(deep angle). The steeper angle models are aimed at understanding ground motion in the 1952 Kern County earthquake as constrained by precarious rock surveys. Numerical simulations show that, due to the geometrical asymmetry of the thrust fault, the ground motions of particle velocities and particle accelerations on the hanging wall are larger than on the foot wall as the dynamic rupture reaches the surface. With a sediment layer involved in the foot wall, the ground motion on the foot wall is governed by a surface wave trapped in the sediment layer, and shows a small increase compared with that without sediment layer. For blind thrust faulting, we find that the particle velocities and accelerations on the foot wall are larger than that on the hanging wall. For three dimensional strike-slip faulting, the primary results show that the slip motions along the fault plane are strongly inhomogeneous and amplified particle occurs as the rupture reaches the free surface. The rupture process is more complex near the free surface. Fault roughness (amplitude and wavelength) and the particle interaction force law involved in the simulation governs many of the characteristics of the failure processes, such as the amplitude of the particle velocity, the size of slip and normal displacements, and the slip time.

S22C MC: 306 Tuesday 1330h

Seismic and Hydro-Acoustic Constraints on Ocean Crustal Dynamics, Volcanism, and Hydrothermal Fluid Circulation in the Northeastern Pacific II

Presiding: **R Dziak,** Oregon State University**; H P Johnson,** University of Washington

S22C-01 1330h INVITED

Earthquakes and Marine Hydrothermal Systems: the Unresolved Connection

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Continental earthquakes have long been known to influence terrestrial groundwater systems, including variations in water well levels, stream flow modulation and the appearance/disappearance of artesian springs after even modest earthquakes. The impact of earthquakes on marine hydrothermal systems is less well-understood, however. New data indicates that marine earthquakes can have a strong influence of the circulation of hydrothermal fluid in upper oceanic crust, and can act over considerable distances with surprisingly long delay times. Monitoring of a high temperature vent field on the East Pacific Rise showed that a microseismic swarm 1 km directly below a vent field caused a +7° C increase in fluid temperature (Sohn et al, 1998; Fornari et al, 1998), although it took 4 days for the disturbance to reach the seafloor. At a different ridge, a June, 1999 off-axis earthquake swarm on the Endeavour Segment of the Juan de Fuca Ridge caused low temperature diffuse vents over a large area to increase in flow by a factor of 10, with a 3.5 day delay after the initiation of the swarm. This earthquake swarm also caused changes in both crustal fluid flow and temperature at Axial Seamount, 220 km to the south. Similarly, a 1997 off-axis earthquake swarm on Endeavour caused dramatic increases in temperature of axial valley diffuse vents, with a non-intuitive 30-day delay for several of the HT systems. Although we do not understand the processes responsible for the interaction between earthquakes and marine HT systems, the new data argues that it is likely to be a triggering phenomena, with reaction delay times that may be site-specific, and a radius of influence too large to be a simple direct transfer of the static stress change caused by the earthquakes. The concept that both earthquakes and HT fluid circulation are extremely sensitive to the stress within the larger oceanic plate is likely to be a fruitful approach.

S22C-02 1345h INVITED

Remotely Triggered Seismicity in Volcanic and Hydrothermal Environments - Which Processes?

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The abrupt increase in seismicity rates at sites throughout much of the western United States immediately following the 1992 M=7.4 Landers earthquake provided compelling evidence that large regional earthquakes can trigger local earthquake activity at sites many source dimensions removed from the mainshock epicenter. Remotely triggered seismicity has since been documented for a number of other large earthquakes including the 1999 M=7.1 Hector Mine earthquake. Well-documented instances of remotely triggered seismicity are largely confined to transtensional or extensional tectonic regimes with a large fraction of these closely associated with hydrothermal and/or young volcanic systems. In the case of Long Valley caldera in eastern California, which responded to both the Landers and Hector Mines earthquakes, the triggered seismicity appears to be secondary to a larger, aseismic deformation transient. Because this is the only remotely triggered site with continuous deformation monitoring, however, it remains unclear whether a deformation transient is fundamental component of the remote triggering process. Fluids, either aqueous or magmatic, play a central role in most models for the triggering process in hydrothermal and/or young magmatic systems. These models span a range of intriguing (and sometimes counter-intuitive) physical processes including pressure increases associated with advective overpressure and rectified diffusion in bubbly fluids, hydraulic surges resulting from rupturing of compartments of super-hydrostatic fluids in the brittle-plastic transition zone, hydraulic pumping of near-surface pore fluids by surface waves, disruption of fine sediment accumulations (dams) in confined aquifers, local stress changes in the brittle crust associated with relaxation or mobilization of a partially crystallized magma body. All appeal to the dynamic stresses from the mainshock triggering a non-linear response in a crustal volume that is in some sense in a near-critical state (arbitrarily close to the Coulomb failure threshold in the case of the brittle crust, for example). Implicit with these models is a recharge time for conditions in the local crust to return to a critical state following an episode of remotely triggered activity. Which of these models (or combination thereof) will stand up to future instances of remotely triggered seismicity remains to be seen.

S22C-03 1400h

Long and Short-term Hydro-Tectonic Events in the South-Iceland Seismic Zone, Associated with Two Large Earthquakes in June 2000

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Two large earthquakes (M 6.6), which struck the S-Iceland Seismic Zone on June 17 and June 21 2000, caused considerable pressure changes in geothermal as well as groundwater reservoirs. These reservoirs range in depth from surface down to a minimum of 2 km. An effort has been made to collect and analyze the hydraulic changes caused by the quakes. Four primary sets of hydraulic events are identified from these data. Firstly, pre-quake fluctuations on a time scale of 23 hours to 6 months. Secondly, immediate pressure changes, perfectly correlated to the focal mechanism of the two quakes. Thirdly, a recovery period of several weeks to months, which in some cases may correlate with a new stress field and, consequently, a change in the shallow crust permeability. These permanent permeability changes have enhanced productivity of two geothermal reservoirs by as much as 1/3. Fourthly, we have identified after-quake local hydraulic perturbations, which may relate to a sudden change in fracture porosity or a change of reservoir status from confined to unconfined. Other events are also of interest, like an ice dammed flooding of a major river in January 2001, near the fault zone of the June 21 quake. This hydraulic load caused lively and synchronized pressure fluctuations in two wells, 15-20 km away. The data collected by the after-quake monitoring program strongly suggest that hydraulic pressure is a valuable parameter in understanding tectonic processes within the S-Iceland seismic zone.

URL: http://www.os.is/ros/eftirlit/

S22C-04 1415h INVITED

Tidal Correlations of Seismicity at Axial Volcano

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The search for tidal effects on seafloor microearthquakes has been hindered by lack of continuous long-term data sets. Further complicating the issue is the need to distinguish between the influence of Earth and ocean tides. In the summer of 1994 a small ocean-bottom seismograph and tiltmeter array located 402 microearthquakes, and recorded Earth tides over a period of 2 months on the summit caldera of Axial Volcano on the Juan de Fuca Ridge. Ocean tides were simultaneously recorded by a NOAA-PMEL ocean bottom pressure recorder, and in this location Earth tides appear to lag ocean tides by approximately 2 hours. The deployment occurred directly following a brief burst of seismic activity on Axial Volcano, observed using SOSUS arrays, that may have been volcanic in nature.

Microearthquakes show a strong correlation with ocean tidal lows, suggesting that faulting is occurring preferentially when ocean loading is at a minimum. Harmonic tremor, interpreted as the movement of super-heated fluid in cracks, is observed on all instruments, and is also seen to have a tidal periodicity. The mid-ocean ridge location, with fractured, weak material that is permeated with water creates a system very susceptible to tidal influences. The variations in water pressure due to ocean tides seem the likely cause. At the time of this experiment, it was the longest time-period that OBSs had ever recorded continuously on the seafloor, and the 402 events located were the most observed in one deployment. It is therefore likely that similar tidal influences exist elsewhere on the seafloor and mid-ocean ridge system. It is also possible that life on the seafloor will operate in cycles that are tidally dependent, as this local seismicity could control the influx of nutrients into the system. There is also some indication that similar to land volcanoes, volcanism on the seafloor may be influenced by Earth tides, though the interaction with ocean tide variations in the tectonic stresses is likely to be complex.

S22C-05 1430h

Detection and Response to a Seafloor Spreading Episode on the Central Gorda Ridge, April 2001

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On April 3, 2001, volcanic seismicity was detected from the Jackson Segment of the Gorda Ridge (near 42^{o} 9'N; 127^{o} 3'W) by the NOAA/PMEL T-phase Real-Time Monitoring System, which monitors data collected from the U. S. Navy SOSUS in the North Pacific. The character of the hydroacoustic signals was nearly identical to that observed from three earlier events that occurred along northeast Pacific spreading centers and were later confirmed to have produced hydrothermal megaplumes and seafloor eruptions. A field response effort was mounted on R/V New Horizon and arrived on the site within 8 days of the initiation of the activity. Unlike earlier response efforts, and despite the fact that this event was well located and field CTD casts were of adequate density and coverage, no evidence for a hydrothermal plume was found. A particle signal that was observed arose from a bottom nepheloid layer of resuspended sediments of a non-hydrothermal origin. Also, pH and 3He profiles were similar to background levels, indicating no input of volcanic CO2 or helium into the water column. In addition, two short camera tows were collected on the axis of the segment near the center of the earthquake epicenters, but no evidence of new lavas or seafloor venting was found. Detailed post-event analyses of the hydroacoustic data indicate that most of the characteristics of earlier plume-producing, extrusive events were present in this episode, including a vigorous earthquake swarm (over 50 events per hour during the first day), lasting nearly ten days, with no initial main shock and a continuous background level of volcanic tremor. Detailed analyses of the t-wave rise times are also consistent with very shallow source locations. The primary difference in this event is that no significant horizontal migration of epicenters, characteristic of lateral dike injection, was recorded. The acoustic results indicate a vertical dike injection that although shallow, apparently did not penetrate the seafloor. The surprising lack of a water-column signal from such a vigorous event suggests that this area had no pre-existing hydrothermal system and the intruding dike failed to reach the seafloor.

S22C-06 1445h

The June 1999 Endeavour Earthquake Sequence: Evidence for a Non-Tectonic Origin

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In June 1999, a large sequence of earthquakes occurred on the Endeavour Segment of the Juan de Fuca Ridge (JdFR). This sequence previously has been suggested to have a tectonic origin and has received much attention due to its association with changes in both the local and regional hydrothermal systems. Analysis of the SOSUS earthquake data and a comparison with data from autonomous underwater hydrophone (AUH) arrays in the equatorial Pacific and northern Atlantic indicate many of the spatial and temporal properties of the Endeavour sequence are inconsistent with aftershock activity. Four important lines of evidence support this. 1) The sequence is not described well by a modified Omori's law (MOL) model of aftershock decay. 2) The sequence lacks a clear mainshock event, with at least four earthquakes of size equal to, or slightly larger than, the initial shock occurring during the first two days. 3) Given the moderate-size of the initial shock (3.4-4.5 M reported by various agencies), the number of events within the sequences is anomalously large for an aftershock sequence. Single-link cluster analysis identified approximately 500 events as belonging to the sequence; however, similar size normal-faulting mainshocks (events initiating MOL-sequences) typically produce more than one order of magnitude fewer aftershocks of sufficient size to be detected by hydroacoustic networks. 4) The along-axis distribution of events, which is constrained well, is roughly three times larger than that predicted from hydroacoustic observations elsewhere. These characteristics are inconsistent with an aftershock sequence and suggest the observed seismic activity and hydrothermal vent anomalies may reflect the response of the lithosphere to magmatic activity, rather than its response solely to stress changes associated with a large tectonic earthquake.

URL: http://www.ldeo.columbia.edu/∼del/tphase.html

S22D MC: 307 Tuesday 1330h

Structure and Evolution of Western North America: SHIPS to Shore *(joint with G, T)*

Presiding: **T M Brocher,** U.S. Geological Survey**; C M Snelson,** Department of Geological Sciences

S22D-01 1330h

The Canby-Molalla Fault, Oregon

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A 60-km-long, north-northwest-striking aeromagnetic lineament near the towns of Canby and Molalla, Oregon, is on strike at its northern end with faults mapped in Columbia River Basalt (CRB) about 25 km south of downtown Portland. Canby and Molalla are approximately 33 km south and 48 km south-southeast of downtown Portland, respectively. We have measured four detailed ground-magnetic profiles, collected 1000 additional ground-magnetic stations, conducted a seismic reflection profile, and compiled logs from more than 70 water wells to further define the cause of the aeromagnetic lineament.

A geologic cross-section, based on a detailed ground-magnetic profile east of Canby, suggests that the aeromagnetic lineament is caused by at least 150 m of near vertical, down-to-the-west offset of CRB, the only significant magnetic lithology near the surface in this area.. This model is consistent with water wells from the area: Two wells immediately east of the fault penetrated CRB at 50 m depth, whereas CRB was not encountered in any wells (150 m maximum depth) west of the fault. Ground magnetic data from elsewhere along the lineament support this interpretation. In addition to vertical displacement, lateral offset of a small magnetic anomaly at the northern end of the aeromagnetic lineament indicates approximately 4 km of right-lateral displacement. A high-resolution seismic-reflection profile was acquired across the aeromagnetic anomaly east of Canby. The profile, 600 m in length, is currently being processed and analyzed, and a brute stack of these data will be available for discussion at the presentation of this paper.

Given the linearity of the aeromagnetic anomaly, its association at its northern end with mapped faults in CRB, and the abrupt offset demanded by ground-magnetic, seismic, and well data, we believe the aeromagnetic anomaly reflects a 60-km-long oblique strike-slip fault. The strike (N25°W) and position of the lineation are consistent with a synthetic fault within a wrench system under north-south compression, bounded on the north and south by the Portland Hills–Clackamas River and Gales Creek–Mt. Angel fault zones, respectively. A small, laterally restricted topographic berm lies within 100 m of our estimated location of the fault, suggesting recent deformation on the fault. Geologic investigations, including trench excavations, are planned to determine the minimum age of deformed sediments above the offset CRB.

S22D-02 1345h

Crustal Structure of the Puget Lowland, Washington State From the Dry SHIPS '99 Seismic Refraction/Wide-Angle Reflection Profile

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The SHIPS (Seismic Hazards Investigations of Puget Sound) experiments are part of a continuing effort to define basin and fault geometry beneath the populated Puget Lowland. In September 1999, the USGS and a number of university collaborators collected the "Dry SHIPS" seismic profile across the Seattle basin of western Washington State. In March 2000, this group collected additional seismic data in the city of Seattle using the implosion of the Kingdome sports arena as a seismic source. The objectives of the Dry SHIPS study were to define the geometry of the Seattle basin in an E-W direction and to determine the structure of the eastern and western boundaries of the basin. In addition, we were testing the hypothesis that N-S trending faults lie beneath Puget Sound or the adjacent Lowland: one of these faults may form the eastern boundary of the Siletz terrane. The main objective of Kingdome SHIPS was to look at the Seattle fault and shallow strata beneath Seattle to estimate site response in Seattle. The Dry SHIPS data are characterized by travel time advances associated with the Siletz terrane to the west and the Cascades to the east and by delays of as much as 2 s caused by the Seattle basin.

P-wave 3-D tomographic results show that the basin is about 70 km wide and contains sedimentary strata with velocities increasing gradually from 1.8 - 4.5 km/s. The contact with underlying basement rocks is characterized by a rapid increase in velocity from 4.5 to 5.0 km/s. At its center the basin is 6 - 7 km deep along this profile. This result is consistent with results from a N-S trending reflection line collected in 1998 during the Wet SHIPS phase of the project that is tied to well control. The symmetry of the Seattle basin is consistent with thrust loading as the major contributor to the formation of the basin. The lower velocities within the upper part of the basement found east of the Puget Sound may be indicative of pre-Tertiary basement rocks of the Cascades. This change is probably an expression of the Coast Range Boundary fault, which has previously been recognized in gravity and magnetic data. Density modeling tied to the velocity model shows similar basin geometry. In addition, the density model shows that the Olympic accretionary wedge is indistinguishable from surrounding rocks below a depth of about 20 km. Preliminary S-wave 3-D tomographic results indicate the basin is more asymmetric compared to the P-wave result. The basin to the east of Puget Sound has a more gradual contact with the basement rocks compared to the west. The Vp/Vs ratio is about 1.8 west of the Puget Sound and about 2.0 east of the Sound. Finally, a low-fold stack produced from these data delineates structures within the middle and lower crust.

URL: http://geohazards.cr.usgs.gov/pacnw/ships/

S22D-03 1400h

Flexural Origin of the Puget Basins: Implications for the Seattle Fault and Puget Basin Tectonics

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At least five distinct basins of varying depth, including the Seattle basin, form a semi-circular ring around the eastern Olympic Mts. Although the Seattle basin has been postulated to result from a northward vergent thrust on the Seattle fault, other basins have a less clear relationship to faulting. A purely thrust origin for the Seattle basin requires uplift, which is not observed, south of the Seattle fault to isostatically balance the large mass deficiency of the Seattle basin. High-resolution P-wave velocity imaging of the Puget region using earthquakes, data from the recent SHIPS experiments, and data from earlier explosion experiments shows that the Puget basins are underlain by approximately 15 km of "tectonically" strong Crescent formation (part of the Coast Range Terrain - CRT). Low velocity core rocks of the eastern Olympics are emplaced beneath the CRT in a radial pattern that mirrors the pattern of the Puget basins, strongly suggesting that the basins are genetically related to the Olympic structure.

A model of basin formation that is consistent with gravity and seismic data, and that explains the observed radial pattern is elastic flexural down-warp in response to uplift and subsequent erosion of the CRT in the central Olympic Mts. The CRT is now erosionally removed from the Olympic core, exposing the underlying accretionary wedge complex. The available information on timing of the Olympic uplift generally agrees with the inferred timing of basin subsidence. Since the "lever arm" which forced the basins downward is removed by erosion from the eastern Olympics, basin subsidence has probably stopped, and isostatic rebound of the Seattle and other basins should play a role in current tectonics. Relative uplift of the Seattle basin, consistent with isostatic rebound, explains the north-side-up mechanism of the June 1997 M 4.9 earthquake near Bremerton, the north-side-up pattern of faults trenched on southern Bainbridge Island, and possibly the uplift of Restoration Point near the southern end of Bainbridge Island. Relocation of the 1997