Seafloor Geodetic Monitoring with the Plate Boundary Observatory

C. David Chadwell, John A. Hildebrand, Fred N. Spiess
Scripps Institution of Oceanography
Herb Dragert
Pacific Geoscience Centre

The proposed Plate Boundary Observatory (PBO) background, San Andreas Fault and volcano monitoring arrays will provide a unique opportunity to study active processes within plate boundaries. However, a few additional site configurations (offshore) are necessary to address three important issues: the variation of convergence vector along the JdF-NA boundary, the updip extent of the lock portion of subduction thrust fault along the Casscadia subduction zone (and the Aleutian Trench) and the pattern of plate movement within the so-called Gorda Deformation zone around the Cape Mendocino triple junction. Addressing these issues requires some geodetic monitoring on the seafloor within the submerged portions of the active boundaries. Centimeter-level seafloor motion can be measured by combining GPS with precise acoustic ranging (GPS-A) to seafloor transponders (Figure 1). We propose three experiments within the offshore portion of the PBO study region.

1 Variations between present-day and geologic-averaged convergence of the Juan de Fuca - North American plates.

A fundamental assumption in all current models of the Cascadia seismogenic (locked) zone is that the JDF/NA plate convergence is constant as derived using magnetic anomaly averages over the past million years. This may not hold for a (dying) microplate system, and changes in the present-day direction and rate of convergence will have substantial impacts on the modelling of the locked zone and the deduced seismic hazard.

Direct evidence of a difference in convergence rates comes from 5-years of GPS-A data collected at a site some 150 km offshore Vancouver Island. In 1994, 1995, 1996 and 1999 the location of the first seafloor array on the Juan de Fuca plate was measured relative to shore stations on Vancouver Island (Figure 2). The 1994-1999 results suggest the JdF plate motion relative to NA is 2.7 cm/yr along a 16 degree azimuth, slower and at a more northerly direction than the predicted NUVEL-1A vector that predicts 4.6 cm/yr along an azimuth of 69 degrees [*DeMets et al.*, 1990; *Wilson*, 1993]. Adding the NUVEL-1A predicted NA-Pacific motion to our measured JdF-NA vector gives the JdF motion relative to the Pacific as 2.9 cm/yr along the same azimuth as the NUVEL-1A predicted vector, but slower than the 5.7 cm/yr long-term geologic rate. This suggests

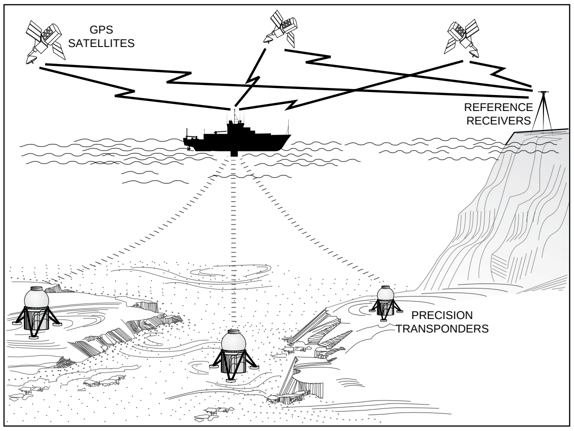

Figure 1: The GPS/Acoustic approach determines the acoustic ranges to the seafloor transponders from the sea-surface transducer while simultaneously determining the location of the sea-surface hydrophone with GPS [*Spiess et al.*, 1998]. To cope with a constantly changing sound speed structure in the near surface portion of the water column the seafloor units are place around a circle with a radius equal approximately to the water depth. Viewed from the center of the array at the surface, as the sound speed changes, the positions of seafloor transponders move vertically in a coherent manner, but the horizontal location of the array remains well defined. With 4 days of continuous GPS/Acoustic tracking the horizontal position of the seafloor point can be measured with a repeatability of ± 1 cm.

the JdF-NA convergence varies from a partitioning of strain from the ridge crest towards the plate interior.

To determine the present-day convergence, we propose to place four new seafloor geodetic arrays at ($41^\circ, 42.5^\circ, 46^\circ$ and 47° N) on the Juan de Fuca plate seaward of the Cascadia subduction zone (Figure 2). The proposed array will be comparable to the spatial resolution achieved with the onshore background array. The position of these seafloor arrays will be measured with GPS and underwater acoustics (Figure 1). The new offshore array should permit observing any variation in the convergence vector which should improve interpretation of deformation observed within the onshore geodetic arrays in the northwestern US.

While our research group is actively pursuing technology that uses buoys to make continuous measurements, to date the best approach to collect GPS/A measurements is annual campaign-style visits with a ship. Monitoring these sites will require the building of four seafloor transponders per site, deployment upon the seafloor, initial epoch measurements, annual re-measurement during 5-day ship visits and data reduction and analysis. Ship-time is typically funded by NSF block grants to the UNOLS fleet.

2 Imaging the updip limit of seismogenic zones JdF-NA subduction thrust fault

Within the Cascadia Subduction Zone (and likewise the Aleutian Trench), seafloor sites on the North America plate landward of the trench can be used to observe crustal deformation that can be modelled to estimate the updip extent of the locked zone (Figure 3). Along with the convergence vector, the extent of the locked thrust fault (seismogenic zone) within the Cascadia subduction zone directly influences the potential earthquake and tsunami hazard. Both the updip and downdip limits of locking are key parameters required in models of the seismogenic zone.

We propose two profiles at 44° and $48^\circ N$. Each profile will contain two seafloor sites located on the overriding North America plate. Using the GPS-A approach the horizontal position of

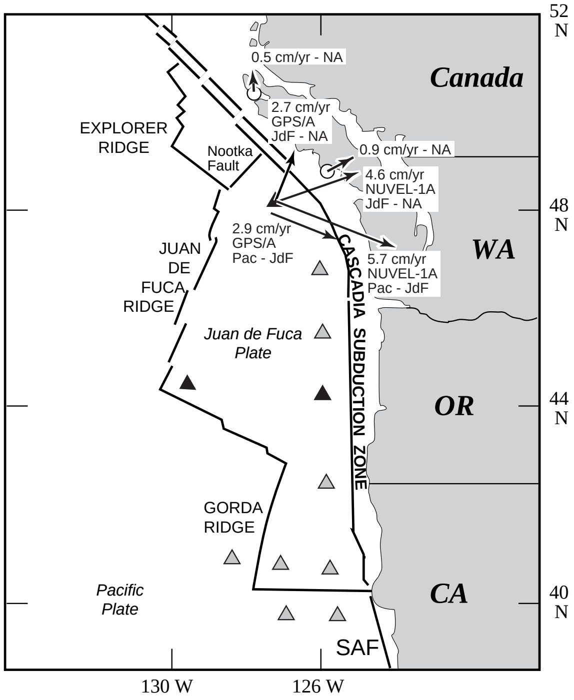

Figure 2: The Juan de Fuca plate. Solid triangle with vectors show the location of the first GPS-A seafloor site established in 1994. Shown are the NUVEL-1A predicted rates for Juan de Fuca - North America and Pacific - Juan de Fuca plates [*DeMets et al.*, 1990; *Wilson*, 1993]. Also shown are the GPS-A estimated rates for Juan de Fuca-North America and Pacific-Juan de Fuca plates observed from measurements collected in 1994, 1995, 1996 and 1999. Shaded triangles are the proposed sites for monitoring variations in JdF-NA convergence and deformation around the Mendocino Triple Junction.

these points will be measured with 1-cm uncertainty on an annual basis. The measured horizontal deformation of the overriding North American plate will be modeled to delineate the slip behavior of the subduction thrust fault beneath the submerged portion of the JdF-NA plate interface. Current evidence suggest the fault may be locked very near the trench. The nature of locking within the portion submerged results in similar deformation at continential sites which can be measured with land-based GPS, but significantly different deformation at offshore seafloor sites. Only seafloor geodetic studies in the near-trench region can delineate slip behavior (including aseismic) along the fault that lies offshore.

Both seafloor measurements and land GPS measurements of crustal motion is required to observe the partitioning of the total convergent plate motion across the entire subduction thrust zone. This should improve understanding of the dynamics of the seismogenic zone at oceanic-continental plate convergent margins, and may lead to refinements in the estimation of earthquake and tsunami hazard.

3 Offshore Monitoring of deformation at the Cape Mendocino triple junction

The pattern of present-day plate deformation around the Mendocino triple junction is largely unknown within the offshore portion the Pacific plate and the Gorda Deformation zone. Geodetic monitoring both north and south of the Mendocino transform on the Juan de Fuca and Pacific plates respectively, can observe the pattern of strain accumulation around the triple junction complementing the proposed San Andreas Fault array. We propose to place five seafloor sites to be measured with the GPS-A approach (Figure 2).

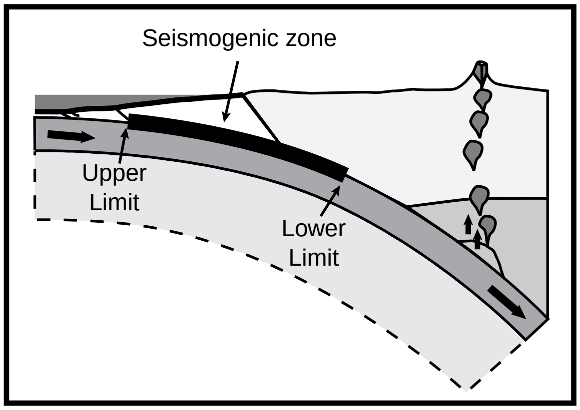

Figure 3: The seismogenic zone of a subduction thrust fault. The fault is aseismic in the seaward updip portion and landward downdip of a critical point (after [*Hyndman et al.*, 1997] .

References

DeMets, C., R. G. Gordon, D. F. Argus, and S. Stein, Current plate motions, *Geophys. J. Int.*, *101*, 425–478, 1990.

Hyndman, R. D., M. Yamano, and D. A. Oleskevich, The seismogenic zone of subduction thrust faults, *The Island Arc*, *6*, 244–260, 1997.

Spiess, F. N., C. D. Chadwell, J. A. Hildebrand, L. E. Young, J. G. H. Percell, and H. Dragert, Precise gps/acoustic positioning of seafloor reference points for tectonic studies, *Phys. of the Earth and Plan. Int.*, *108*, 101–112, 1998.

Wilson, D. S., Confidence intervals for motions and deformation of the juan de fuca plate, *J. Geophys. Res.*, *98*, 16,053–16,071, 1993.