Stress and Strain Regimes of the Pacific Northwest: A Comparative Study with SW Japan

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Investigations Undertaken

(1) Geodetic data collection and strain analyses in the Pacific Northwest. (2) Forearc stress analyses in the Pacific Northwest, SW Japan, and other subduction zones. (3) 3-D elastic dislocation and viscoelastic finite element interseismic deformation modeling for Cascadia.

Results

1. In the past year, we continued to upgrage the Western Canada Deformation Array (WCDA), the northern component of the PAcific Northwest Geodetic Array (PANGA), for continuous GPS monitoring of active crustal deformation. Successful transition to the Bernese software package accomplished in the previous year has significantly improved the accuracy of GPS data processing. The most important result of processing and analysis of continuous GPS data with the improved accurasy was the discovery of silent slip events along the Cascadia subduction interface. One such event was reported in Dragert et al. [2001]. In the summer of 1999, a cluster of seven stations briefly reversed their direction of motion. No seismicity was associated with this event. The sudden displacements are best explained by ~2 cm of aseismic slip over a roughly 50 km by 300 km area on the subduction interface downip from the currently locked seismogenic zone, a "rupture" equivalent to an earthquake of moment magnitude of 6.7 (Fig.1). A more recent event, within a more confined area, has also been identified, and the analysis is in progress. These silent events have revealed a previously unrecognized behavior of the deeper, plastic part of the subduction interface: Episodic fast slip and hence stress loading of the megathrust earthquake zone. Similar behavior of the subduction fault has been evidenced by continuous GPS data in SW Japan. We are pursuing comparative studies of the silent slip events in these two subduction zones with colleagues in the Geographical Survey Institute of Japan.

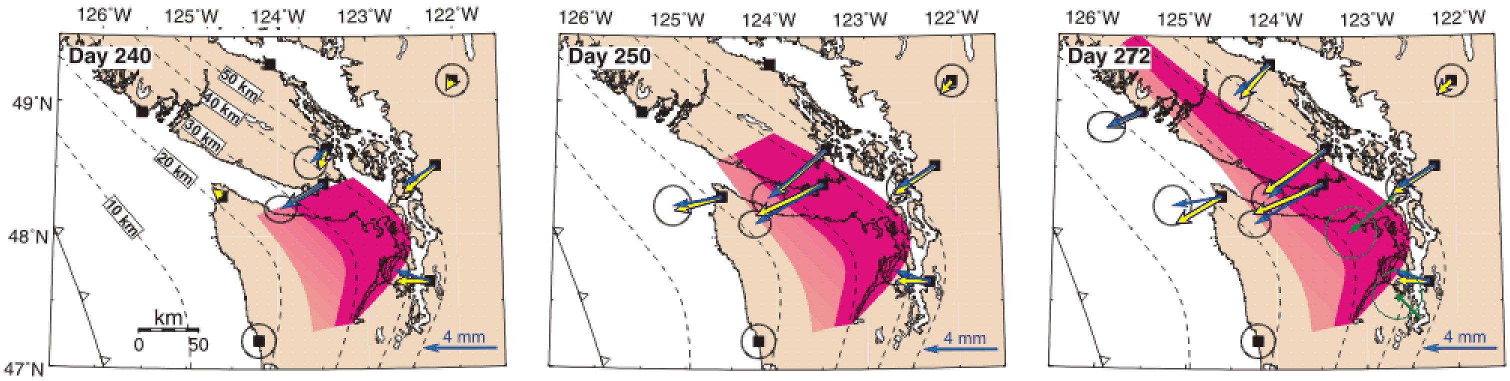

Figure 1. Silent slip event on Cascadia plate interface in 1999. Dark shading indicates the plate interface area with full (2.1 cm) slip; lighter shading indicates area where slip tapers linearly from 2.1 cm to zero updip. Panels, marked by the day of year 1999, show the total area of slip on the interface in 3 time slices and the commensurate evolution of the surface displacement vectors (broad (yellow) = model; thin (blue) with error ellipses = observed).

2. A stress gradient is present across the Nankai and Cascadia forearcs. In the frontal part of the accretionary prism, the stress field is dominated by margin-normal compression as evidenced by the thrust and fold structure. Further landward, the margin-normal stress is similar to or less than the vertical stress as evidenced by the focal mechanisms of crustal earthquakes. The margin-normal stress is controlled mainly by the total shear force along the subduction fault (or the plate coupling force) and the gravitational force. Plate coupling creates compression, and gravity induces lateral tension (all relative to the lithostatic state). The analysis ans modelling has been expanded to include many other subduction zones [Wang, 2001]. The results show that low margin-normal stress is a common feature of subduction zone forearcs, and only in exceptional cases is the plate coupling force large enough to overcome the gravitational effect (Fig.2). The results are of fundamental importance to defining the stress environment for both megathrust and crustal earthquakes in the Pacific Northwest.

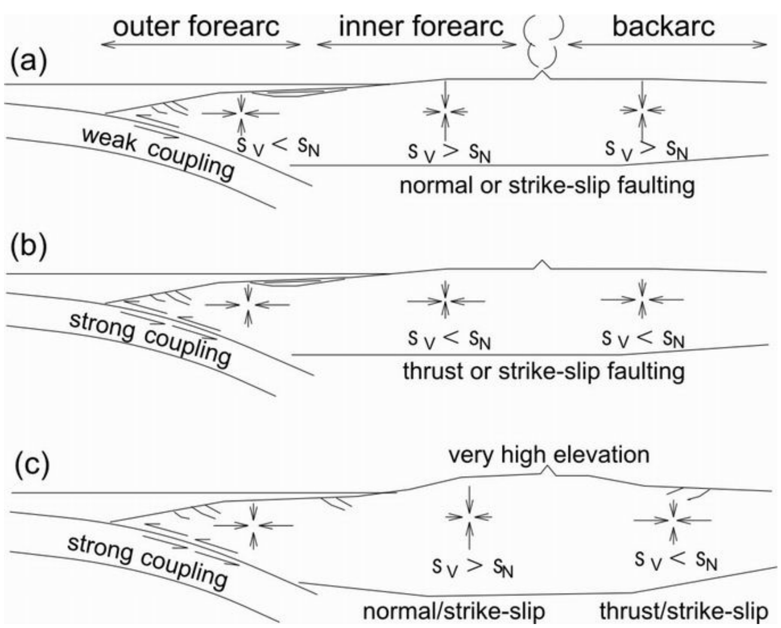

Figure 2. Schematic illustration of stress variations across the forearc-backarc system. The outer forearc is usually under compression. The states of stress in the inner forearc, volcanic and backarc regions are similar to one another ((a) and (b)), except where the inner forearc and volcanic zone have a very high elevation (c). The faulting regime depends on the strike-parallel stress. For Cascadia and SW Japan, maximum compression is strike-parallel.

3. Both a new 3-D dislocation model and a 3-D viscoelastic finite element model have been developed under this project to model interseismic deformation rates at the Cascadia subduction zone. Fig.3 is a summary of the dislocation model results. The effect of northward secular motion of the central and southern Cascadia forearc sliver is subtracted to obtain the effective convergence between the subducting plate and the

forearc. Horizontal deformation data, including strain rates and surface velocities from GPS measurements, provide primary geodetic constraints, but uplift rate data from tide gauges and leveling also provide important validations for the model. A locked zone, based on the results of previous thermal models constrained by heat flow observations, is located entirely offshore beneath the continental slope. Similar to previous dislocation models, an effective zone of downdip transition from locking to full slip is used, but the slip deficit rate is assumed to decrease exponentially with downdip distance. The exponential function resolves the problem of over-predicting coastal GPS velocities and under-predicting inland velocities by previous models that used a linear downdip transition. A wide effective transition zone partially accounts for stress relaxation in the mantle wedge that cannot be simulated by the elastic model. The pattern of coseismic deformation is expected to be different from that of interseismic deformation at present, 300 years after the last great subduction earthquake, as is evidenced in the viscoelastic model results. The coseismic transition zone (downdip transition from full coseismic rupture to no slip) should be much narrower zone than the present interseismic transition zone.

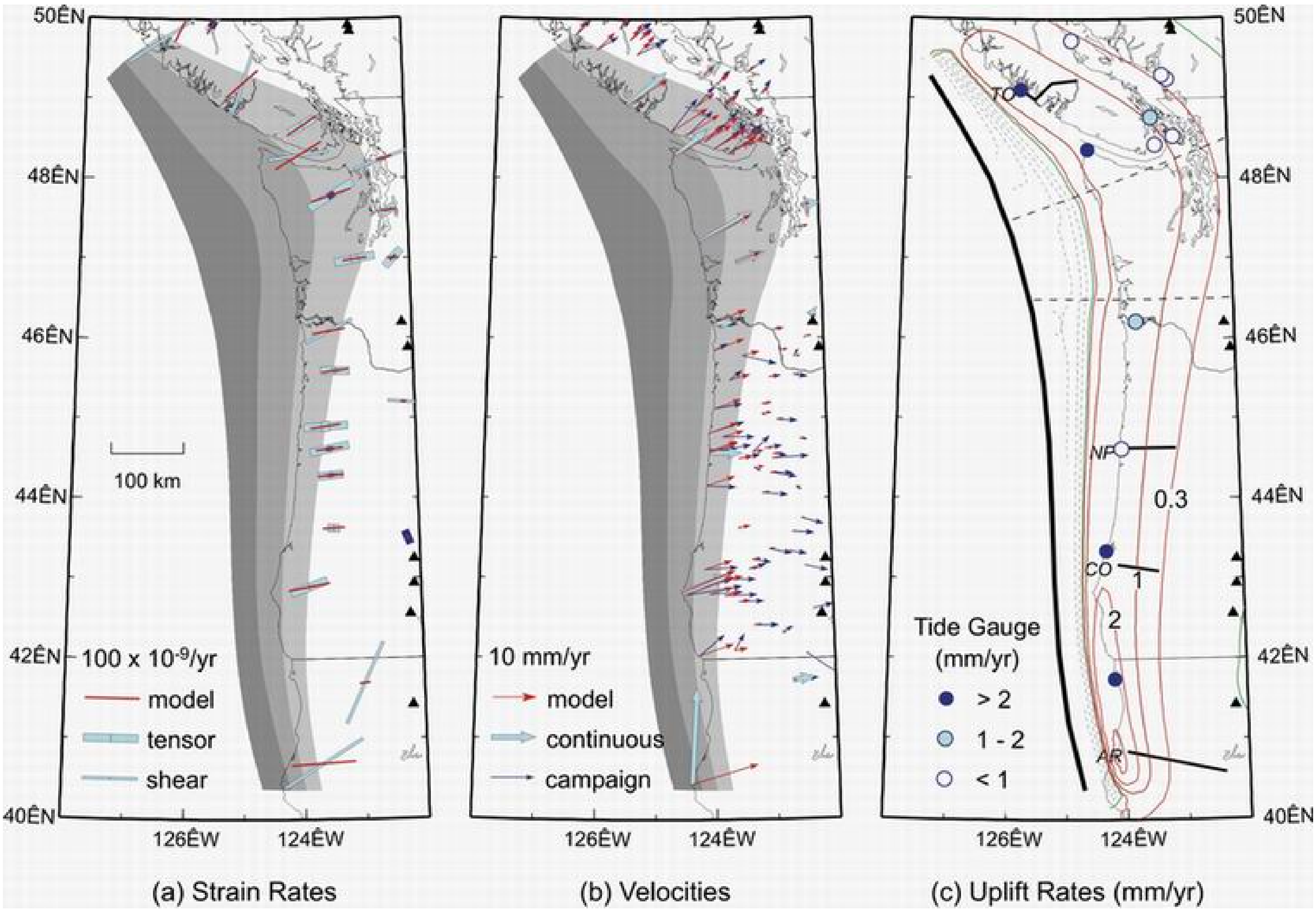

Figure 3. New dislocation model compared with geodetic observations. (a) Model and observed strain rates. The “tensor” strain rates are the best geodetic data constraints for an interseismic deformation model. (b) Model velocities and GPS velocities. GPS data for central and southern Cascadia have been corrected for secular forearc motion. (c) Model uplift rates (contour lines) and uplift rates derived from tide gauge records. Dark shading represents the locked zone. Intermediate and light shading represent the effective transition zone (ETZ) overwhich backslip rates decrease exponentially landward. Coseismic rupture is assumed to involve the seaward half (intermediate shading) of the ETZ.

Non-technical Summary

This project is directed at quantitatively explaining the observed crustal deformation and stresses in the Pacific Northwest. Understanding the mechanism of the stress and strain regimes leads to understanding the causes and consequences of both megathrust and crustal earthquakes. The stress and strain regimes in SW Japan, as well as its tectonic setting, are very similar to those in Pacific Northwest, and a comparative study will help us understand the common processes. Much progress has been made in gathering and analyzing GPS data, modelling forearc stresses, and developing 3-D elastic and viscoelastic models for earthquake related crustal deformation.

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