The Cascadia Subduction Zone And Related Seismicity

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Tectonic Framework

“warm-slab”

Explorer plate
Juan de fuca Plate
Gorda plate

Klamath Mountains
Siletzia Terrane (43°N)
Crescent Formation
Olympic Peninsula (47°N)

Porritt et al., 2011
Crustal Architecture

A series of active source crustal imaging experiments:
- Lithoprobe 86
- OR89/91
- Mendo93/94
- SW-Wash
- Orwell 96
- SHIPS 98/99
Wells, Blakely and Weaver: Cascadia microplate models and within-slab earthquakes

The maximum convergence along the northern and southern Cascadia subduction zone. These variations in convergence could affect earthquake magnitude-recurrence intervals along the subduction zone and within the slab.

Seismicity and volcanism

Great subduction zone earthquakes have occurred repeatedly along the plate boundary in the recent geologic past [e.g., Atwater and Hemphill-Haley, 1997], but the subduction zone is presently seismically quiet. Paleo-seismic evidence indicates that the entire plate boundary has ruptured in the past, although geodetic evidence suggests that the width of the plate boundary locked zone may be much narrower off Oregon. The thick mafic core [Tréhu et al., 1994] has the lowest uplift rate along the coast [Mitchell et al., 1994; Hyndman and Wang, 1995], and the inferred narrow locked zone is entirely offshore, apparently following the western limit of the accreted Siletzia mafic terrane. Outboard of the Siletz terrane, sediments of the Eocene to Quaternary accretionary wedge and marginal basin complex comprise the geodetically and thermally defined locked zone along the plate boundary megathrust [Hyndman and Wang, 1995].

McNeill et al. [1998; 2000] and Wells et al. [2000] have suggested that the accretionary-marginal basin complex is subdivided by a variety of oblique, upper plate folds and faults that may in part be related to large-scale seismic segmentation of the subduction zone. The Oregon segment, which is characterized by a narrow locked zone and our calculated slower convergence rates, coincides with the region of low crustal and slab seismicity and may indicate lower strains inboard of the narrow locked zone. Slower inferred convergence rates (~30 mm/yr) in central Cascadia are still consistent with 500 year great earthquake recurrence intervals, assuming 15 m average slip per event is typical, as was calculated from the 1700 AD tsunami waveforms [Satake and Wang, 2000].

Contemporary seismicity in Cascadia is concentrated in western Washington, Vancouver Island and northern California (Figure 2). The crustal earthquakes and active faults outline a western Oregon region that has very low rates of seismicity and internal deformation. Although internal deformation rates are low, paleomagnetic rotation rates are high, consistent with its rotation as a large, semi-rigid block, as discussed above. Focal mechanisms in the forearc indicate north–south compression and are consistent with north–south shortening against the Canadian Coast Mountains re-entrant.

On the trailing edge of the rotating Oregon forearc block, the extensional Cascade arc accommodates some of the westward motion through magmatism and normal faulting (Figure 2). The extensional arc ends near the latitude of the calculated pole of rotation and the sparse arc volcanoes to the north rest on a folded and uplifted basement (Figure 2c). Compared to some other circum-Pacific arcs, Cascade volcanic production rates are modest [Sherrod and Smith, 1990]. The arc is producing two major end member primitive basalts which reflect variable input of slab volatile component and mantle sources: 1) Low potassium olivine tholeiite (LKOT), which indicates hot dry melting of depleted upper mantle; and 2) more fluid-rich calc-alkaline basalt (CAB; Bacon et al., 1997; Conrey et al., 1997). LKOT dry melts are associated with rifting and are common in the basin and range and in the extensional arc as far north as Mount St. Helens [Conrey et al., 1997]. These magma types and modest volumes are consistent with subduction of a young, warm slab [Kirby et al., 1996], but it is worth noting that the largest slab earthquakes occur north of Mount St. Helens and the LKOT-bearing OC-SN pole.
Crustal Architecture

Forearc block rotation is a legacy of accretion of the Siletz terrane – thickened oceanic crust that was too thick to subduct.

Wells et al., Forearc migration in Cascadia and its neotectonic significance, Geology, 1998
TABLE 1: Convergence velocities of the Juan de Fuca plate (JDF) with respect to North America (NA) and Oregon Coastal block (OC).

Note: DD 99 is pole of DeMets and Dixon (1999); WS00 is pole of Wells and Simpson, [2001]; bold rates are used in this paper.

Wells et al., 2002
Seismicity

People argue that the co-location of upper and lower plate earthquakes is the result of fluid flow into the upper plate from dehydration reactions in the subducting plate.
Some of the earthquakes in the lower plate beneath Washington appear to line up along gravity gradients presumed to be caused by structures in the upper plate.
Why is it lack of with-in slab earthquake and upper plate earthquake in Oregon?

tectonic segmentation
+
convergence rate
+
seismicity segmentation

Basalt $\rightarrow$ Eclogite?
Lack of deep slab (so lack of slab-pull force) coupled with the decrease of convergence rate?

receiver functions migrated to dV$_s$/V$_s$

15-20 km vs. 8 km
120 km vs. 40 km
ETS in Cascadia

ETS (episodic tremor and slip) between the locked and steadily slipping zones.

The synchronous occurrence of slow slip and vigorous tremor activity.
Slow slip vs earthquakes
Some observations about ETS:

• Generally occurs where plate is 30-40 km deep.

• Average repeat rate varies along strike and may also vary with time.

WHY?

• Patterns vary along the subduction zone.

• Slip generally correlated with tremor, although it may extend farther up-dip
ETS can inform us about earthquake hazard:

80-100% of plate tectonic motion at depth > 25 km accommodated by slip events and that coupled part of the plate extends farther landward than indicated by the 450 degree isotherm.

Chapman and Melbourne, GRL, 2009
Subducted seamounts and shallow megathrust earthquake

Correlations between buried seamounts on the subducting plate, structures in the upper plate, ETS, and interseismic locking. What do they mean for seismic hazards?

Trehu et al., 2011
Thanks!