic Array (PANGA) consortium, monitors crustal deformation from accumulating tectonic stress--which ultimately drives damaging earthquakes and presages volcanic eruptions--with millimeter-level precision. Currently, eight GPS receivers in British Columbia and ten in the U.S. are operating under the auspices of the PANGA consortium (Table 1). Network installation and coordinated data analysis began in August, 1997, and results are now available at http://www.panga.cwu.edu/.The network is designed to support geophysica models that resolve the kinematics and dynamics of deformation in the Pacific Northwest. Geodeticall constrained modeling will discriminate the relative importance of the various tectonic forces described in detail. In addition, this work will better characterize important crustal faults in Vancouver, Seattle, Portland, and other populated areas that pose seismic risk to the region.

Tectonic History

The Pacific Northwest lies adjacent to the small, obliquely subducting Juan de Fuca plate, between two migrating triple junctions (Figure 2) and deforms in response to complex North America, Juan de Fuca and Pacific boundary interactions. The Eastern California shear zone, which accommodates ~12 mm/ Pacific-North America motion, continues into the Pacific Northwest, where it splays into several branches across Oregon and Washington. In addition, deformation is concentrated on western side of this shear system on faults that in the Portland and Seattle areas; however, a paucity of data makes it difficult to determine strain distribution. The change from a narrow zone of dextral deformation south the Mendocino triple junction to a broad zone in Washington and northern Oregon in the north suggest that different processes are active in these two regions. The crustal faults pose significant risk to the Pacific Northwest.

Cascadia subduction zone structure and dynamics.

The convergence of the Juan de Fuca and North America plates (DeMets et al., 1994) is approximately 42 mm/a. The Cascadia subduction zone is locked, as indicated by elastic strain accumulation in the overriding plate, and thus poses a significant seismic hazard to densely populated areas such as the Vancouver, Seattle and Portland metropolitan areas, as well as other rapidly developing communities along the west flank of the Cascades. Geologic evidence for subsidence, tsunamis, and ground shaking indicates prehistoric great earthquakes along the Cascadia subduction zone. Modeling of a widespread tsunami in Japan that was not associated with local seismicity indicates a magnitude 8.9 earthquake along the length of the Cascadia subduction zone 300 years ago (Satake et al., 1996). Such an event or several smaller events occur every 300 to 600 years (Atwater, 1987 and 1992). If the segmentation of the subducting slab, which is suggested by conventional geological data, can be confirmed by precise geodetic measurement of strain accumulation, geologists can assess the seismic risk, which may lead t strengthening of the building codes in the Pacific Northwest. We will also increase our understanding one of the world's most intriguing continental subduction zones, which has been difficult to study because of the lack of inter-plate earthquakes.

The Cascadia subduction zone has three distinct segments based upon uplift rate, geometry of the arc-fore-arc-trench system, and seismic character. The northernmost segment is characterized by seismic activity and oblique convergence, which is indicated by a transpressive arc. The middle segment, in Oregon, is characterized lack of seismicity and an extensional arc. This block, or constituent smaller blocks, is rotating clockwise. The third and southernmost segment is the seismically active and rapidly deforming triple junction region. These three are linked kinematically and possibly, dynamically. The clockwise rotation of the middle segment broadly accommodates extension behind the southern segme and transpression behind the northern segment. It also accommodates north-south shortening, which results from the northward component of the Juan de Fuca plate coming into contact with the Vancouv Island buttress. The shape and varied tectonic regime of the margin may be related to an arch in the Ju de Fuca plate beneath the Olympic Mountains and Puget Sound, or it may reflect inherited heterogenei in the overlying North American plate. North American Plate DeformationIn addition to monitoring subduction zone dynamics, this study characterizes the kinematics of deformation within the North American plate (Figure 2).

The Pacific Northwest accommodates deformation in the arc and back-arc region that is ultimately related to Pacific-North America plate motion. In southern California, as much as 12 mm/a of dextral shear is fed off the plate boundary into a broad zone of deformation in the Mojave Desert and east of t

Sierra Nevada, in the Eastern California shear zone. This deformation feeds northward into the wester
Nevada seismic belt (Wallace, 1984) and ultimately into the northwestern U. S. or the Canadian Rockies.

Crustal deformation in Oregon and Washington has been characterized by Pezzopane and Weldon (1993), who compiled existing field and seismic data, augmented by new air photo interpretations and original paleoseismic investigations, to document crustal faulting above the convergent margin (Figure 2). The paucity of published data make their new observations critical to the analysis. In a partly overlapping area including the fore-arc, Neogene geologic relations have also been summarized by Wells and Heller (1988). While considerable disagreement exists in some areas about the specifics of location and activity of individual structures, scientists agree that the largest earthquakes in the Pacific Northwest during the last 125 years have been along crustal faults within the North American plate or the downgoing Juan de Fuca plate. Thus, beyond illuminating the process of continental deformation, these faults pose seismic risk.

Active deformation zones transect Oregon, Washington and adjacent states and provinces, separating stable crustal blocks and feeding dextral shear from the continental interior back out to the plate margi
resulting in rotation of blocks in the fore-arc. Tectonically active regions of faulting within the fore-ar
arc, and back-arc separate more stable crustal blocks and apparently partition deformation. While som
crustal faults accommodate Juan de Fuca-North America plate convergence, most accommodate north-south shortening or related dextral slip in response to Pacific-North America motion. For instance, son
Pacific Northwest faults are ultimately fed by transfer of slip associated with the Walker Lane, Eastern California shear zone and Western Nevada seismic belt (Figure 2). Deformation in Oregon is attribute
to four zones, which converge in central Washington.

The PANGA Network GPS sites that are currently funded and operating under the auspices of the PANGA consortium (Figure 1) include: the well-established Canadian network (Western Canada Deformation Array, WCDA) of eight sites; three existing and three planned NSF-funded sites installed and maintained by Central Washington University; two sites jointly maintained by Rensselaer Polytechnic Institute and Oregon State University; two sites installed and maintained by the Cascade Volcano Observatory, supported by the internal Volcanic Hazards and NEHRP (National Earthquake Hazard Reduction) programs; and three existing and two planned NSF- and NEHRP-funded sites installed and maintained by the University of Washington. The network currently operates a mix of Trimble, Turbo Rogue and Ashtech receivers; all but two have standardized Dorne Margolin choke rin
antennas. NSF-funded sites use the Wyatt design for drilled braced monuments (Figure 3); a variety of other high quality monuments are in use at the older sites. Data analysis facilities are supported in Canada at the Pacific Geoscience Centre (PGC) and at Central Washington University. These labs use independent software and analysis strategies that provide robust results.

Summary

The geodetic monitoring by PANGA in the Pacific Northwest will improve understanding of regional kinematics, tectonics, volcanism and hazards. Principal scientific goals include studying the Pacific-North America interaction that feeds into the Cascadia plate margin, modeling the three dimensional geometry of Juan de Fuca-North America interaction that controls seismic risk in the Cascadia fore-ar
and providing an internally consistent, near real-time geodetic data base to the geoscience community over the internet. This work will develop a framework for evaluation of seismic risk posed by both

subduction zone interseismic strain accumulation and crustal faulting in the Pacific Northwest. Dynam models of these results will constrain plate driving forces. Building on previous efforts, modelers at several institutions are using the geodetic results. Under the coordinated NSF initiatives, University of Oregon will conduct a geophysical modeling. Finite element modeling of constraints on Pacific Northwest deformation will allow the development of a kinematically consistent, two dimensional estimate of the surface deformation, as well as a three-dimensional model of the forces that drive that deformation.

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Table1. Operational PANGA GPS sites, from north to south, valid 1997

Location	ID	Latitude	Longitude	Start Date	Operating agency
Williams Lk, B.C.	WILL	52.2369	122.1678	Oct-93	PGC
Holberg, B.C.	HOLB	50.6404	128.135	Jul-92	PGC
Whistler, B.C.	WSLR	50.1265	122.9212	Sep-96	PGC
Penticton, B.C.	DRAO	49.3226	119.625	Feb-91	PGC
Nanoose, B.C.	NANO	49.2948	124.0865	May-95	PGC
Ucluelet, B.C.	UCLU	48.9256	125.5416	May-94	PGC
Sidney, B.C.	PGC1	48.6486	123.4511	Dec-89	PGC
Sedro Woolley, WA	SEDR	48.50	122.22	Oct-97	UW
Victoria, B.C.	ALBH	48.3898	123.4875	May-92	PGC
Neah Bay, WA	NEAH	48.2979	124.6249	Jul-95	UW
Pacific Beach, WA	PABH	47.2128	47.2128	Aug-97	CWU
Satsop, WA	SATS	46.9657	123.5412	May-97	CVO
Johnston Rdg., WA	JRO1	46.2751	122.2176	May-97	CVO
Kelso, WA	KELS	46.1181	122.8959	Oct-97	UW
Goldendale, WA	GOBS	45.8388	120.8147	Aug-97	CWU
Newport, OR	NEWP	44.5850	124.0619	Jun-96	OSU
Corvallis, OR	CORV	44.5855	123.3046	May-96	OSU
Cape Blanco, OR	CABL	124.5633	124.5633	Aug-97	CWU

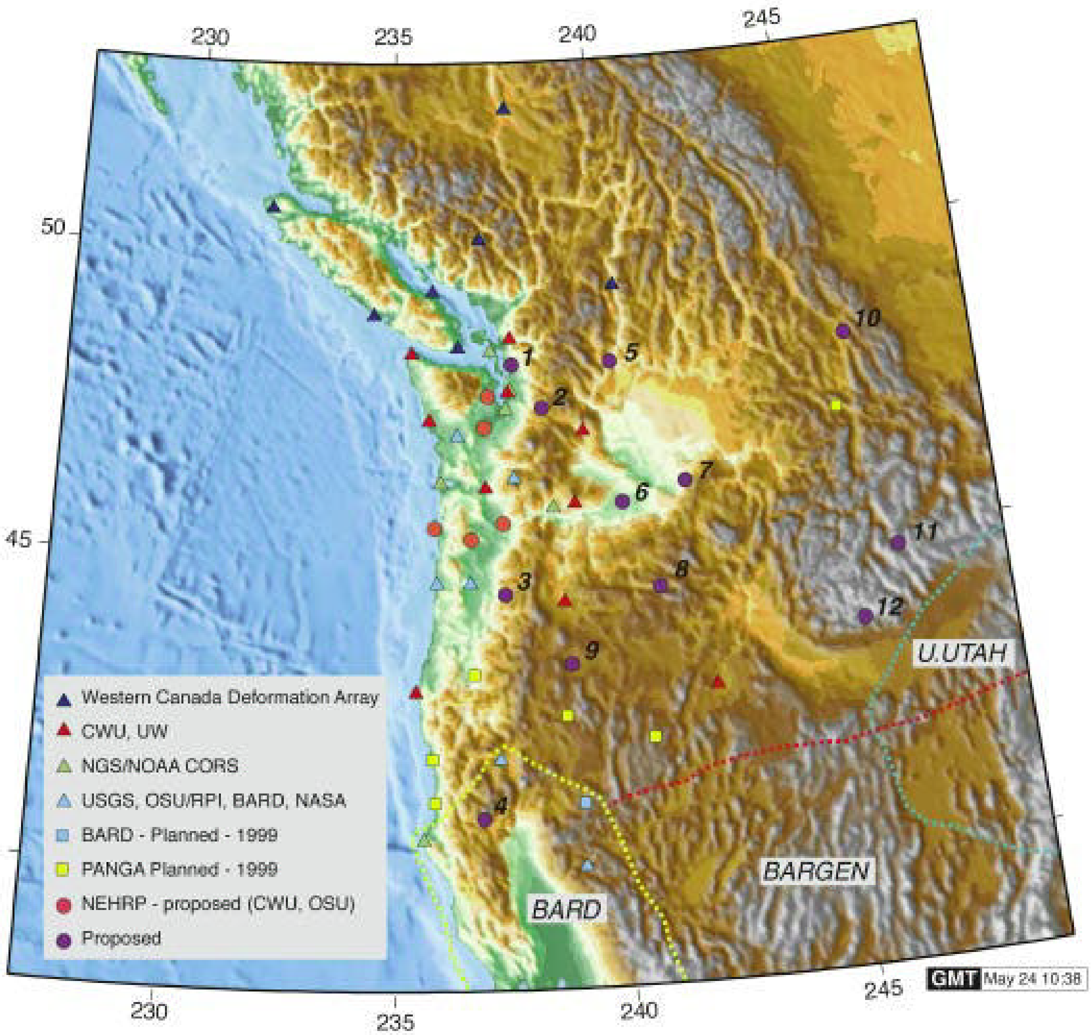

Figure 1. Updated (June, 1999) Pacific Northwest Geodetic Array (PANGA). Continuously operating GPS sites and proposed augmentation of the PANGA array. See Table 1 for 1997 locations and intervals of operation.

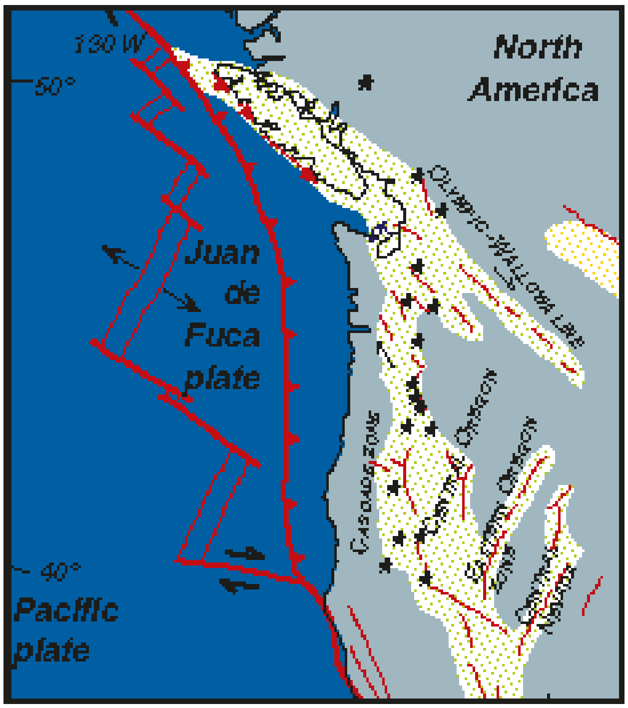

Figure 2. Tectonic setting of the Cascadia margin. The Juan de Fuca plate system lies between two migrating triple junctions. Because of entrainment of the western margin of North America in Pacific plate motion, the Pacific Northwest is deformed in response to the interaction of all three plates. Stipple areas show actively deforming zones; the red arrow shows the Juan de Fuca-North America convergence direction. Base map from Pezzopane and Weldon (1993).

Figure 3. GPS site installation. Deeply anchored, drilled braced monument installed at Cape Blanco, Oregon. Each of five pipes drilled to approximately 12 meters depth, set in non-shrink grout, and isolated from soil and ground motions in the upper 4 meters by padded casing. The Pacific Northwest offers challenging conditions for stable site conditions. Much of the area is underlain by pervasively jointed volcanic rocks, poorly consolidated Tertiary strata, or other unstable lithologies. This monument was designed to provide stability under such conditions.