Assistance Award 02HQPA0001

"Geodetic constraint on seismic vs. aseismic deformation in the Pacific Northwest: Collaborative Research Central Washington University, Oregon State University, and University of Washington" Proposal dated Spring, 2001.

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Final Technical Report
(budget period 03/02-03/03)

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Abstract

In the Pacific Northwest, efforts to quantify the hazards associated with the Cascadia subduction zone and crustal faults have been hampered by the difficulty of geologic field work and the lack of plate boundary seismicity. Global Positioning System (GPS) measurements now offer a new methodology applicable to just this type of difficult tectonic problem. GPS measurement of crustal motion has rapidly taken the lead in the study of plate boundary interactions at subduction and transform boundaries worldwide. We address large scale plate-margin-scale deformation as well as local seismic risk by continued monitoring of widely spaced PANGA sites and developing a much denser network of high-quality observations by integrating campaign and continuous measurements into a regional velocity field.

PANGA is a consortium of US and Canadian institutions engaged in GPS geodetic investigation of the Cascadia plate boundary system. Currently, 50 permanent GPS sites have been installed and are now collecting continuous data in the Pacific Northwest. These sites are funded by NSF, US Geological Survey, and the Geologic Survey of Canada and are supplemented by non-geodetic quality sites operated by the NGS. The primary focus of PANGA is to establish a velocity field for the Cascadia region that can be used directly to assess seismic hazards from the Cascadia plate interface, and also to understand the complex kinematics of the Pacific Northwest as a whole.

At this year's PANGA Investigator Community Meeting, we developed a unified set of priorities for a science plan for geodetic earthquake studies in the Pacific Northwest.

Goals of the project:

The goal of the project is to enhance regional geodetic studies related to seismic hazard through a coordination of the investigator community, forming the basis for characterizing seismic risk in densely populated regions of the Pacific Northwest.

Annual meetings of the PANGA Investigator Community continue to play a critical role in enhancing regional GPS studies. As the GPS velocity estimates mature, many workers have undertaken modeling of PANGA results under the umbrella of NEHRP and other funding sources. To date, this growing PANGA community has had seven annual meetings that have resulted in the current plans and progress.

Results

PANGA Investigator Meeting:

NEHRP funded one CWU – proposed task in FY 2002. This task was convening the PANGA investigator community meeting, which occurred during November, 2002. A 2-day PANGA investigator community meeting was held at the Geodesy Laboratory and PANGA Data Analysis Facility, Central Washington University. The agenda included technical reports, scientific investigations, and development of a draft science plan.

Pacific Northwest Geodetic Array (PANGA) is a consortium of U.S. and Canadian institutions engaged in GPS geodetic investigation of the Cascadia plate boundary system, committed to using CGPS to investigate the modern deformation processes. Currently, 50 continuous GPS sites are now collecting GPS data in the Pacific Northwest (Figure 1).

Non-technical summary

Global Positioning System (GPS) geodesy allows us to study fault motions and related deformation of the earth's surface. In the Pacific Northwest, seismic risk is posed by both a very large fault off shore, where ocean floor is consumed under the edge of the North American plate, and by smaller, and shallower faults that lie closer to population centers within the edge of the continent. This project uses GPS geodesy to characterize real-time deformation of the Earth's surface in the Pacific Northwest and to better characterize earthquake hazards in the region. NEHRP supports an annual scientific workshop for investigators interested in Pacific Northwest geodesy.

Reports published

Journal publication:

M. Meghan Miller, Tim Melbourne, Daniel J. Johnson, and William Q. Sumner, 2002, Periodic slow earthquakes from the Cascadia subduction zone. Science. v. 295, n. 5564: p 2423.

Stephane Mazzotti, Herb Dragert, Roy D. Hyndman, M. Meghan Miller, and Joseph A. Henton, 2002, GPS deformation in a region of high crustal seismicity: North Cascadia forearc. Earth and Planetary Science Letters, v. 198, p. 41-48.

Theses:

Andrew Miguel Miner, 2002, Eocene tectonics and active deformation in Cascadia. M.S. Thesis, Central Washington University, Ellensburg, Washington. 101 p.

Charles Ardoin, 2002, Vertical deformation near Willapa Bay, Washington. M.S. Thesis, Central Washington University, Ellensburg, Washington. In progress.

Data Availability

These data are freely available from the ftp site at ftp://panga.cwu.edu. The data are in standard RINEX format and any questions regarding data can be directed to Marcello Santillan, marcelo@geology.cwu.edu. The resulting velocity field is posted to http://www.geodesy.cwu.edu/ and links contained there.

Panga Meeting 2002 Summary

2002 PANGA Investigator Meeting
November 14-15, 2002
Central Washington University
Ellensburg, Washington

The 2002 PANGA Investigator Meeting was attended by 28 scientists from institutions and agencies concentrated in the western U.S. but from as far away as New York state. The focus of this meeting was reflected in three special presentations and a working session: developing broader scientific perspectives, examining resource issues, and staging for Earthscope.

There were several highlights this year: Kerry Sieh delivered a keynote address on The subduction earthquake cycle: Paleogeodetic and paleoseismic evidence from Sumatra. Tom Brocher presented the goals of the NEHRP program relative to PANGA investigations. Dan Johnson and Dave Verdonck summarized their recent work on gravity studies and vertical leveling results respectively. Charlie Rubin gave a summary of recent field studies along the Denali fault rupture.

Thursday afternoon began with technical summaries of the networks by Herb Dragert and Andrew Miner. Both reported progress in densification of PANGA/ WCDA. Mike Jackson talked about the shape of Earthscope and PBO implementation. Stephane Mazzotti presented a new subduction zone inter-seismic model.

Friday morning started off with a session devoted to developing a science plan for PANGA that will reside on the web and will be periodically updated through community feedback. Ray Wells contributed his summary of PANGA issues from the Earthscope and PBO planning workshops. This will provide a starting point for shaping the community science plan. We have decided to revisit a more formal organizational structure for PANGA efforts and the idea of an Executive Committee was floated. The PANGA core institutions will be invited to appoint a representative to that community: Cascade Volcano Observatory, Central Washington University, Oregon State University, Pacific Geoscience Centre, Rensselaer Polytechnic Institute, University of Idaho, University of Oregon, and University of Washington. The Executive Committee will meet early in the spring to take up a number of issues related to Earthscope prioritization and committees, proposal submission, and other coordination issues.

A poster session followed with contributions from Mike Caron, Noah Fay, Pat McCrory, and Ray Wells. Oral presentations by Ronnie Ning, Bill Sumner, Meghan Miller and Tim Melbourne focused on recent GPS results.

Follow-up activities include implementation of a PANGA Investigator Community page on the PANGA web site and web access to the list serve. Details of the presentations, attendees, and this report can be found at http://www.geodesy.cwu.edu/ on the Panga Community page.

Abstracts submitted for the Panga Meeting

- Seismicity and Strain Analysis in Pacific Northwest

  Zuoli Ning and Anthony Qamar

- Status of WCDA GPS Network Operations, Data Analysis and Preliminary Results from Vertical Deformation Surveys on Vancouver I. in 2002

  M. Schmidt, H. Dragert, A. Lambert, N. Courtier, L. Wolynec, Y. Lu, W. Sundholm, B. Schofield

- Coseismic Slip Beneath Forearc Basins in Great Subduction Zone Earthquakes: Implications for the Size and Mode of Rupture on the Cascadia Subduction Zone

  Ray E. Wells, Richard J. Blakely, Yuichi Sugiyama, and David Scholl

- The subduction earthquake cycle: Paleogeodetic and paleoseismic evidence from Sumatra

  Kerry Sieh

- PBO and Regional Existing Arrays

  Michael Jackson

- Aseismic Slip and the Nisqually Earthquake

  William Q. Sumner and M. Meghan Miller

- Monitoring the active magma chamber at South Sister Volcano with gravity and GPS measurements

  Daniel J. Johnson

- Realization of Continuous GPS Velocities over a Neotectonic Crustal Block Model for the Puget Sound Area and the Implications for Seismic Risk

  Michael E. Caron, M. Meghan Miller and Daniel J. Johnson

- TSFIT, A GPS Timeseries Analysis Tool

  Noah Fay and M. Meghan Miller

- Putting Dots on the Map: Some Progress South of the Border

  Andrew M. Miner

- Fate of the Eastern California shear zone along the Cascadia margin and entrainment of the Cascadia fore-arc in oblique subduction

  M. Meghan Miller and Daniel J. Johnson

- Crustal uplift and a comparison of deformation models

  David Verdonck

Realization of Continuous GPS Velocities over a Neotectonic Crustal Block Model for the Puget Sound Area and the Implications for Seismic Risk

Michael E. Caron, M. Meghan Miller and Daniel J. Johnson[1]

Abstract

Data collected from continuously-recording GPS stations of the Pacific Northwest Geodetic Array (PANGA) provide a key input to investigating partitioning of strain among active crustal faults in the Puget Sound area. Neotectonic deformation in this area is related in large part to northward-directed motion of the Cascadia forearc due to entrainment above the obliquely subducting margin between Juan de Fuca and North America. A rational crustal fault block model for the Pacific Northwest has been constructed, using data from a variety of sources, including extant geologic mapping, aeromagnetic and gravity survey data, digital elevation model imaging and seismic survey data. The current model, which includes all of Washington and Oregon and a portion of southern British Columbia, consists of nine blocks of varying size. In addition to ensuring that each block was bounded by reasonably well-defined crustal faults, additional consideration was given to the need to have at least two GPS stations located on each block in order to properly drive rotations and translation vectors during inversion.

Previous crustal strain partitioning in the Puget Sound area has relied in large part on paleoseismic constraints, although widespread unconsolidated Quaternary sediments and extensive urban development obscure many of the critical structures and direct observation is often difficult or impossible. However, recent marine and land-based high-resolution seismic surveying has allowed formulation of important paleoseismic constraints for several of the more important faults in the Puget Lowlands, including constraints on Quaternary slip rates for the Seattle and South Whidbey Island faults.

Although relatively sparse, sufficient high quality data have recently become available from the PANGA network to allow inversion of these data across a kinematically consistent crustal block model. The inversion process requires input of the basic block model parameters including individual fault segment definitions such as spatial location, strike and dip, locking depth and burial depth. Where deemed appropriate, the model also allows input of a priori constraints such as dip, tensile and strike-slip rates. The other key inputs to inversion are robust velocity solutions for continuously recording GPS stations, including data from the PANGA network in the Pacific Northwest as well as data from several stations on the North American craton used to provide a stable reference frame.

Inversion of a completely unconstrained model results in unrealistically high rates of closure motion across critical crustal faults in Puget Sound, in part due to the sparseness of the velocity field. Consequently, reasonable a priori slip constraints were applied to the Seattle and South Whidbey Island faults, as well as to the less-well-constrained Tacoma fault. With these three faults reasonably constrained, model inversion produces small residual velocity vectors, indicating substantial agreement between model and observed velocities.

An analysis of block model results may allow formulation of key constraints on the way the forearc behaves under strain and the likelihood of catastrophic or damaging release of this strain by seismic rupture. Although robust conclusions are premature, modeled fault slip rates from inversion show, for example, up to 8mm of reverse dip slip on the fault bounding the north side of the Olympic Mountains uplift. This fault is not currently known to have significant Quaternary slip rates. The amount of slip modeled on this fault exceeds modeled (and in part paleoseismically constrained) slip across the Tacoma, Seattle, South Whidbey Island and Devils Mountain faults in Puget Sound. This modeled slip budget excess implies that slip is either being taken up along poorly known (or unknown) faults to the south in the large area of Quaternary cover in the lowlands to the south of the Olympic Mountains uplift, or is being accommodated by folding.

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TSFIT, A GPS Timeseries Analysis Tool

Noah Fay[1] and M. Meghan Miller[2]

Abstract

We have developed a GPS analysis tool, TSFIT, to fit timeseries for station velocity (timeseries slope) while simultaneously accounting for annual and semi-annual atmospheric and solid earth signals (e.g., Blewitt et al., 2001), steps in the timeseries due to antenna swaps at individual stations, and steps due to tectonic events (e.g., Nisqually or silent earthquakes). We fit the timeseries according to the equation

$$y = m \cdot x + b + A_1 \cdot \sin\left(2\pi / P_1 \cdot \left(x + \phi_1\right)\right) + A_2 \cdot \sin\left(2\pi / P_2 \cdot \left(x + \phi_2\right)\right) + steps\ ,$$

where

y	=	position (daily or weekly),
m	=	slope (station velocity),
x	=	time (date),
b	=	ordinate intercept on position vs. time plot,
$A_{1/2}$	=	amplitude of annual/semi-annual signal,
$P_{1/2}$	=	1/0.5 years (wavelength of annual/semi-annual signal),
$\phi_{1/2}$	=	phase of annual/semi-annual signal, and
steps	=	offset due to mechanical or tectonic events.

This fit determines the average slope of the timeseries, and thus a velocity that only reflects the secular deformation rate and is not sensitive to annual and semi-annual systematic noise. By fitting the mechanical steps we are able to use stations that otherwise do not have a sufficiently long step-free timeseries. We find that in general the fitted velocities agree with those found by simple least-squares regression, though the uncertainties found through TSFIT are smaller.

G. Blewitt, D. Lavallee, P. Clarke, and K. Nururtdinov, A new Global mode of earth deformation: Seasonal cycle detected. Science, 294, 2342-2345, 2001.

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PBO and Regional Existing Arrays

Michael Jackson[1]

Abstract

The Plate Boundary Observatory (PBO), as a core component of EarthScope is designed to study the three-dimensional strain field resulting from deformation across the active boundary zone between the Pacific and North American plates in the western United States. Other components of EarthScope include USArray, a seismic look at continental structure, and the San Andreas Fault Observatory at Depth, SAFOD, a 4 km drill hole near Parkfield. EarthScope consists of three primary funding elements including, peer reviewed science proposals that utilize the EarthScope infrastructure and data products, a Major Research Equipment and Facilities Construction (MREFC) component with a five year lifespan that will build the core EarthScope Facilities, and an Operations and Maintenance component with a 10 year duration that will be funded through Research and Related Activities (R&RA) funds.

The PBO Facility will consist of four elements. First. . .View the entire abstract with figures.

[1] PBO Interim Director

Monitoring the active magma chamber at South Sister Volcano with gravity and GPS measurements

Daniel J. Johnson[1]

Abstract

In the spring of 2001, USGS volcano researchers discovered a zone of recent crustal uplift immediately west of South Sister stratovolcano, central Oregon Cascade Range, using the technique of satellite interferometric synthetic aperture radar (InSAR). In response, the USGS has installed a Global Positioning System (GPS) instrument near the center of uplift, reoccupied electronic distance measurement (EDM) and tilt networks last measured in 1986, and scrutinized additional InSAR images. These efforts have confirmed that uplift is presently continuing at a pace of approximately 40 mm/year at the center of uplift and that it began in ~1998. Modeling of the uplift data indicates that the inflation source lies 5 to 7 km below the surface. Currently it is unknown if the inflation is due to injection of new magma, or due to expansion - for example vesiculation - of older magma at depth, or simply due to changes within a hydrothermal system. To help answer these questions, a series of repeated precise gravity and GPS surveys will be conducted at monitoring points established in the uplift region. The primary observation is the ratio of gravity change to vertical uplift, which may be interpreted in terms of mass and density change at depth. If it is new magma injection that is producing the uplift, then an important second goal will be to characterize the magma chamber. Does the chamber contain only material added within the past few years, or a significant volume of magma that accumulated earlier? What kind of magma is present and what is its gas content?

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Fate of the Eastern California shear zone along the Cascadia margin and entrainment of the Cascadia fore-arc in oblique subduction

M. Meghan Miller and Daniel J. Johnson[1]

Abstract

High-precision, continuous GPS geodesy in the Pacific Northwest provides a synoptic view of the along-strike variation in Cascadia margin kinematics. Here, we present a version 2 velocity field that uses a different period of data collection, improvement in the processing of daily solutions, a North America-based approach to daily network stabilization, and only 50% overlap in the set of stations to define the North America reference frame in version 1 [Miller et al., 2001]. Yet version 2 yields a velocity field and stable continent reference frame that agree at better than the 95% confidence level, detailed structure of the time series are realized and precision is improved.

These results constrain interfering deformation fields. Coastal stations in the northern and central parts of the margin are strongly entrained in the Juan de Fuca-North America convergence direction. The magnitude of northward forearc motion relative to North America increases southward from Vancouver Island (2 mm/yr), to western Washington (5-7 mm/yr) to northern and central Oregon (~7-8 mm/yr), consistent with oblique convergence and geologic constraints on permanent deformation. The margin-parallel strain gradient, concentrated in western Washington across the populated Puget Lowlands, compares in magnitude to shortening across the Los Angeles Basin. The California-southern Oregon boundary reflects a composite velocity that includes the San Andreas transform system, Mendocino triple junction migration, and interaction between North America and the south Gorda plate. The Klamath Mountains are partially entrained with the impinging Sierra Nevada block, and Eastern California shear zone deformation previously believed to penetrate the arc and back arc is at least partly distributed back out to the plate boundary. Inland stations have lesser motions, consistent with their structural domains from south to north: the Canada and northern Washington back arc experiences slow convergence parallel motion, the Yakima fold belt actively contracts, and southeastern Oregon shows integrated Basin and Range extension.

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Putting Dots on the Map: Some Progress South of the Border

Andrew M. Miner[1]

Abstract

The Nisqually earthquake and its aftermath (and now the earthquake sequence on the Denali fault) again demonstrate that a quick response by geodesists to large earthquakes is likely to have serendipitous results. In the former case, time-series from sites installed near the earthquake (e.g., CPXF) quickly suggested that some sort of afterslip might have occurred. The relatively large magnitude of this putative effect, however, seemed to cast doubt on its reality: I for one didn't loose much sleep over it. Meanwhile, the somewhat arbitrary decision to install sites further afield proved to be a lucky one. SC02 (Friday Harbor), whose location was driven largely by convenience, has quickly become a poster child of the slow earthquake set. In turn, deep creep, which was not widely contemplated when SC02 went in (at least south of the border) may explain the geodetic peculiarities surrounding the Nisqually event (Sumner and Miller, this conference).

Despite the funding limbo pending a yea or nay on the Plate Boundary Observatory, we are trying to take advantage of opportunities to be similarly fortunate. SC03 (Snow Dome) takes advantage of a unique location and a window of opportunity that may close in the next few years. The Puget Reference Station Utility (PRSU) is a mainly county and municipal GPS network for which we are funded (NSF) to provide geodetic-quality monuments over the next three years. Other projects in early planning stages at CWU are intended to densify existing transects that are already of considerable interest (proposed sites BPET, HUDU, OCTO, STPK, EOU). At these sites good bedrock is exposed, so inexpensive monuments can be constructed and occupied in campaign-fashion if funding for full instrumentation is not available. Oregon State University and the University of Idaho are also installing new continuous sites as time and funding permit. More continuous sites and longer campaign time-series in the swath between these two institutions will, I believe, paint a much more interesting picture than present block models would suggest.

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Seismicity and Strain Analysis in Pacific Northwest

Zuoli Ning and Anthony Qamar[1]

Abstract

GPS data up to 2001 from nearly 300 GPS sites in Washington and Oregon have been used in order to understand seismicity patterns in the Pacific Northwest. After gridding this area, a translation vector of velocity at each node is calculated by using all stations within a radius of 100km from the node. Guided by computed site velocities and seismicity patterns in this area, we then separate the Oregon block from the Washington block at latitude 46^o, and further divide the Washington block into six sub-blocks, four in western Washington and two in eastern Washington. Each sub-block contains many nodes. Fault plane solutions and the distribution of seismicity suggest that Juan de Fuca plate locking has little direct effect on earthquake occurrence in the Pacific NW. In our approach we remove contributions of JDF plate locking from the computed translation vectors, then find a block rotation pole and strain rate for each sub-block. In the Oregon block, plate locking and rigid block rotation are sufficient to explain the GPS observations. This is consistent with previous studies by McCaffrey and others.

The Washington block is more complicated. The southern three sub-blocks have bigger rotation rates and smaller strain rates than the northern three sub-blocks. The two western sub-blocks show EW extensions as well as NS compression. The Olympic Peninsula sub-block has the greatest NS compression in the Pacific NW(2.3mm/degree/yr). The Puget Lowland sub-block and Mt. Rainier sub-block are shortening along a NNE direction which is roughly consistent with the direction of maximum principal stress from focal mechanism solutions. NS compression dominates the Yakima block which is also consistent with principal stress direction derived from fault plane solutions. However the northeast Washington sub-block shows EW extension.

When western Washington is pushed against the ''backstop'' of British Columbia, block rotation in Oregon is converted to NS compression in northern Washington. The southern three sub-blocks in WA act as a transition zone between Oregon and British Columbia. The variation of strain rate in WA compared to Oregon may explain the increased crustal seismicity in WA. The driving force of crustal earthquakes in Washington can be interpreted as coming from block rotation in Oregon which changes to NS compression in WA. GPS derived velocities in NE Washington are still too uncertain to determine the details of block rotation there.

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Status of WCDA GPS Network Operations, Data Analysis and Preliminary Results from Vertical Deformation Surveys on Vancouver I. in 2002

M. Schmidt[1], H. Dragert[1,2], A. Lambert[1], N. Courtier[1], L. Wolynec[1,2], Y. Lu[1], W. Sundholm[3], B. Schofield[1]

Abstract

During 2002 the Western Canada Deformation Array (WCDA) was enhanced by two new sites on southern Vancouver Island, (PTAL and BAMF), bringing to a total of 15 stations currently in the array. WCDA network operations enhancements currently underway include a complete audit of all site meta-data and the re-RINEXÕing of all WCDA data. The complete WCDA data set from 1991 will be made available on the new FTP server (wcda.pgc.nrcan.gc.ca) in the near future. Near term enhancements to the data management system include a RAID level 5 system for all GPS (WCDA and campaign) data as well as levelling and other geodetic data sets, meta data and site information files. A RAID level 1 FTP server external to the PGC firewall is planned for FY 2003-04.

Data analysis has expanded in scope to include data from permanent GPS reference stations operated by the Province of British Columbia and recently relocated onto geodetic quality, stable antenna piers. The primary WCDA analysis using the Bernese software currently encompasses approximately 30 sites from Canada and from the U.S. (PANGA consortium). A re-analysis of the continuous GPS data from the WCDA, PANGA and BC arrays from 1994 to 2002, has yielded an indication of seven aseismic slip events in the northern Cascadia Subduction Zone (CSZ). The surface displacement detected at each continuous GPS site is similar in amplitude, direction, and duration from epoch to epoch. This consistency suggests that the location of the slip is centered beneath southern Vancouver Is. (BC) and the eastern Olympic Plateau (WA).

During the summer of 2002 a combined GPS, Absolute Gravity and precise levelling campaign took place across Vancouver Island in order to improve the resolution of vertical deformation across the island. This was the first time all three methods were used simultaneously on this transect. Precise levelling and relative gravity transects have been run in the past and Absolute Gravity measurements are routinely carried out at the permanent GPS sites Ucluelet (UCLU) on the west coast and Nanoose (NANO) on the east coast of the island. The results from the recent re-analyses of 6.5 years of continuous GPS data (1995 to 2002) and four years of quarterly Absolute Gravity data (1997Ð2001) indicate almost no tilting between UCLU and NANO. Preliminary indications from the comparison of past levelling campaigns with the 2002 survey similarly indicate minimal net cross-island tilting over the past 10 years.

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Aseismic Slip and the Nisqually Earthquake

William Q. Sumner and M. Meghan Miller[1]

Abstract

Continuous Global Positioning System (GPS) stations in the Pacific Northwest move northeast with respect to the North American plate as a result of coupling along the subducting Juan de Fuca plate. In early 2001 GPS stations from Puget Sound to northern Oregon reversed this northeast direction of motion for several weeks. The reversed motion shares some of the spatial and temporal signatures of aseismic creep events (or silent earthquakes) previously reported farther north along the Cascadia plate interface [1,2], although the periodic recurrence observed farther north has not been established here. The strongest aseismic motion was detected southwest of Seattle at the GPS stations SATS and RPT1. On February 28, 2001, during this period of aseismic slip, the Mw 6.8 Nisqually earthquake ruptured a fault within the Juan de Fuca plate. The rupture occurred at some 50 km depth; its epicenter lies between these two stations. The aseismic motion preceeding the earthquake is consistent with slip on the plate boundary. The displacements from the Nisqually earthquake itself are in good agreement with calculations using fault parameters from the inversion of seismic data.

1) Herb Dragert,, Kelin Wang, and Thomas S. James, Science, 292, 1525-1528, 2001
2) M. Meghan Miller, Tim Melbourne, Daniel J. Johnson, and William Q. Sumner, Science, 295, 2423, 2002

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Crustal uplift and a comparison of deformation models

David Verdonck[1]

Abstract

Several recent studies have suggested that the Cascadia Subduction zone may be locked in more than one location. When the subduction interface contains multiple locked sections the traditional elastic dislocation analogy breaks down. Other modeling methods such as finite element or boundary element methods may be required to accurately represent the interseismic deformation associated with this type of complex plate boundary. In an effort to develop a better analog for the interseismic subduction process, several models are compared. Results indicate that vertical deformation sensitive to the modeling technique while horizontal deformation is not. As a consequence of this result, a better understanding of the active vertical deformation is required.

Leveling is a time tested precise geodetic technique. Data from over 500 leveling lines passing through Oregon and Washington are archived by the United States National Geodetic Survey. Many locations have been surveyed multiple times over the past 80 years. Precise changes in relative elevation can be determined from analysis of data from repeated leveling lines. Data from leveling conducted along the Columbia River during the 1920s, 1940, 1960s, and 1980s are analyzed to determine relative uplift rates. Preliminary results indicate that in some regions the relative rate of vertical crustal deformation varies over time.

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Coseismic Slip Beneath Forearc Basins in Great Subduction Zone Earthquakes: Implications for the Size and Mode of Rupture on the Cascadia Subduction Zone

Ray E. Wells[1], Richard J. Blakely[2], Yuichi Sugiyama[3], and David Scholl[4]

Abstract

We have examined the relationship between coseismic slip and forearc structure for 29 of the largest circum-Pacific megathrust earthquakes. Coseismic slip distributions were compiled from published seismic, geodetic, and tsunami waveform inversions, and we interpreted forearc structure from satellite gravity and bathymetry and marine geology. Seismogenic slip is generally focused beneath forearc deep sea terraces and basins, which are underlain by relatively high velocity arc or continental crust. Along the Nankai and Sagamai Trough of SW Japan, slip in the 1923, 1944, 1946, and 1968 earthquakes was focused beneath five forearc basins, and the presently locked Tokai source region is centered on a sixth. The steep gravity gradient marking the landward edge of the basins coincides with the landward decrease in coseismic slip and the 350¡C isotherm on the plate boundary, approximately marking the down-dip limit to stick-slip behavior. In the 1960 Chile event, the highest coseismic slip coincides with forearc basin-centered gravity lows along the entire rupture length. Similar coseismic slip beneath basins is also observed along the Aleutian, Mexico, and Peru subduction zones. Transverse forearc gravity highs which separate the basins commonly overlie areas of lower coseismic slip, as at Cape Erimo separating the 1952 and 1968 Tokachi-oki earthquakes off Hokkaido, the Shumagin gap separating the 1938 and 1946 earthquakes in S. Alaska, and the Portlock anticline separating the Kodiak and Prince William Sound asperities in 1964. If the long-term slip budget is balanced along the margin, then the intervening gravity highs may be future sources of great slip not observed historically, or more likely are regions of smaller interseismic strain accumulation, as is observed in the Shumagin gap and permitted by geodetic data at Cape Erimo and off Kodiak. The empirical relationship between high coseismic slip and forearc basins suggests that forearc basins may be useful indicators of long-term seismic moment release in some subduction zones. The inferred source zone of the 1700 AD Mw~9 Cascadia earthquake contains five very large basin-centered gravity lows, the largest of which is 350 km long off the mouth of the Columbia River. These lows, corresponding to the Eel, Coos Bay, Newport-Willapa, and Olympic basins, lie within the locked and transition zones inferred from geodetic data and may indicate potential high slip regions at depth. The steep gravity gradient marking the inboard edge of the basins and presumably the downdip limit to large coseismic slip lies beneath Grays Harbor and the westernmost Olympic Peninsula in Washington and just offshore Oregon, between the modeled 350^{o}C and 450^{o}C isotherms on the megathrust. Transverse gravity highs between the basins suggest the margin is seismically segmented and may produce a variety of large earthquakes.

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