arcs in the auroral oval are extracted from the same parent plasma population.

Future Work

The key to the formation of theta aurorae lies in the consequences of "merging" boundary conditions on the dayside magnetopause changing with IMF B_y and B_z. It is generally known how the magnetosphere reacts under various, steady-state IMF configurations. However, observations show that IMF conditions change frequently. The magnetosphere therefore adjusts in response to these changes and the polar cap reconfigures accordingly. The theta aurora is but one example. Measurements from both in situ and groundbased instruments continue to develop more evidence for motion of the boundary between the open and closed magnetic field lines. Multi-point observations derived from the International Solar-Terrestrial Physics (ISTP) mission provide exciting opportunities to explore the near-Earth space environment. Thus one gains a better understanding of the interactions between the solar wind/IMF and the magnetosphere/ionosphere.

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Precise Measurements Help Gauge Pacific Northwest's Earthquake Potential

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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 [*Atwater*, 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. The 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.

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When will a great earthquake next hit this region, where is it most likely to occur, and what kind of hazard will it present to 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 United States are operating under the auspices of the PANGA consortium (Table 1). Network instal-

Table 1: Currently operating permanent PANGA GPS sites, from north to south.

Location	ID	Latitude North	Longitude West	Start Date	Operating Agency
Williams Lk, B.C.	WILL	52.2369	122.1678	10/93	PGC
Holberg, B.C.	HOLB	50.6404	128.1350	7/92	PGC
Whistler, B.C.	WSLR	50.1265	122.9212	9/96	PGC
Penticton, B.C.	DRAO	49.3226	119.6250	2/91	PGC
Nanoose, B.C.	NANO	49.2948	124.0865	5/95	PGC
Ucluelet, B.C.	UCLU	48.9256	125.5416	5/94	PGC
Sidney, B.C.	PGC1	48.6486	123.4511	12/89	PGC
Sedro Woolley, WA	SEDR	48.5216	122.2238	10/97	UW
Victoria, B.C.	ALBH	48.3898	123.4875	5/92	PGC
Neah Bay, WA	NEAH	48.2979	124.6249	7/95	UW
Pacific Beach, WA	PABH	47.2128	124.2046	8/97	CWU
Satsop, WA	SATS	46.9657	123.5412	5/97	CVO
Johnston Rdg., WA	JRO1	46.2751	122.2176	5/97	CVO
Kelso, WA	KELS	46.1181	122.8961	10/97	UW
Goldendale, WA	GOBS	45.8388	120.8147	8/97	CWU
Newport, OR	NEWP	44.5850	124.0619	6/96	OSU
Corvallis, OR	CORV	44.5855	123.3046	5/96	OSU
Cape Blanco, OR	CABL	42.8361	124.5633	8/97	CWU

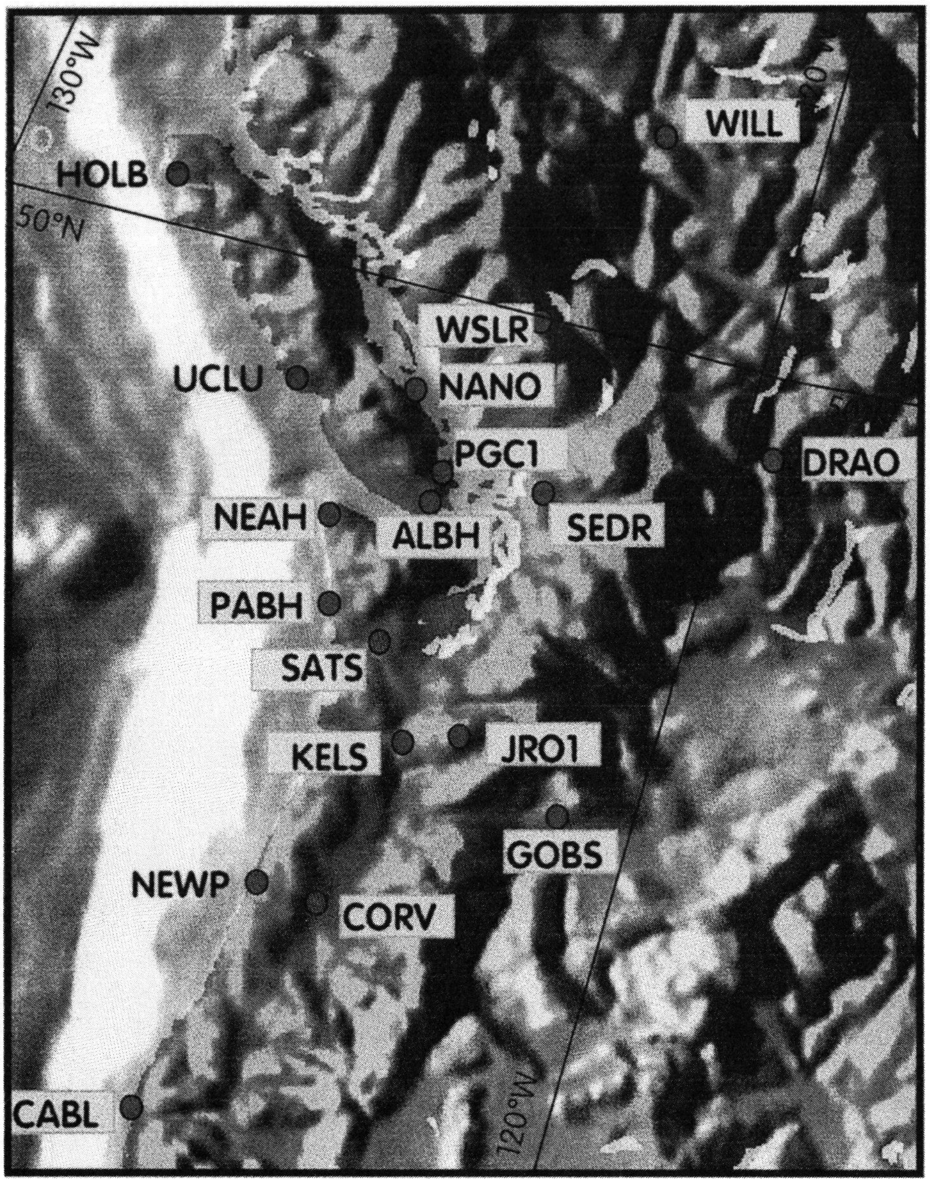

Fig. 1. Pacific Northwest Geodetic Array (PANGA). Continuously operating GPS sites of PANGA. See Table 1 for locations and intervals of operation. Original color image appears at the back of this volume.

lation 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 geophysical models that resolve the kinematics and dynamics of deformation in the Pacific Northwest. Geodetically 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 Setting

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 the western side of this shear system on faults that are 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 of the Mendocino triple junction to a broad zone in Washington and northern Oregon in the north suggests 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] occurs at approximately 42 mm/yr. 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, 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 to strengthening of the building codes in the Pacific Northwest. We will also increase our understanding of 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 by the 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 segment 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 Vancouver Island buttress. The shape and varied tectonic regime of the margin may be related to an arch in the Juan de Fuca plate beneath the Olympic Mountains and Puget Sound, or it may reflect inherited heterogeneity in the overlying North American plate.

North American plate deformation In 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

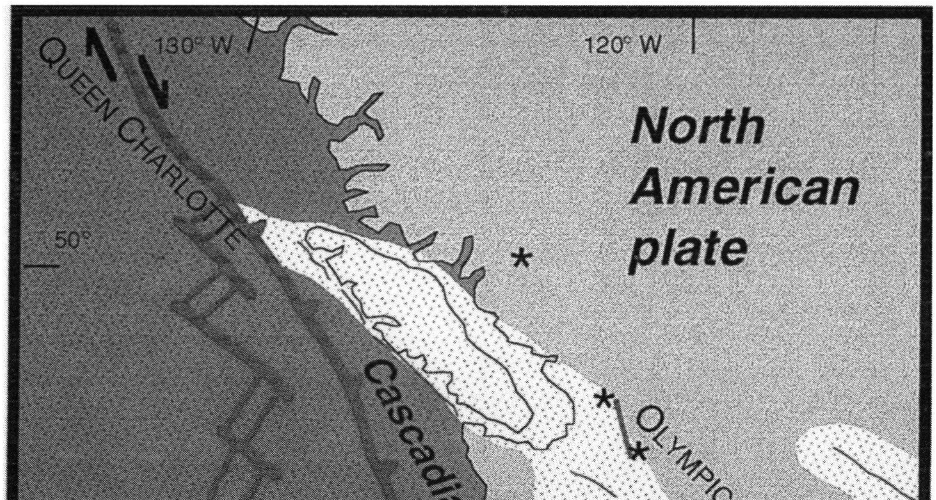

Fig. 2. Tectonic setting of the Cascadia margin. The Juan de Fuca plate system lies between two migrating triple junctions. Because of entrainment of the western margin of North America in Pacific plate motion, the Pacific Northwest is deformed in response to the interaction of all three plates. Stippled areas show actively deforming zones; the red arrow shows the direction in which the Juan de Fuca-North American plates converge. Base map from Pezzopane and Weldon *[1993]. Original color image appears at the back of this volume.*

Fig. 3. GPS site installation. Wyatt-style drilled braced monument installed at Cape Blanco, Oregon. Each of five pipes drilled to approximately 12 m depth, set in non-shrink grout and isolated from soil and ground motions in the upper 4 m 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. Original color image appears at the back of this volume.

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

This deformation feeds northward into the western Nevada seismic belt [*Wallace*, 1984] and ultimately into the northwestern United States 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 makes 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 margin, resulting in rotation of blocks in the fore-arc. Tectonically active regions of faulting within the fore-arc, arc, and back-arc separate more stable crustal blocks and apparently partition deformation. While some 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, some 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 attributed 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 ring 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.

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-arc, and providing an internally consistent, near real-time geodetic database 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. Dynamic 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, the 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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NSF Geosciences Directorate Outlines Two Major Planning Processes

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"We want to do more than just evolve into the next decade," Robert Corell, assistant director for geosciences at the National Science Foundation (NSF), told an audience at a "town meeting" held in May during the AGU Spring Meeting in Boston, Mass.

Corell, along with the Geoscience Directorate Division directors for atmospheric, Earth, and ocean sciences, said that two concurrent planning processes underway at the directorate will help to guide the direction of the science, and also support the annual geosciences science plan and the NSF budget in a competitive fiscal environment.

The meeting focused on the study of facilities needs for the years 1999-2003, and also outlined the goals for creating a "Geo 2000" plan to map the course for the geosciences directorate into the next decade.

According to Michael Purdy, NSF team leader on the facilities study and director of the Division of Ocean Sciences within the geosciences directorate, goals for that study include providing the directorate and NSF decision-makers with an overall scope of infrastructure and facilities needs; communicating the status of the plan to the geosciences community; providing a framework for budget planning; maintaining close connections between the facilities plan and what he called its twin, the annual geosciences science plan; and conveying messages of quality, competitiveness, and the importance of partnerships.

Purdy said that the heart of the facilities plan is the infrastructure needs themselves, with the term "infrastructure" defined broadly as including not only Earth observing systems such as ships, airplanes, and buoy networks, but also computational, laboratory, and data access systems that serve experimental, analytical, observational, or computational needs of extended user communities.

Purdy said the plan defines facilities by their role and function, rather than by how they are supported financially.

He said all facilities supported by NSF should be driven by the research program, managed efficiently and in a cost-effective manner, and emphasize partnerships—with other agencies and possibly other nations—and the role that facilities can play in educational efforts. They should also provide access to the community rather than to just a select group of principal investigators, he said.

Corell expressed his concern about a global trend to limit data access. "Every force I see on the horizon is to lock data up, and if you lock data up, you are going to lock the geosciences up."

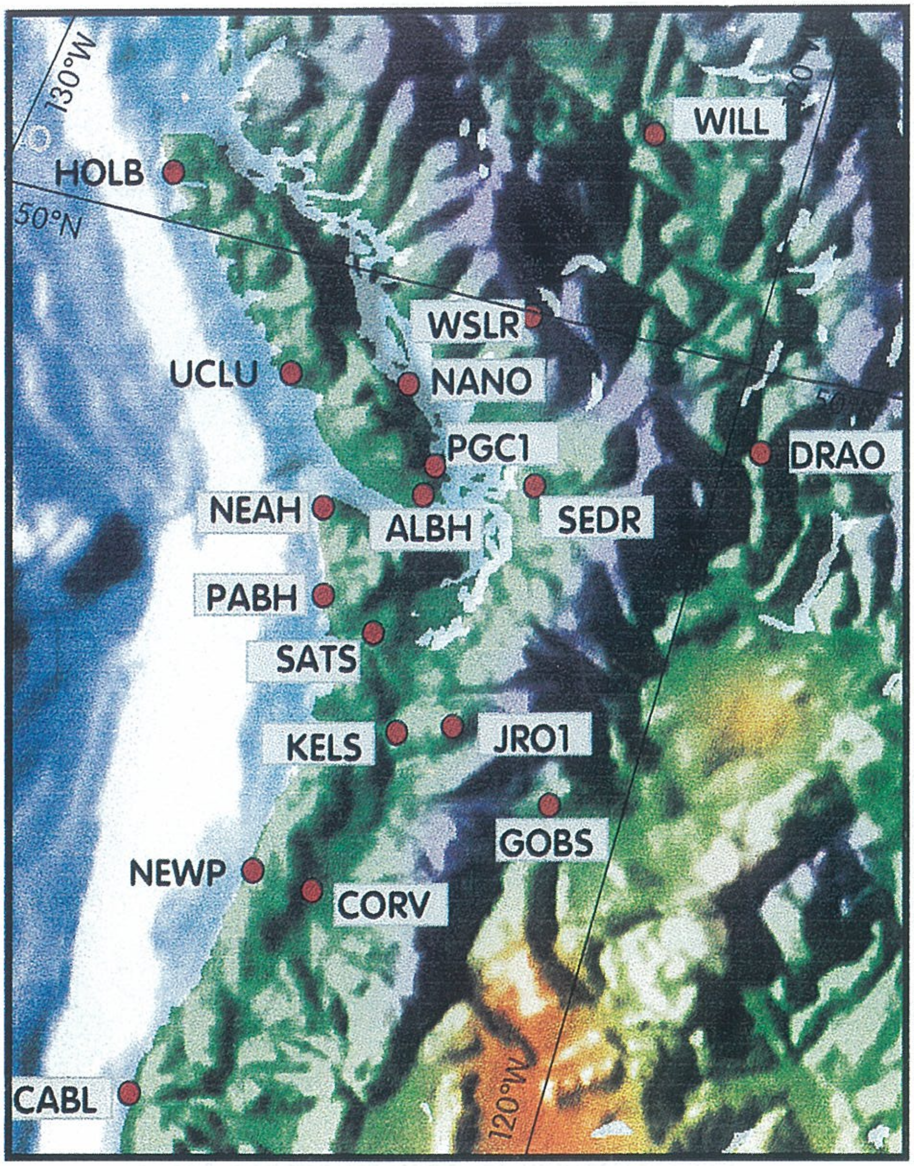
Purdy said the final section of the report will link it with the geosciences science plan and weave together themes in the geosciences, including a growing integration across disciplines, the data access revolution whereby investigators can gain speedy access to extremely large datasets, and a larger emphasis on long time series measurements. He said that while geoscientists in previous decades primarily observed processes on the Earth spatially, exploring processes in the time domain is an increasingly important mode of discovery.

Purdy said the first draft of the facilities plan will circulate to a small working group of the advisory committee of the Geosciences Directorate within a few weeks, a second draft will be posted on the Web site in August, a third draft will be written in October, and the report will be finalized in November. He said the plan will be updated every 2 years.

"What we are not ready to do yet is provide shopping lists of exactly what is going to be in [the plan.] That's what we hope to develop in the coming months," Purdy added, inviting broad input from the geosciences community.

Corell said that Geo 2000, which could require upwards of 2 years to complete, takes a broader perspective than the facilities plan.

He said the report will explore what are the driving and cutting edge scientific issues



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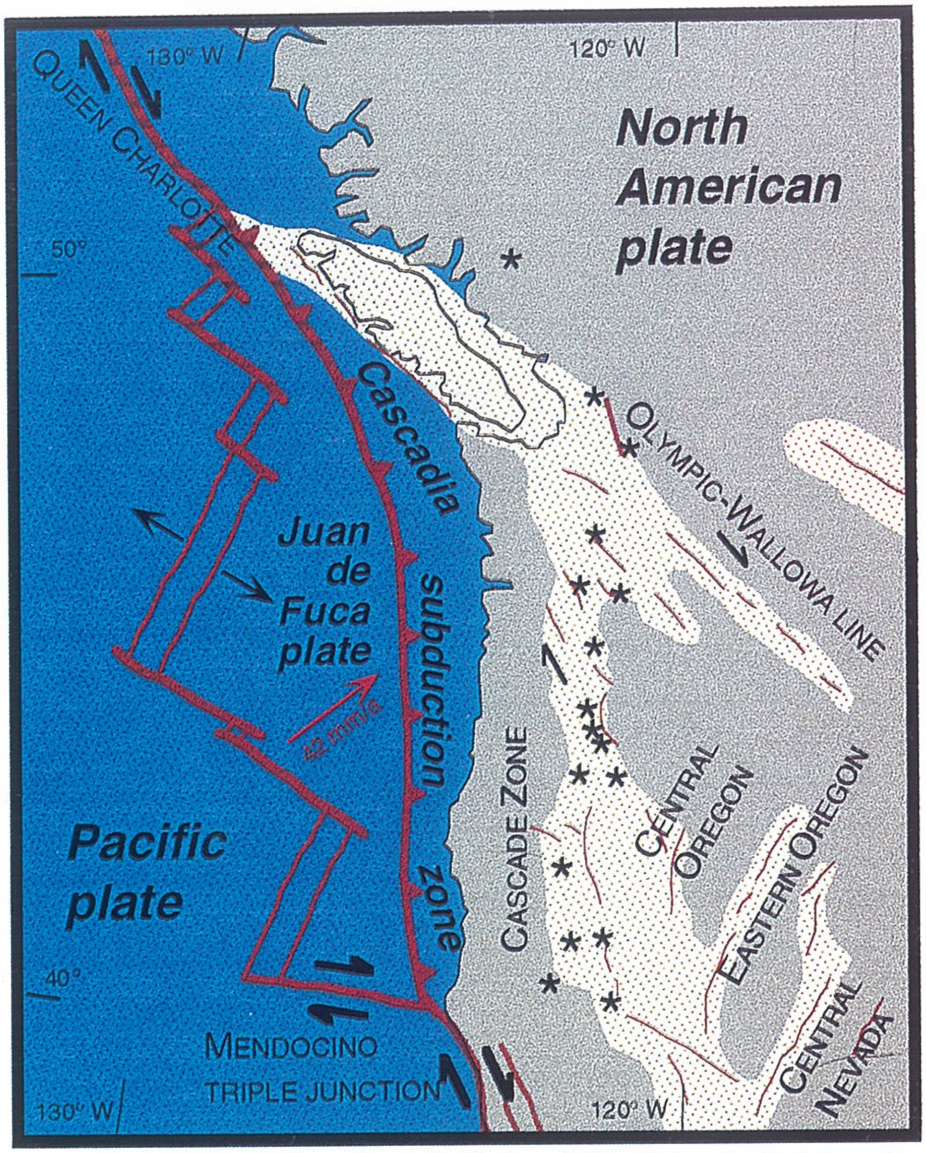

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