with 4.5-Hz vertical geophones. Shear velocities, vertically averaged to 30-m depths (V30), provided NEHRP soil classifications of ground shaking potential. We also performed P-wave refraction analyses at several points along the transect. Arrays in a highway cut on the gneissic bedrock of the San Gabriel Mts. yielded V30 between 520 and 640 m/s, NEHRP hazard class C. Measurements approach NEHRP-B (>760 m/s) only at the locations of the coarsest surficial alluvium in Azusa, below the mouth of San Gabriel Canyon, and near Santa Fe Dam. The maximum V30 along the transect was 730 m/s. Our results suggest much of the line north of Whittier Narrows is NEHRP class C (350-760 m/s), or on the C/D boundary. We find NEHRP-D values for V30 (150-350 m/s) from Whittier Narrows south to Seal Beach. The lowest velocities from the transect, 230 m/s, are still well above the NEHRP-E range. The lowest velocities occur near the south end of the line at Alamitos Bay. At Seal Beach, in the littoral sands, velocities rise slightly toward the NEHRP-C/D boundary. We interpret a lesser shaking hazard in the northern San Gabriel Valley and at Alamitos Bay than do assessments based on existing geologic maps. In San Gabriel Mts. bedrock on the other hand, rated NEHRP-B/C on maps, we interpret a somewhat elevated hazard, finding a NEHRP-C velocity of 640 m/s at most. Variations in V30 we measured may well be explained by the presence of a steep hydraulic gradient and a large average clast size near the San Gabriel Mts., with the gradient decreasing and the sediments fining downstream to Alamitos Bay. Corroborating measurements near Alamitos Bay, Long Beach, and Azusa, at locations removed from the active river channel, proved to match results from the transect.

URL: http://www.seismo.unr.edu/hazsurv

S42H-06 1715h

Nonlinear Dynamic Rupture Inversion of the 2000 Western Tottori, Japan, Earthquake

Kim B Olsen[1] (805 893 7394; kbolsen@crustal.ucsb.edu)

Sophie Peyrat (805 893 2820; peyrat@crustal.ucsb.edu)

[1]Institute for Crustal Studies, University of California at Santa Barbara, Santa Barbara, CA 93106-1100, United States

Such inversion has traditionally been carried out kinematically, which has some important limitations, in particular unphysical constraints on the rupture velocity and the choice of source-time function. A more physically correct inversion would therefore take into account the dynamics of the rupture, i.e., the stress, and friction parameters. While the radiated waves are highly sensitive to the distribution of stress and friction parameters on the fault, an essential requirement for the inversion to work, such inversion is highly complicated due to the strong nonlinearity of the dynamic problem. We have developed a fully systematic, nonlinear inversion method to estimate dynamic rupture parameters using a Neighbourhood algorithm and a finite-difference technique for the forward modeling. The method provides an objective means of routinely estimating dynamic rupture parameters for large earthquakes. We test the method by estimating the initial stress within 32 regions on the causative fault for the 2000 M6.6 Western Tottori, Japan, earthquake. The synthetics for the dynamic models with the smallest misfit provide a good fit to 0.5 Hz strong motion data recorded at 12 near-field stations. The dynamic models with the smallest misfit agree with the slip distributions from conventional kinematic analyses in the location of the largest asperity. In the surrounding areas on the fault, where kinematic inversions generally produce only one, final model, our method provides an ensemble of nearly equally acceptable rupture models.

S42H-07 1730h

Rupture Process Inversion Using 3-D Green's Functions: The 1995 Kobe Earthquake Revisited

Kazuki Koketsu[1] (+81-3-5841-5782; koketsu@eri.u-tokyo.ac.jp)

Taichi Ohno[2] (ohno@feg.co.jp)

Yasushi Ikegami[3] (y-ikegami@crc.co.jp)

[1]Earthquake Research Institute, University of Tokyo, 1-1-1 Yayoi, Bunkyo-ku, Tokyo 113-0032, Japan

[2]Faculty of Science, Ibaraki Univ., 2-1-1 Bunkyo, Mito 310-8512, Japan

[3]CRC Solutions Corp., 2-7-5 Minamisuna, Koto-ku, Tokyo 136-8581, Japan

In order to reliably simulate and predict strong ground motions, we need accurate models of the earthquake source and rupture process. The models are usually determined by inversion of strong motion, teleseismic or geodetic data, and the choice of Green's functions (GFs) greatly influences the inversion results (Graves and Wald; Wald and Graves, 2001). In particular, this problem should be critical for situations such as the 1995 Kobe earthquake where strong velocity variations are known to exist, but all the previous studies (e.g., Yoshida et al., 1996) used only 1-D (horizontally layered or halfspace) GFs. The GFs in this study are calculated for strong motion and geodetic data from the 1995 Kobe earthquake using a 3-D crustal structure with surface topography (Afnimar et al., 2002) and the voxel FEM code (Koketsu et al., 2003). The comparison of the 3-D GFs to the 1-D ones used in Yoshida et al. (1996) shows that the strong motion GFs are greatly deformed by the 3-D structure. The Green's seismograms at stations in the Osaka basin have surface wave codas with large amplitudes and long duration, and the basin sediments delayed the arrival of the S wave train. However, the geodetic GFs are not changed so much by the crustal structure, though some amplification can be found in horizontal displacements at the basin stations. The results of inversions reflect this difference in sensitivity. The slip distribution recovered by a strong motion inversion with the 3-D GFs is significantly different from the result of Yoshida et al. (1996). The most distinct feature in the 3-D strong motion result is that the asperity under the downtown of Kobe is more intensified than the asperity close to the rupture initiation. The slips under the Awaji island are now concentrated in a shallow part along the Nojima fault as in the other studies. On the other hand, the 3-D geodetic result is not so different from the counterpart in Yoshida et al. (1996), except that the slips in the asperities become a little larger. We will also compare our 3-D results with those by inversion with a hybrid set of 1-D rock and soil GFs (Sekiguchi et al., 1996; Wald, 1996).

S42H-08 1745h

How do near-source ground motions change when ruptures go super-shear?

Brad Aagaard[1] (baagaard@usgs.gov)

Thomas Heaton[2] (heatont@caltech.edu)

[1]U.S. Geological Survey, 525 South Wilson Ave, Pasadena, CA 91106, United States

[2]California Institute of Technology, 104-44 Caltech, Pasadena, CA 91125, United States

We simulate long-period near-source ground motions from kinematic ruptures of Mw 7.4 events on a strike-slip fault with different rupture speeds, including ruptures that propagate below the shear-wave speed (subsonic), between the shear-wave speed and the dilatational-wave speed (intersonic), or above the dilatational-wave speed (supersonic). The strong shear-wave directivity present in scenarios with subshear rupture speeds disappears in the scenarios with ruptures propagating faster than the shear-wave speed. Furthermore, the maximum horizontal displacement and velocities rotate from generally fault-perpendicular orientations at subshear rupture speeds to generally fault-parallel orientations at supersonic rupture speeds. For rupture speeds just above the shear-wave speed, the orientations are spatially heterogeneous as a result of the random nature of the slip assumed in the model. The polarization of the horizontal ground motion time histories provides a much more robust feature than maximum amplitude orientation with which to gauge the rupture speed; subshear ruptures are associated with significant fault-perpendicular motion *before* fault-parallel motion and super-shear ruptures are associated with fault-perpendicular motion *after* significant fault-parallel motion. Based on these simulation results, we examined the near-source recordings from the 1979 Imperial Valley and 2002 Denali fault earthquakes, for which there is some evidence for super-shear rupture. In the Imperial Valley earthquake, the long-period ground motions contain much more energy in the fault-perpendicular direction than in the fault-parallel direction, suggesting predominantly subshear rupture. The polarity of the velocity waveforms are also consistent with subshear rupture. This is consistent with previous studies that found predominantly subshear rupture but leaves open the question of super-shear rupture over a limited area. On the other hand, in the 2002 Denali fault earthquake, the recording closest to the fault (pump station 10) exhibits characteristics found in the simulations with rupture propagation slightly above the shear-wave speed, including orientation of the peak velocity away from the fault-perpendicular direction and nearly simultaneous arrival of large-amplitude motion in the fault-perpendicular and fault-parallel directions. Thus, these simulations and recordings provide additional support for the existence of super-shear ruptures in earthquakes but illustrate the difficulty in obtaining definitive evidence without an extremely dense seismic network along the surface trace of the fault.

S42I MCC: 3011 Thursday 1600h

New Views of Seismic Hazard in Cascadia II *(joint with G, T, V)*

Presiding: **T M Brocher,** U.S. Geological Survey**; A J Calvert,** Simon Fraser University

S42I-01 1600h

Evidence for a Tear in the Juan de Fuca Plate in the Vicinity of the 2001 Nisqually Earthquake

Patricia A McCrory[1] ((650) 329-5677; pmccrory@usgs.gov)

Fred F Pollitz[1]

J Luke Blair[1]

[1]US Geological Survey, 345 Middlefield Road, Menlo Park, CA 94025, United States

Deep earthquakes within the Juan de Fuca (JdF) plate beneath western Washington define a linear trend that may mark a tear within the subducting plate. This earthquake trend is oriented ENE, in the direction of plate convergence. Earthquakes within the zone reach depths approaching 100 km—20 km deeper than seen elsewhere in the JdF plate. The earthquakes bound the south flank of an arch in the slab and mark an abrupt change in seismicity rate, with many earthquakes to the north and few to the south. All the large historic earthquakes in the Puget Lowland—including the 2001 (M6.8) Nisqually earthquake—have occurred along this linear trend. We interpret the earthquake zone to result primarily from flexural stresses associated with unbending the arch. The high background seismicity and large earthquakes observed along this zone may also denote localized stress concentrations between contrasting strain segments in the slab. The zone marks an abrupt change in slab dip, from a very shallow dip on the north side (~8°) to a less shallow dip (~15°) on the south side. We hypothesize that the flatter slab to the north resists subduction, promoting strain segmentation between the two regions. Furthermore, an accommodation structure—such as a tear zone—may exist at the segment boundary. We speculate that such a discontinuity would concentrate stress locally, and thus expect future earthquakes to occur in the same vicinity. Tomographic data depict an abrupt 10-km step in *p*-wave velocity isocontours (south side down) in the vicinity of the earthquake trend. Geodetic data depict a perturbation in rate of surface elevation change along the trend, with slower subsidence to the north and faster subsidence to the south. These regional elevation changes are consistent with the slab geometry. The contrast in slab pull forces expected from the change in dip should lead to left-lateral, strike-slip focal mechanisms along the segment boundary, allowing a test for whether a through-going tear has yet formed or slips aseismically.

S42I-02 1615h INVITED

Mapping Great Earthquake Rupture Area

Mladen R. Nedimović[1] (845-365-8561; mladen@ldeo.columbia.edu)

Roy D. Hyndman[2] (rhyndman@nrcan.gc.ca)

Kumar Ramachandran[2] (kumaran@eos.ubc.ca)

George D. Spence[3] (gspence@uvic.ca)

Thomas M. Brocher[4] (brocher@usgs.gov)

[1]LDEO, 61 Route 9W, P. O. Box 1000, Palisades, NY 10964, USA, Palisades, NY 10964-8000, United States

[2]PGC, 9860 W. Saanich Rd, Sidney, BC V8L 4B2, Canada

[3]UVic, P.O. Box 3055, Victoria, BC V8W 3P6

[4]USGS, 345 Middlefield Road, Menlopark, CA 94025, United States

At the northern Cascadia margin, the Juan de Fuca plate is underthrusting North America at about 45 mm/yr. Thermal and deformation studies indicate that, off southern Vancouver Island, the interplate interface is presently fully locked for a distance of some 60 km downdip from the deformation front. Great thrust earthquakes on this section of the interface, with magnitudes of up to 9, have been estimated to occur at an average interval of about 590 yr. Further downdip there is a transition zone from fully locked behavior to aseismic sliding, with the deep aseismic zone exhibiting slow slip thrust events. We show that at the northern Cascadia margin there is a change in the reflection character on seismic images from a thin reflection

S

package (< 2 km thick) where the subduction thrust is inferred to be seismogenic, to a broad reflection band (> 4 km thick) at greater depth where there is aseismic slip. This change in reflection character provides us with a new technique for detailed mapping of the maximum landward extent of great earthquake rupture. The landward edge of the locked zone on the northern Cascadia subduction thrust inferred by reflection imaging appears to lie some 25-30 km closer to the land than estimated from thermal and dislocation modeling, possibly suggesting a somewhat greater megathrust seismic hazard at inland cities. Deep seismic reflection images from Alaska, Chile and SW Japan show a similar broad reflection band above the subduction thrust in the region of stable sliding and thin thrust reflections further seaward, perhaps suggesting that reflection imaging may be a globally important predictive tool for determining the maximum expected rupture area in megathrust earthquakes. The eastern Alaska-Aleutian subduction zone is an ideal setting for testing this hypothesis. In this region, recent megathrust earthquake rupture areas are defined by aftershocks, inversion of geodetic data points to strong lateral variations in coupling, and wide shelf area allows for a relatively inexpensive and full marine mapping of the locked and transition zones, and partial mapping of the slow slip zone.

S42I-03 1630h

Deep Seismic Reflection Evidence for Duplex Formation Within the Northern Cascadia Inter-Plate Boundary Zone

Andrew J. Calvert (604-291-5511; acalvert@sfu.ca)

Simon Fraser University, Department of Earth Sciences, 8888 University Drive, Burnaby, BC V5A 1S6, Canada

Deep seismic reflection surveys shot over the last twenty years show that two distinct regionally extensive seismic reflectors, denoted E and F, exist beneath southern Vancouver Island and the Strait of Juan de Fuca. The E reflection package is a prominent 5-15 km thick zone of high amplitude reflectors that dips between 4° and 15° to the northeast, and increases in depth from approximately 20 km to 40 km across Vancouver Island. The F reflection is less than 2 km thick, and is intermittently observed beneath Vancouver Island approximately 1.8 s after the deepest E reflection. But near the west coast of Vancouver Island, the F reflector shallows and approaches the base of the overlying E reflectors. In both the deep ocean basin and beneath the continental shelf, the Moho of the incoming oceanic plate is observed 1.8-2.2 s after the top of the igneous crust, implying that the F reflector cannot originate at the oceanic Moho. The F reflector is best interpreted as the top of the subducting Juan de Fuca plate for four reasons: first, beneath central Vancouver Island receiver function analyses place the oceanic Moho 6 km deeper then the F reflector; second, near the west coast of Vancouver Island, relocated inslab seismicity does not occur above the F reflector; third, large lateral velocity variations immediately above the F reflector imply that the relatively homogeneous oceanic crust must lie below it; fourth, the F reflector can be correlated with the top of the subducting plate beneath the continental shelf. The F reflector also approaches the deepest of the E reflectors east of Vancouver Island where their dip increases to 15°. The top of the subducting Juan de Fuca plate thus exhibits a slightly tilted ramp-flat-ramp geometry, and defines the floor thrust of a >100 km-wide duplex structure whose roof thrust is formed by the deeper E reflectors. Deep seismicity occurs primarily beneath the F reflector where the dip of the subducting plate suddenly increases, but a small number of earthquakes occur close to the E reflectors near the eastern edge of Vancouver Island. These earthquakes may be associated with imbrication above the subducting plate, and could imply that the E reflectors are an active roof thrust extending north from the Strait of Juan de Fuca to central Vancouver Island. In this region, the inter-plate boundary may be best viewed as a >6 km-thick zone of active deformation, involving two major thrusts above the subducting Juan de Fuca plate.

S42I-04 1645h

Inverse Modeling of Surface Deformation Data to Determine the Depth of Coupling at the Cascadia Subduction Zone

David Verdonck (dverdonck@eglab.org)

Eastern Geodynamics Lab, 60 Larchmont Road, Elmira, NY 14905

Understanding the extent of seismic coupling along the Cascadia subduction zone is important in assessing earthquake hazards in the Pacific Northwest of the United States and southwestern Canada. Recently developed models suggest that surface deformation can be the result of seismic coupling deeper on the subduction interface than previously accepted models indicate. Models also indicate that the depth of coupling varies along the strike of the subduction zone. I use a two-dimensional, non-negative, least squares technique to model vertical and horizontal deformation data simultaneously. The inversion is based on a standard dislocation model, where the subduction interface is divided into small fault segments. The amount of slip deficit on each segment is determined by the inversion. In this study, horizontal surface deformation rates, derived from GPS data, are combined with surface uplift rates determined from historic leveling surveys. Adjustments to the leveling data are also calculated during the inversion. The data from two parallel profiles are inverted separately generating two independent models. The northern model, running through the southern Puget Sound region, indicates slip deficit is accumulating in two separate locations. A shallow locked region extends eastward from the toe of the wedge to beneath the coastline and a second distinct region is located down dip beneath the Puget Sound. The southern model, at the latitude of the Columbia River, indicates slip-deficit is only accumulating in a single shallow region.

S42I-05 1700h

Holocene History of Great Earthquakes in the Cascadia Subduction Zone Based on the Turbidite Event Stratigraphy

C. Hans Nelson[1] (34 958 240508; odp@ugr.es)

Chris Goldfinger[2] (gold@coas.oregonstate.edu)

Joel E. Johnson[3] (jjohnson@coas.oregonstate.edu)

Julia Gutierrez-Pastor[4] (jgpastor@ugr.es)

[1]Instituto Andaluz de Ciencias de la Tierra, CSIC, Universidad de Granada, Campus de Fuente Nueva s/n, Granada 18002, Spain

[2]COAS, Oregon State University, Ocean Administration Building, Corvallis, OR 97331

[3]COAS, Oregon State University, Ocean Administration Building, Corvallis, OR 97331

[4]Instituto Andaluz de Ciencias de la Tierra, CSIC, Universidad de Granada, Campus de Fuente Nueva s/n, Granada 18002, Spain

Submarine channels along the Cascadia convergent margin have recorded a Holocene history of turbidity currents, in the form of turbidites, most likely triggered by great earthquakes. Turbidite systems from four regional sites, the Rogue, Astoria, Juan de Fuca, and Cascadia Channels, contain 13 correlative post Mazama turbidites (T1-13) based on the first occurrence of Mazama Ash (MA) at 7344 +/- 130 cal. yr BP below T 13 and another T18 datum of 9744 +/- 70 cal. yr BP. Based on these datums and tests of synchronicity, turbidity currents appear to have been triggered synchronously by great earthquakes along 660 km of the Cascadia Subduction Zone on average every 587 yr from T1-13 and every 480 yr from T13-18. Based on semi-independent methods of AMS radiocarbon ages and hemipelagic sediment thickness plus sedimentation rate beneath each turbidite, the average recurrence intervals of great earthquakes in Cascadia Basin are 530 years and 524 years respectively for the past 4000 yr, compared to coastal paleoseismic events of 533 yr at Willapa Bay , WA and 529 yr at the Sixes River,OR. The most complete and reliable hemipelagic record of recurrence intervals and ages for the 18 great earthquakes during the Holocene (past 9,744 years) has been determined at the Cascadia Channel site. Hemipelagic thicknesses and time intervals based on sedimentation rates have been calculated for every turbidite event from 8 replicate cores. When there has been some erosion of the hemipelagic sediment interval in one core, it is evident because the thicknesses in the other cores at the site are greater and usually equal. In general, there is a trend towards thicker hemipelagic sediment and longer recurrence times (hemipelagic average interval = 324 yr and radiocarbon average interval = 400 yr) toward the later Holocene. The maximum recurrence time, based on radiocarbon ages (1477 yr), occurs between T10 and T11 and coincides with the maximum interval (922 yr) and thickness of hemipelagic sediment. From T1 to T9 events, the variance of recurrence times is least, based on hemipelagic sediment thickness in Cascadia Channel, while radiocarbon results indicate a high variability for the same interval, consistently showing the intervals prior to T7 and T4 as long intervals > 1000 years. The T1 to T9 events for the past 4620 cal yr BP have a minimum recurrence time of 409 yr and maximum of 644 yr in Cascadia Channel using hemipelagic thickness, but a range of 321 to 1077 years (+ 120) with radiocarbon alone. The differences in the two methods appear to be the result of uniform hemipelagic thickness data following T8 and T5, whereas multiple radiocarbon ages at two sites suggest very long, > 1000 year intervals. These results also point out the need for further refinement of both methods, since the events can be correlated well without age information. When complete, the corrected age table should reveal an earthquake history 10,000 years in length. This record can then be compared to the land record to identify differences that may reveal upper-plate, slab, or other events that did not trigger turbidity currents.

S42I-06 1715h

Interpretation of the Seattle Uplift, Washington, as a Passive Roof Duplex

Thomas M Brocher[1] (650-329-4737; brocher@usgs.gov)

Richard J Blakely[1] (650-329-5316; blakely@usgs.gov)

Ray E Wells[1] (650-329-4933; rwells@usgs.gov)

[1]U.S. Geological Survey, 345 Middlefield Road, Menlo Park, CA 94025, United States

Seismic reflection, tomography, aeromagnetic, geologic mapping, paleoseismic excavations, seismicity, and borehole data provide evidence that the Seattle uplift is a passive-roof duplex. A roof duplex, also known as a triangle wedge, is defined as wedge bounded at top and bottom by thrust faults with opposite senses of vergence; in a passive-roof duplex the upper thrust moves only when the lower thrust slips. The Seattle fault is a south-dipping reverse fault that we propose is the leading edge of a 40-km-wide fold-and-thrust belt. The recently discovered, north-dipping reverse Tacoma fault is interpreted as a back thrust along the trailing edge of the belt, thus making the belt doubly vergent. Divergent, e.g. north and south dipping, seismic reflections from Tertiary sedimentary strata in both the Seattle and Tacoma basins, define triangle wedges that uplift and tilt sedimentary rocks in the hanging walls. Master floor thrusts defining the base of the wedges in the Seattle and Tacoma fault zones are interpreted as flattening updip into bedding plane thrusts, and are thus blind structures. Along the eastern end of the Seattle uplift, between the Seattle and Tacoma faults, the seismic data image several shallow, short-wavelength folds that are more compatible with shallow thrusting than with a deeper reverse fault. From reflector truncations, at least 10 north-dipping thrust faults are inferred in the cores of these shallow folds. These faults, often interpreted as bedding plane thrusts, appear to root into shallow roof thrusts overlying the triangle wedges. Only a few of these shallow thrusts appear to have been activated during recent slip events on the underlying master floor thrusts of the Seattle fault, and all are currently aseismic, but they nevertheless pose a seismic hazard due to their ability to deform the surface over a broad area. These thrusts actively fold and uplift the seafloor at Alki, Restoration, Three Tree, and Robinson Points. These folds are evident in aeromagnetic data, where short-wavelength aeromagnetic anomalies in Puget Sound are compatible with the shallow folding of Miocene conglomerate rich in Crescent Formation clasts. The doubly vergent thrust fault system beneath the Seattle uplift provides an explanation for the widespread vertical offset of coastal marsh deposits at about 1100 years ago in central and southern Puget Sound.

S42I-07 1730h

Morphology of Submarine Landslides in Puget Sound

Shane B Smith[1] (775-784-6723; sbsmith@unr.nevada.edu)

Robert Karlin[1] (775-784-1770; karlin@mines.unr.edu)

[1]Department of Geological Sciences, University of Nevada, Reno, Reno, NV 89557, United States

Submarine landslides, probably triggered by large earthquakes, disturb Holocene sediments in Puget Sound. High-resolution seismic reflection profiling and sidescan swath surveys were conducted over large submarine landslides and debris flows. These large slides are in close proximity to the South Whidbey Island fault zone at Possession Point, Mukilteo, and Edgewater; near the Seattle fault off Alki Point; and near the Tacoma fault at Maury Island. The boundaries of the slides were mapped using sidescan swath surveys. Preliminary slide morphologies were determined from the seismic cross-sections. Three large slide complexes with multiple block slides and debris flows are found off Possession Point; the largest of which is 1.5 km x 1.0 km with a maximum thickness of approximately 50 meters. Large sand flows with maximum thicknesses of 30 to 40 meters occur off Mukilteo and Edgewater. An approximately 3.3 km x 2.2 km, 30 meter thick flow off Alki Point was deposited on top of folded sediments within the deformation zone of the Seattle Fault zone. Three large block slides are present off Maury Island; the largest of which is 2.75 km x 1.0 km, with a maximum thickness of approximately 100 meters. The volumes of these landslides are more than an order of magnitude larger than subaerial landslides in the region. Tsunamis generated by landsliding potentially constitute a major seismic hazard in coastal areas of the Puget Lowland.