A focused study of Cascadia upper-plate structure and its impact on subduction-zone segmentation

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GeoPRISMS Science Plan Questions Addressed:
1) What governs the size, location, and frequency of great subduction zone earthquakes, and how is it related to the spatial and temporal variation of slip behavior observed along subduction faults? 2) How does deformation across the subduction plate boundary evolve in space and time, through the seismic cycle and beyond?

Goal: Develop a 3-D structural map of upper-plate, upper crustal tectonic structures spanning an entire proposed subduction-zone segment.

Data infrastructure utilized/established: New aeromagnetic survey; existing LiDAR data; ongoing USGS trenching and geologic mapping studies; new targeted magnetotelluric (MT) and gravity transects; existing EarthScope/Amphibious Array seismic data and regional MT data.

Key investigation efforts: Analysis of new aeromagnetic data will help identify and extend newly-discovered and known faults within forearc and arc upper crust of SW Washington and NW Oregon, roughly between Grays Harbor and Tillamook. Supporting analysis of LiDAR data will define neotectonic activity. These efforts will target new MT, ground-magnetic, and gravity transects across structures of interest, constrained by existing geologic mapping and seismic data, all leading to detailed 2-D models across important forearc structures. Combining 2-D models and map view interpretations will lead us to a 3-D model of upper-crustal structure. We will compare our structural map to indicators of subduction interface segmentation (e.g. tremor density, free-air gravity, offshore structure) to determine the causal association of upper-plate structure and interface segmentation/variations.

The Project:

Segmentation of the Cascadia subduction zone interface appears to manifest in the distribution of seismicity and slow slip along the interface. This type of segmentation is a multifaceted target of interest for many reasons: it may bear on the length of rupture during megathrust earthquakes and hence the maximum magnitude of future great earthquakes, and it may bear on the geographic limits of ETS behavior during interseismic intervals. Many aspects likely control the spatio-temporal segmentation of slip along the subduction interface including (but not limited to) the spatial distribution of materials along the interface, changes in plate geometry and hence physical and thermal state of interface materials, temporal placement within the seismic cycle, migration of fluids through the subduction interface, and the location of preexisting weak (or strong) zones within the subducting and overriding plates. We are particularly interested in the upper plate and understanding its geologic and tectonic structure, its segmentation both normal and parallel to the trench, and how that structure affects the distribution of stress during and after megathrust earthquakes. The research community hypothesizes that segmentation of slip on the subduction interface is triggered or stalled by interactions with the overriding plate, but we cannot understand these relationships without a complete picture of structural segmentation of the overriding plate. In Cascadia, trench-parallel structural heterogeneity of the upper plate is evident in data ranging from surface topography to deep geophysical imaging, all indicating that forearc strain is heterogeneous and accommodated in three dimensions: parallel to the trench, perpendicular to the trench, and down the dip of the subduction interface.

To address these issues, we propose a systematic geophysical investigation of the Cascadia forearc and arc across a complete subduction zone “segment” in western Washington and Oregon. This segment falls between two proposed boundaries for segmentation of the subduction interface (near Grays Harbor and Tillamook) as defined by spatio-temporal tremor distributions, free-air gravity data, and offshore basin structure after Wells et al. (2003; Figure 1). Internally, this segment is marked by features signifying that the overriding crust is broken by numerous faults, including the Doty fault and faults responsible for the Mt. St. Helens and West Rainier seismic zones (Figure 2). These features are identified by aligned seismicity, enhanced electrical conductivity, gravity and low-resolution aeromagnetic anomalies, and geologic mapping. Yet, little is understood about the deep structure of this segment or the connectivity of tectonic elements within it. We propose to integrate existing and new airborne magnetic, gravity, seismic, and MT data to produce structural models of the upper crust consistent with geologic mapping, LiDAR, and available subsurface information. Our overarching goal is to define forearc and arc heterogeneity in relation to a proposed Cascadia subduction-zone segment, and through this process determine the relationship between proposed predictors of subduction interface segmentation and concrete physical segmentation of the forearc upper crust. Lessons learned about what defines a segment in the absence of large, historical earthquakes will apply to segmentation elsewhere along the Cascadia subduction zone and at other subduction margins.

We will attempt to answer a number of specific questions about the structure of the forearc/arc and fault connectivity in the crust of SW Washington and NW Oregon using various geophysical methodologies: 1) The Doty fault is an important, trench-normal crustal structure arguably extending to Willapa Bay. Does the Doty fault extend offshore, and does it influence megathrust seismicity? If so, what are the causal reasons? 2) How laterally extensive are other faults within this segment, and what is the geometry of their deep structure? 3) How do faults and other tectonic features connect with each other on the surface and at depth, if at all? 4) Which faults exhibit neotectonic activity? 5) The Mt. St. Helens and West Rainier seismic zones bound crust of unique magnetic and electrical properties. What is the physical nature of this crustal block and does it influence arc seismicity and tremor distribution? 6) How does the spatial distribution of mapped faults and lineations compare to ‘markers’ of subduction zone segmentation (ETS distribution and recurrence intervals, heterogeneity in the gravity field, forearc rotation boundaries, along-strike changes in fluid release)?

New 3-D structural models of SW Washington and NW Oregon will help identify crustal faults that contribute their own seismic hazard, as well as influence subduction-interface events. Our project thus will inform two major geohazard concerns: subduction interface events and shallow crustal earthquakes. New aeromagnetic data (Figure 2) should be acquired and interpreted early in the GeoPRISMS process to define upper plate fault geometry within the forearc. This interpretation will facilitate early development of structural models that can serve as *a priori* constraints in geodetic models (e.g. McCaffrey et al., 2007), models derived from other newly acquired geophysical datasets (e.g. broadband seismic), and 3-D kinematic or dynamic models that test hypotheses for the interconnection between upper-plate structure and subduction interface segmentation.

References

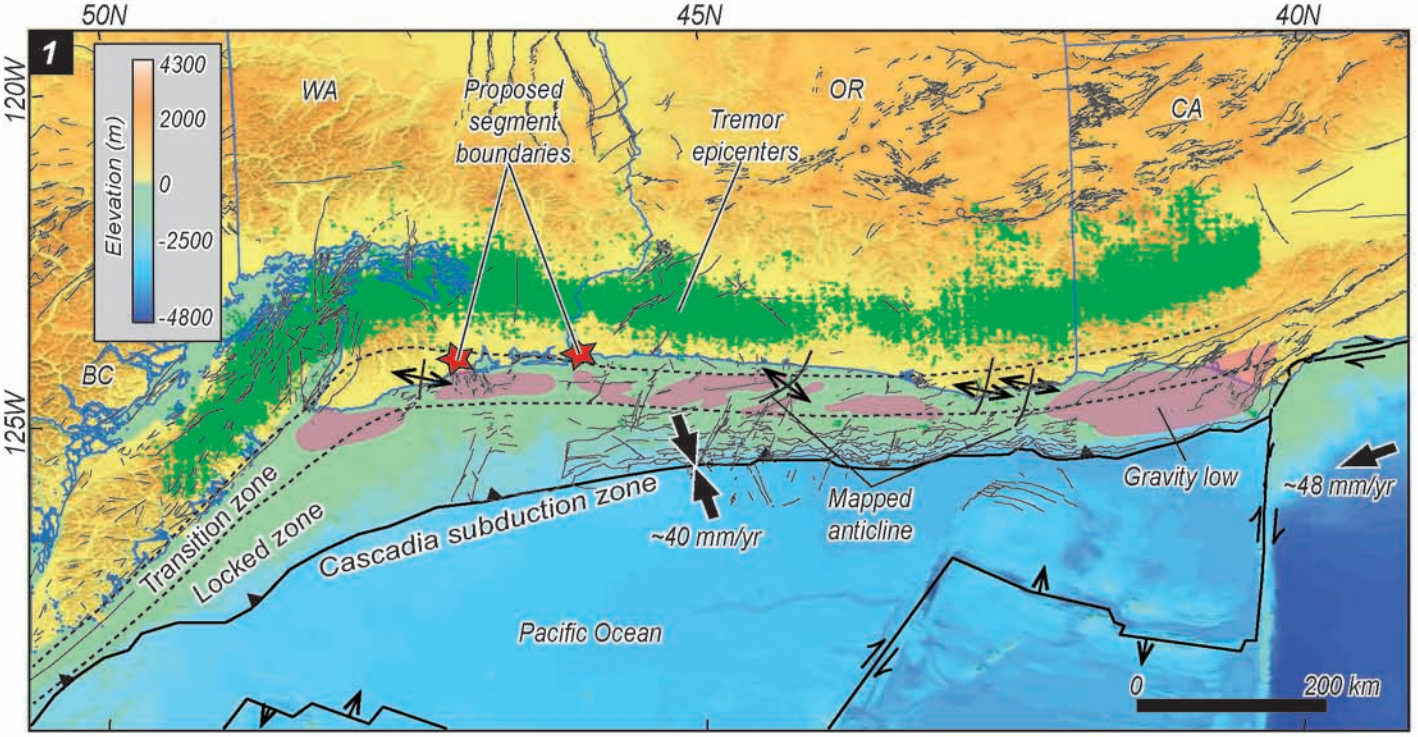
McCaffrey, R., Qamar, A. I., King R. W., Wells, R., Khazaradze, G., Williams, C. A., Stevens, C. W., Vollick, J. J., Zwick, P. C., 2007, Fault locking, block rotation and crustal deformation in the Pacific Northwest, Geophysical Journal International, v. 169, p. 1315-1340.

Wells, R. E., Blakely, R. J., Sugiama, Y., Scholl, D. W., Dinterman, P. A., 2003, Basin-centered asperities in great subduction zone earthquakes: A link between slip, subsidence, and subduction erosion?, Journal of Geophysical Research, v. 108, n. B10, doi: 10.1029/2002JB002072.

Figure Captions

Figure 1. Upper- and lower-plate structure and the distribution of episodic tremor. Green dots indicate episodic tremor epicenters (Pacific Northwest Seismic Network). Gray lines are Quaternary faults (USGS Quaternary Fault Database, digital geologic map of British Columbia, Geologic Survey of Canada). Offshore pink areas indicate gravity lows interpreted as forearc basins, possible indicators of greatest slip during past great earthquakes (Wells et al., 2003). Red stars show north-south limits of study area.

Figure 2. Magnetic anomalies, earthquakes, and quaternary faults of Washington and northern Oregon. Subdued rainbow colors are magnetic anomalies based on low-resolution airborne surveys older than 1995. Bright rainbow colors are high-resolution magnetic surveys acquired by the USGS since 1995. Warm colors indicate positive anomalies, cool colors are negative anomalies. Black lines, Quaternary faults (USGS Quaternary Fault Database). White circles, upper-plate earthquakes sized proportional to magnitude (Pacific Northwest Seismic Network). Red polygons, boundaries of proposed aeromagnetic survey. D, Doty fault; WRSZ, west Rainier seismic zone; MSHSZ, Mt. St. Helens seismic zone.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50N
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40N
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125W
Elevation (m)
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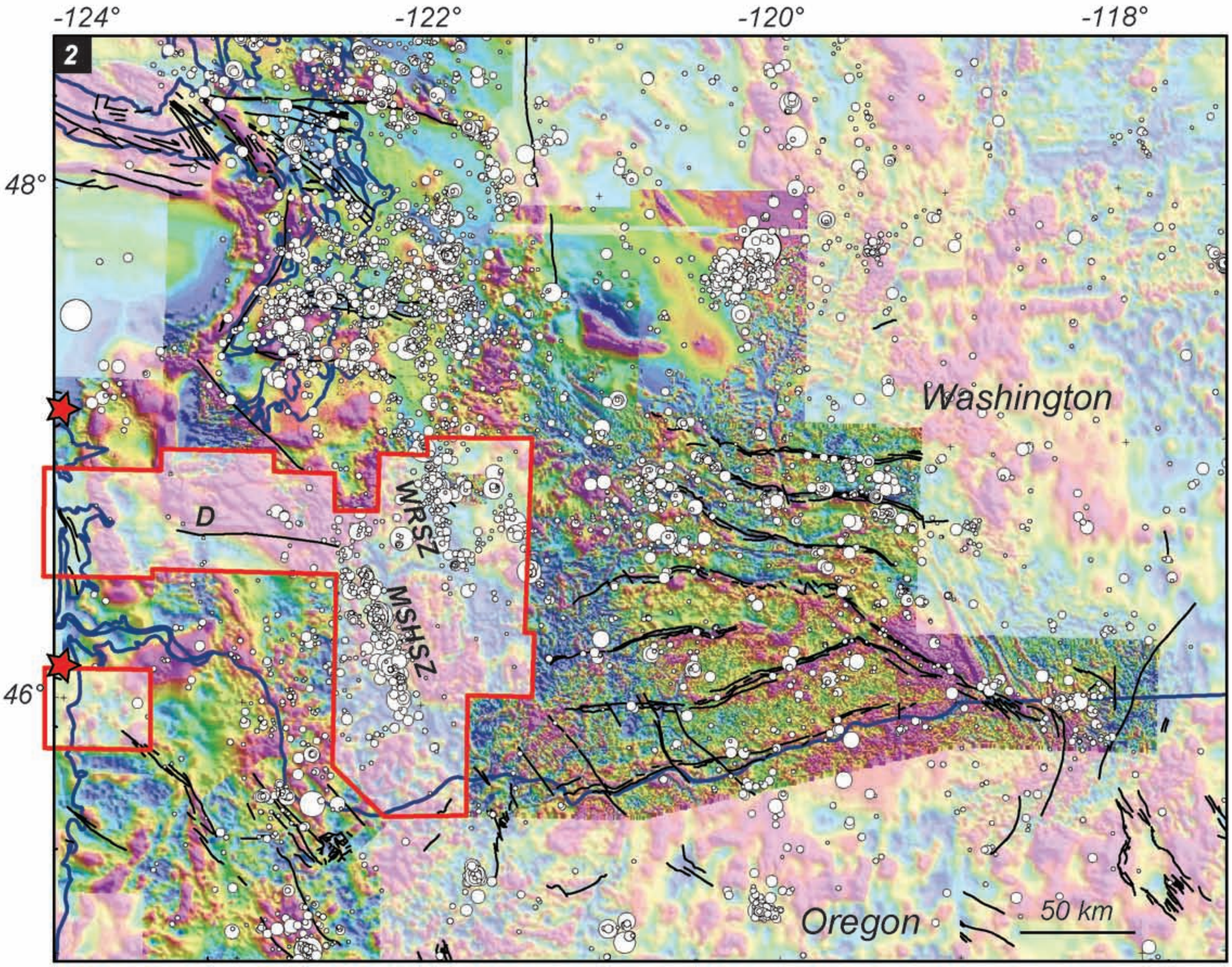
0
-2500
-4800
WA
OR
CA
BC
Proposed segment boundaries
Tremor epicenters
Transition zone
Locked zone
Cascadia subduction zone
~40 mm/yr
Mapped anticline
Gravity low
~48 mm/yr
Pacific Ocean
0
200 km


2
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Washington
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