S42E-0221 1330h POSTER

Stratigraphic imaging of sub-basalt sediments using waveform tomography of wide-angle seismic data

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The oil industry is interested in imaging the fine structures of sedimentary formations masked below basalt flows for commercial exploration of hydrocarbons. Seismic exploration of sediments hidden below high-velocity basalt cover is a difficult problem because near-vertical reflection data are contaminated with multiples, converted waves and scattering noise generated by interbeds, breccia and vesicles within the basalt. The noise becomes less prominent as the source-receiver offset increases, and the signals carrying subsurface information stand out at the wide-angle range. The tomography of first arrival traveltime data can provide little information about the underlying low-velocity sediments. Traveltime inversion of wide-angle seismic data including both first arrivals and identifiable wide-angle reflected phases has been an important tool in the delineation of the large-scale velocity structure of sub-basalt sediments, although it lacks the small-scale velocity details. Here we apply 2-D full-waveform inversion ("waveform tomography") to wide-angle seismic data with a view to extracting the small-scale stratigraphic features of sedimentary formations. Results from both synthetic data, generated for a realistic earth model, and field dataset from the basalt covered Saurashtra peninsula, India, will be presented. This approach has potential to delineate thin sedimentary layers hidden below thick basalt cover also, and may serve as a powerful tool to image sedimentary basins, where they are covered by high-velocity materials like basalts, salts, carbonates, etc. in various parts of the world.

S42E-0222 1330h POSTER

A Study of the Shallow Seismicity (1971-1999) in the Anchorage, Alaska, Region

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Previous earthquake studies in the Anchorage region (60 to 62N, 148 to 152W) have shown little to no correlation between shallow earthquakes (depths less than 30 km) and known large-scale faults. The Double Difference earthquake relocation technique is utilized in this study to identify seismogenic structures in more detail, thus contributing information needed for future seismic hazard assessment. These hypocenter relocations indicate a number of linear, seismogenic features, some of which appear to correlate with mapped faults. The nearest concentration of crustal seismicity to the city of Anchorage is located within Upper Cook Inlet. This seismicity seems to involve deformation along several smaller en echelon structures. These structures do not appear to be associated with mapped faults and anticlines but may correlate with longer wavelength features seen in filtered aeromagnetic data. The principal orientations of stress determined from the inversion of first motion data for these events show that the regional principal stress orientation is not aligned with the regional direction of plate convergence. This principal stress orientation, however, is not uncommon for the region when compared to borehole breakout and other focal mechanism studies. The stress results are also consistent with geodetic studies that suggest that the North American plate is not strongly coupled to the down going Pacific plate within the Upper Cook Inlet/western Kenai Peninsula region.

S42F MCC: 3009 Thursday 1340h

Strong Ground Motion Prediction I

Presiding: **R Graves,** URS Corporation**; P M Mai,** Institute of Geophysics, ETH Hoenggerberg

S42F-01 1340h

Seismic Shaking Maps of Osaka Sedimentary Basin, Southwest Japan (Preliminary Version)

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Active Fault Research Center, Geological Survey of Japan/AIST conducts a project of ground motion prediction in the Osaka sedimentary basin, southwest Japan, for hypothetical large earthquakes that would cause considerable damage in the future. Our ground motion prediction is characterized by a detailed 3D structure model of the Osaka sedimentary basin and rupture scenarios based on dynamic rupture simulations under constraints of geological data of active faults (Kase et al., in this meeting). A 3D Osaka basin structure model is constructed based on geological and geophysical data obtained by seismic reflection surveys, borings, and gravity measurements. The model area is 90 km in EW direction, 85 km in NS direction and down to 3 km depth. Medium constants are given in mesh data of 100 m and 50 m intervals in horizontal and vertical directions, respectively. Geometry of key sedimentary layers and basement floor, including overhang at reverse faults, are realistically expressed. Medium constants such as P- and S-wave velocities and density are given to each grid point based on empirical relations among P- and S-wave velocities, density, depositional age and depth. For active faults with enough paleoseismological information, we take the following two steps to construct rupture scenarios. First, we estimate heterogeneous slip distributions from surface displacement distributions of past earthquakes measured along an active fault. We assume that long-wavelength component of heterogeneity in rupture process is stable over geological (10e+6 yrs) time scale In the slip distribution model, slip varies along fault strike in a similar way to coseismic displacement. Along the downdip direction, it varies similar to those of source models for recent, well-analyzed earthquakes. The slip distribution thus estimated is converted into static stress change. Second, the static stress change is incorporated into dynamic rupture simulations as a variation of initial stress. Ground motion in the 3D Osaka basin structure model from the rupture scenarios is computed by the 3D finite difference method incorporating medium with S-wave velocity larger than 0.55 km/s. Response of subsurface structure shallower than engineering basement (portion with S-wave velocity lower than 0.55 km/s) is evaluated with multiple reflection theory in 1D media. For the earthquakes on active faults within the target area, we compute ground motion up to 1Hz by the 3D finite difference method with the smallest grid size of 100 m.

S42F-02 1355h INVITED

Simulations of Ground Motion in Southern California based upon the Spectral-Element Method

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We use the spectral-element method to simulate ground motion generated by recent well-recorded small earthquakes in Southern California. Simulations are performed using a new sedimentary basin model that is constrained by hundreds of petroleum industry well logs and more than twenty thousand kilometers of seismic reflection profiles. The numerical simulations account for 3D variations of seismic wave speeds and density, topography and bathymetry, and attenuation. Simulations for several small recent events demonstrate that the combination of a detailed sedimentary basin model and an accurate numerical technique facilitates the simulation of ground motion at periods of 2 seconds and longer inside the Los Angeles basin and 6 seconds and longer elsewhere. Peak ground displacement, velocity and acceleration maps illustrate that significant amplification occurs in the basin. Centroid-Moment Tensor mechanisms are obtained based upon Pnl and surface waveforms and numerically calculated 3D Frechet derivatives. We use a combination of waveform and waveform-envelope misfit criteria, and facilitate pure double-couple or zero-trace moment-tensor inversions.

S42F-03 1415h INVITED

Recipe of Strong Ground Motion Prediction for Senario Earthquakes

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From recent development of the waveform inversion analysis for estimating rupture process during large earthquakes, we have understood that strong ground motion is relevant to slip heterogeneity inside the source rather than the entire rupture area. The source characterization was made defining the entire rupture areas with a certain criterion in slip, and the asperities as regions that have two times slip as large as the average slip over the rupture area (Somerville et al., 1999). The important aspect from the source characterization is that the asperity areas as well as total rupture areas are expressed as a function of seismic moment. Based on the above scaling relationships, the source model for the prediction of strong ground motions is constructed by three kinds of parameters, outer, inner, and extra fault parameters. The outer fault parameters are defined as entire rupture area and total seismic moment. The inner fault parameters are defined as slip heterogeneity inside the source, i.e. area of asperities and stress drop on each asperity. We examined that strong motion generation areas approximately coincide with the asperity areas where stresses are strongly released (Miyake et al., 2001). A source model satisfying such characteristics is expressed as a dynamically-constrained multi-asperity model that is a extension a single-asperity model proposed by Das and Kostrov (1986). We have developed a recipe for predicting strong ground motions, which is to characterize the source model for scenario earthquakes. For the outer fault parameters, at first the total fault length is given as a sum of active fault segments. The fault width is related to the thickness of seismogenic zones. The entire source area is defined as a product of the length and width, and then the total seismic moment is derived following the empirical scaling relationship. For the inner fault parameters, the area of asperities is estimated from the scaling with the total seismic moment. Stress drop on each asperity is estimated by the ratio between the asperity and total rupture areas, and average stress drop over the entire rupture area. We found that the slip of the asperities is dynamically constraint depending on the number of the asperities. The pattern of rupture nucleation and termination as the extra fault parameters are related to geomorphology of active faults and plates. We have examined the validity of the earthquake sources constructed by the recipe, comparing simulated and observed ground motions for recent large earthquakes, such as the 1995 Kobe, 1999 Kocaeli, 1999 Chi-chi, 2000 Tottori, and other earthquakes.

S42F-04 1435h

Physically Self-Consistent Earthquake Source Models for Strong Ground Motion Prediction

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Accurate predictions of the intensity and variability of near-source strong ground motions for future large earthquakes depend strongly on our ability to simulate realistic models of earthquake rupture. Commonly used kinematic earthquake source models are characterized by heterogeneity in the slip distribution and a temporal rupture evolution (rise time, rupture velocity, slip-velocity function) that is assumed *a priori*. Such kinematic source models may not be physically realizable as a self-sustaining fault rupture. In order to make near-field ground motion simulations more accurate, we have developed a procedure to generate physically consistent earthquake rupture models. This so-called *pseudo-dynamic* source characterization constitutes inherently kinematic rupture models that are designed to emulate important characteristics of fully dynamic rupture models through a series of empirical relationships derived from the analysis of a set of spontaneous rupture models.
We construct pseudo-dynamic models by first generating a slip distribution using a spatial random-field model that is consistent in its overall scaling and spatial variability with slip distributions observed in past earthquakes [*Mai and Beroza*, 2000; 2002]. We then compute the static stress drop $\Delta\sigma$ associated with this slip distribution [*Andrews*, 1980], which is then used to calculate the local rupture velocity through empirical relations between stress drop $\Delta\sigma$, fracture energy G_C and crack length L_C [*Andrews*, 1976; *Guatteri et al*, 2003]. An equivalent approach is used to simulate the distribution of rise time over the fault and the parameters describing the slip-velocity function. A simple energy-budget calculation is used to discard source models that would not be realizable as spontaneous ruptures.
Our pseudo-dynamic source characterization reproduces the important features of dynamic rupture without full dynamic simulations, and hence circumvents the limits imposed by the computational demand of dynamic rupture modelling for multiple scenario earthquakes. While the relationships between source parameters described in this paper are significant simplifications of the true complexity of the physics of the rupture process, they help identify important relationships between source properties that are relevant for strong ground motion prediction.

S42F-05 1450h INVITED

Strong Motion Network as Infrastructure

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After the 1995 Hyogoken-Nanbu earthquake, NIED (National Research Institute for Earth Science and Disaster Prevention) installed the K-NET that uniformly covers all Japan with more than one thousand strong-motion accelerometers on the ground surface. In addition to the K-NET, NIED constructed uphole/downhole observation network, KiK-net, with approximately 660 stations. Each KiK-net station has a borehole of 100m or more in depth and strong-motion seismographs have been installed both on the ground surface and at the bottom of the boreholes. The velocity profiles and geological information are widely accessible on the website as well as the observed records. We are coming into an era where we can obtain the data immediately when the earthquakes occur, as we are able to obtain water in every house by just turning on a water faucet. These networks recorded strong-motion waveforms near the source-region. In fact, for most of large inland earthquakes, strong motion records were obtained within 15 km of epicenter and largely contributed to investigating both source processes and ground motion characteristics. For example, approximately 800 stations were triggered by the 2003 Off-Miyagi earthquake (Mw 7.0), an intra-slab earthquake that occurred at 70 km deep. At three stations, PGA (peak ground acceleration) exceeded 1g (980 gal). During the crustal earthquake in July of 2003 at Miyagi prefecture, the other governmental seismograph network for measuring seismic intensity recorded more than 1.5 - 2g at very near-fault stations. The dense network showed that the large accelerations were not accidental phenomena, although they were observed at spatially limited area. When the observation is sparse, it is difficult to judge whether the large ground motions are caused just by locally special situation like the effects of topography and fill-up ground or not. Accumulation of the near-source strong-motion data is very important for evaluating the ground-motion both for the past and future earthquakes.

URL: http://www.k-net.bosai.go.jp/

S42F-06 1510h

Simulation of Broadband Time Histories Combining Deterministic and Stochastic Methodologies

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We present a methodology for generating broadband (0 - 10 Hz) ground motion time histories using a hybrid technique that combines a stochastic approach at high frequencies with a deterministic approach at low frequencies. Currently, the methodology is being developed for moderate and larger crustal earthquakes, although the technique can theoretically be applied to other classes of events as well. The broadband response is obtained by summing the separate responses in the time domain using matched butterworth filters centered at 1 Hz. We use a kinematic description of fault rupture, incorporating spatial heterogeneity in slip, rupture velocity and rise time by discretizing an extended finite-fault into a number of smaller subfaults. The stochastic approach sums the response for each subfault assuming a random phase, an omega-squared source spectrum and simplified Green's functions (Boore, 1983). Gross impedance effects are incorporated using quarter wavelength theory (Boore and Joyner, 1997) to bring the response to a generic baserock level (e.g., V_S = 1000 m/s). The deterministic approach sums the response for many point sources distributed across each subfault. Wave propagation is modeled using a 3D viscoelastic finite difference algorithm with the minimum shear wave velocity set at 620 m/s. Short- and mid-period amplification factors provided by Borcherdt (1994) are used to develop frequency dependent site amplification functions. The amplification functions are applied to the stochastic and determinsitic responses separately since these may have different (computational) reference site velocities. The site velocity is taken as the measured or estimated value of $V_S{}^{30}$. The use of these amplification factors is attractive because they account for non-linear response by considering the input acceleration level. We note that although these design factors are strictly defined for response spectra, we have applied them to the Fourier amplitude spectra of our simulated time histories. This process appears to be justified since the amplification functions vary slowly with frequency and the method produces favorable comparisons with observed broadband motions. We have tested the methodology using ground motion recordings of the Northridge and Loma Prieta earthquakes.

S42F-07 1525h

The Effects of 3D Structure and Finite Sources on Ground Motion in the Yanhuai Basin

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Three dimensional finite difference earthquake scenarios from finite faults are compared with those from a point source for the 1792, Mw 6.75 Shacheng Earthquake, Beijing area, with different velocity models – homogeneous, layered, and heterogeneous. The goal is to separate the effects of fault dimension and heterogeneity on the ground motion and shaking hazard in the study region. The kinematic finite source model is a traditional one (Hartzell, 1978), in which the rupture initiates at the hypocenter of the fault plane and propagates radially. The velocity of this propagation is assumed to be about 80 percent of the shear wave velocity. From the magnitude we can derive the geometrical parameters of the finite fault plane, assumming the shape of the fault is rectangular. Then the fault plane is divided into elements. Each element is treated as a separate point source. The scalar moments of these elements are assigned randomly with the summation equal to the total moment of the point source. We use the same gauss function for these separate elements as for the point case, with the rise time relative to the length and the rupture propagation velocity. Our comparisons are in terms of the velocity and rotation seismograms, the PGV (peak ground velocity), the PGR (peak ground rotation), the shaking duration distribution and response spectrum of velocity. Generally it is observed that the attenuation rate (both of PGV and PGR) at the area of hanging wall is higher than on the opposite side. Further preliminary findings point to (1) enhanced near-fault ground motion in the finite-fault case and (2) complex interaction between the finite fault radiation and the 3D heterogeneity.

URL: http://woerth.geophysik.uni-muenchen.de/~haijiang/abstract.pdf

S42G MCC: 3011 Thursday 1340h

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

Presiding: **G A Ichinose,** URS Corporation**; H Kao,** Geological Survey of Canada

S42G-01 1340h

The north Cascadia Episodic Tremor and Slip (ETS) Event of February and March 2003

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Repeated slip has been detected on the deep interface of the northern Cascadia subduction zone by observing surface deformation on a network of continuous Global Positioning System sites. These slip events have now been found to have, accompanying tremor-like, non-earthquake, seismic signatures. The tremor is mainly shear wave energy concentrated in a bandwidth of 1-5Hz. We refer to this associated tremor and slip phenomena as Episodic Tremor and Slip (ETS). From the regular 13 to 16 month recurrence times of the previous five ETS events identified beneath southern Vancouver Island since 1996, an ETS event was expected in the region early in 2003. The seismograph and GPS networks operated by the Geological Survey of Canada were supplemented with additional stations to ensure that the seismic and deformation signature of the expected ETS event were well recorded. The first ETS tremors started on February 25 just south of Victoria, British Columbia in the region of the International border. Within a few days, slip was confirmed by southwest displacements at continuous GPS stations in the vicinity of Victoria. The source locations of tremor and slip migrated northwest about 150 km, traversing the southern third of Vancouver Island. The last tremor signal of the sequence was detected on March 26. Tremors emanated from a region on, or very close to, the subduction interface between the two lithospheric plates. They were confined to a band about 50km wide, consistent with the region of the modelled slip, just down dip from the proposed locked zone on the subduction interface.

S42G-02 1355h

Temporal and Spatial Distribution of the Tremors in the Episodic Tremor and Slip (ETS) Event Observed Beneath the Northern Cascadia Subduction Zone in Early 2003

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The tremors associated with the most recent ETS event observed along the northern Cascadia margin were recorded in the greatest detail to date, by a combination of stations from CNSN, POLARIS, and the deployment of a temporal broadband seismic network in the region. Because no clear arrivals of P or S phases can be identified, we develop a method, called "source-scanning", to locate the tremors and to image their source distribution in both time and space. The algorithm systematically examined three-component continuous digital waveforms (from late February to late March, 2003) recorded at 25 broadband seismic stations (spacing at an interval of about 10 km) and identified more than 1600 tremor events with sufficient waveform quality to give coherent patterns of source configuration. The identified events span a width of about 50 km