the analysis of synthetic data, it has recently been suggested that robust constraints on both the shear velocity profile and the depth to the first impedance jump can be obtained if single station H/V spectral ratios are jointly inverted together with dispersion curves obtained from array analysis. In order to test this hypothesis, in August of 2002 we have performed array measurements of ambient vibrations at the Euro-SEISTEST in northern Greece, at six different locations within the city of Thessaloniki, and on the island of Lefkas where strong non-linear effect have been observed in a previous study. At all these locations, the subsurface structures are well known and shear wave velocity profiles have been determined by independent geophysical and geotechnical surveys. Furthermore, information about the intensity and damage distribution is available for the city of Thessaloniki. This detailed knowledge, as well as numerous data from temporary and permanent seismological networks makes these locations unique test cases for site response analysis. We present first encouraging results of the comparison of site models obtained from ambient vibrations with the existing structural models and discuss the consequences for site response prediction using ambient vibration recordings.

S72A-1139 1330h POSTER

Comparison of P-Wave and S-Wave Reflection Surveying Effectiveness for Detection of Mine-Related Subsidence Activity Beneath a Heavily Traveled Roadway

Erich D. Guy[1] (614-688-8438; erichguy@hotmail.com)

Jeffrey J. Daniels[1] (614-292-4295; jeff@geology.ohio-state.edu)

[1]The Ohio State University, 275 Mendenhall Laboratory 125 South Oval Mall, Columbus, OH 43210, United States

We acquired high-resolution multicomponent seismic reflection data along an undermined 2200 ft (671 m) section of Interstate highway 70 (I-70) in eastern Ohio, in order to identify areas of active subsidence or soil piping into subsurface collapse features. This paper presents results from research conducted: 1) to investigate potential advantages and disadvantages associated with near-surface P- and S-wave reflection surveys, and 2) to determine the subsidence detection potential of common-mode P- and S-wave data components acquired in the study area. P-wave data have traditionally been acquired during shallow reflection surveys, however, the number of reports concerning shallow S-wave surveys is relatively small, and very few reports concerning the concurrent acquisition and analysis of P- and S-wave reflection data exist.

Although S-wave reflections from the top-of-bedrock (located above the coal mine and targeted for subsidence detection purposes) were consistently observed in both XX component (inline-inline, SV-SV) and YY component (crossline-crossline, SH-SH) data, surface wave noise resulted in the optimum reflection window of XX data being relatively narrow. Stacks produced using YY data had a higher signal-to-noise ratio and better imaged the target horizon than those produced using XX data. Whereas S-waves were relatively insensitive to changes in overburden moisture content, P-wave reflections from the top-of-saturated-overburden (located above bedrock) were recorded in ZZ component (vertical-vertical, P-P) data. The arrival times of P-wave reflections and the characteristics of the recorded noise modes made it difficult to process and use P-wave reflections from this interface. P-wave events from deeper impedance contrasts were not observed in field data due to several factors: surface wave and air wave noise, a high P-wave reflection coefficient at the top-of-saturated-overburden, low P-wave reflection coefficients at deeper interfaces, and interference effects/resolution issues. Calculations suggest that the resolution of S-waves in the study area dry overburden is more than 1.7 times that of P-waves, and that the resolution of S-waves in the study area saturated overburden is more than 4.5 times that of P-waves.

Given the study area subsurface conditions and acquired data characteristics, areas of the subsurface where subsidence processes have been active could be most accurately delineated through the processing and interpretation of YY (relative to XX and ZZ) data. Processed YY data indicate that the bedrock horizon is significantly disrupted due to mine-related subsidence processes at numerous locations along the roadway in the study area. Hence, these locations are regarded as having a relatively high risk for future mine-related surface failure.

S72A-1140 1330h POSTER

3-D Waveguide Effects of Topographical Structural Variation on Full Waveform Propagation: 3-D Finite Difference Modeling Comparisons with Field Data From Yuma Proving Ground, Arizona

Thomas S. Anderson[1] (603-646-4751; thomas.s.anderson@erdc.usace.army.mil)

Rick Miller[2] (785-864-2091; rmiller@kgs.ku.edu)

Roy Greenfield[3] ((814)-237-1810; roy@essc.psu.edu)

David Fisk[1] (603-646-4571; David.J.Fisk@erdc.usace.army.mil)

[1]USACE ERDC-CRREL, 72 Lyme RD, Hanover, NH 03755, United States

[2]Kansas Geological Survey, 1930 Constant Ave., Lawrence, KS 66047, United States

[3]Greenfield Associates, 600 N. McKee, State College, PA 16803, United States

The propagation of seismic waves through regions of complex topography is not thoroughly understood. Surface waves, are of particular interest, as they are large in amplitude and can characterize the source depth, magnitude, and frequency content. The amplitude and frequency content of seismic waves that propagate in regions with large topographical variations are affected by both the scattering and blockage of the wave energy. The ability to predict the 3-d scattering due to topography will improve the understanding of both regional scale surface wave magnitudes, and refine surface wave discriminants as well as at the local scale (<2 km) where it will aid in the development of rule of thumb guide lines for array sensor placement for real time sensing technologies. Ideally, when validating the numerical accuracy of a propagation model against field data, the input geologic parameters would be known and thus eliminates geology as a source of error in the calculation. In March of 2001, Kansas Geological Survey (KGS) performed a detailed seismic site characterization at the Smart Weapons Test Range, Yuma Proving Ground, Arizona. The result of the KGS characterization study is a high-resolution 3-d model that is used in our seismic simulations. The velocities Vs, Vp are calculated by tomography and refraction, attenuation coefficients estimated from the surface wave and from p-waves and are provided in a model with attributes resolved in 3-d to 0.5 meters.

In the present work, we present comparisons of synthetic data with seismic data collected at the Smart Weapons Test Range to benchmark the accuracy achieved in simulating 3-d wave propagation in the vicinity of a topographical anomaly (trench). Synthetic seismograms are generated using a 3-d 8th order staggered grid visco-elastic finite difference code that accounts for topography. The geologic model is based on the Yuma site characterization. The size of these calculations required use of the DoD High Performance Computers and parallelized code. Results are compared with field data. Preliminary results show an excellent match with field data using the 3-d fdtd technique.

S72B MCC: Hall C Sunday 1330h

Radiated Energy and Apparent Stress: Constant or Nonconstant Scaling? II Posters *(joint with T)*

Presiding: **L Zhu,** Saint Louis University**; I M Tibuleac,** Weston Geophysical Corporation

S72B-1141 1330h POSTER

Scaling of Earthquake Source Parameters for Small Earthquakes Recorded at the Western Nagano, Japan Deep Borehole

Anna L Stork[1] (+81-298-61-3757; anna.stork@aist.go.jp)

Kazutoshi Imanishi[1] (imani@ni.aist.go.jp)

Hisao Ito[1] (+81-298-61-3757; hisao.itou@aist.go.jp)

[1]Geological Survey of Japan/AIST, AIST Tsukuba Central 7 1-1 Higashi 1-Chome, Tsukuba, Ibaraki 305-8567, Japan

The scaling of stress drop and apparent stress with seismic moment for small earthquakes (M<3) has been the subject of much discussion and research but the question remains unresolved. In this work 90 earthquakes of -0.5<M<3.0 were studied using recordings made at the 800m deep borehole in western Nagano, central Japan. Data is recorded at a sampling rate of 10kHz and spectra show high signal to noise ratio up to frequencies of 200-300Hz. High quality recordings of nearby earthquakes make it possible to determine good estimates of seismic moment and energy for small events.

The P and S wave direct arrivals were picked on velocity seismograms and amplitude spectra for the events were fitted with an ω^2 model comparing results obtained for different length P and S wave time windows. Source parameters were calculated using frequency dependent and independent quality factors (Q values). Q(f) values were calculated using the extended coda normalisation method of Yoshimoto et al. (1993) and the results compared to the relationships obtained by previous studies in this area (Yoshimoto et al.,1998 and Matsuzawa et al., submitted for publication). The Q(f) values obtained increased with frequency and were found to agree with the results of the previous studies. A breakdown in scaling of apparent stress with moment was observed for seismic moments around 10^{11}Nm with results for frequency dependent and independent Q. This indicates the assumption of a constant Q is valid in this case. No change in scaling of static stress drop with moment was observed above 10^{10}Nm but an investigation into the restrictions the instrumentation places on the analysis revealed that the results for events with Mo<10^{10}Nm are unreliable.

The possibility of the change in apparent stress scaling being dependent on area and/or hypocentral distance was investigated. No area dependence was observed but a decrease in apparent stress was found with increasing hypocentral distance and the effect becomes obvious at shorter distances for smaller events. A similar but less striking trend was seen for stress drop values. This result leads to the conclusion that path effects are the cause of the observed trend in apparent stress scaling and therefore they must be considered for small events even in the analysis of clean seismograms recorded by deep boreholes.

S72B-1142 1330h POSTER

Source scaling relationships of small earthquakes estimated from the inversion method using stopping phases

Kazutoshi Imanishi[1] (+81-298-61-3836; imani@ni.aist.go.jp); Minoru Takeo[2] (takeo@eri.u-tokyo.ac.jp); Hisao Ito[1] (hisao.itou@aist.go.jp); William L. Ellsworth[3] (ellsworth@usgs.gov); Takanori Matsuzawa[2] (tmatsu@eri.u-tokyo.ac.jp); Yasuto Kuwahara[1] (y-kuwahara@aist.go.jp); Yoshihisa Iio[4] (iio@rcep.dpri.kyoto-u.ac.jp); Shigeki Horiuchi[5] (horiuchi@geo.bosai.go.jp); Shiro Ohmi[4] (ohmi@rcep.dpri.kyoto-u.ac.jp)

[1]Geological Survey of Japan/AIST, AIST Tsukuba Central 7 1-1, Higashi 1-Chome, Tsukuba, Ibaraki 305-8567, Japan

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

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

[4]Disaster Prevention Research Institute, Kyoto University, Gogashou, Uji, Kyoto 611-0011, Japan

[5]National Research Institute for Earth Science and Disaster Prevention, 3-1, Tennoudai, Tsukuba, Ibaraki 305-0006, Japan

We estimate source parameters of small earthquakes from stopping phases and investigate the scaling relationships between source parameters. The method we employed [Imanishi and Takeo, 2002] assumes an elliptical fault model proposed by Savage [1966]. In this model, two high-frequency stopping phases, Hilbert transformations of each other, are radiated and the difference in arrival times between the two stopping phases is dependent on the average value of rupture velocity, the source dimension, the aspect ratio of elliptical fault, the direction of rupture propagation and the orientation of the fault plane. These parameters can be estimated by a nonlinear least squares inversion method. Earthquakes studied occurred between May and August 1999 at the western Nagano prefecture, Japan, which is characterized by high levels of shallow earthquakes. The data consist of seismograms recorded by an 800 m deep borehole and a 46 surface seismic array whose spacing is a few km. In particular, the 800 m borehole data provide a wide frequency bandwidth and greatly reduce ground noise and coda wave amplitude compared to surface recordings. High-frequency stopping phases are readily detected on accelerograms recorded in the borehole. After correcting both borehole and surface data for attenuation, we also measure the rise time, which is defined as the time lag from the arrival time of the direct wave to the first slope change in the displacement pulse. Using these durations, we estimate source parameters of 25 earthquakes ranging in size from M1.2 to M2.6. The rupture

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aspect ratio is estimated to be about 0.8 on an average. This suggests that the assumption of a circular crack model is valid as a first order approximation for earthquakes analyzed in this study. Static stress drops range from approximately 0.1 to 5 MPa and do not vary with seismic moment. It seems that the breakdown seen in the previous studies by other authors using surface data is simply an artifact of attenuation in the crust. This is consistent with the conclusion by Stork et al. (2002) inferred from the spectral analysis using the 800m deep borehole data. The average values of rupture velocity do not depend on earthquake size, and are similar to those reported for moderate and large earthquakes. We then calculate the seismic energy following Sato and Hirasawa (1973). The magnitude scaling of the apparent stress is almost constant in the analyzed events, ranging from 0.05 to 1 MPa. Since most of apparent stresses for large earthquakes are in the range of 0.1 to 10 MPa, there may be small differences in apparent stress between large and small earthquakes. However, it is likely that earthquakes are self-similar over a wide range of earthquake size and the dynamics of small and large earthquakes are similar from a macroscopic viewpoint.

S72B-1143 1330h POSTER

Rupture Velocities of Small Earthquakes (0.0 < M < 1.5) in a South African Gold Mine: Constraints on Fracture Energy

Takuji Yamada[1] (+81-774-38-4188; takuji@rcep.dpri.kyoto-u.ac.jp); Jim Mori[1] (+81-774-38-4205; mori@rcep.dpri.kyoto-u.ac.jp); Hironori Kawakata[2] (kwkt@drs.dpri.kyoto-u.ac.jp); Hiroshi Ogasawara[3] (ogasawar@se.ritsumei.ac.jp); Satoshi Ide[4] (ide@eps.s.u-tokyo.ac.jp); Shigekazu Tanbo[1] (tanbo@rcep.dpri.kyoto-u.ac.jp); . Earyhquake in S African Gold Mines

[1]RCEP, DPRI, Kyoto University, Gokasho, Uji 611-0011, Japan

[2]DRS, DPRI, Kyoto University, Gokasho, Uji 611-0011, Japan

[3]Faculty of Science and Engineering, Ritsumeikan University, 1-1-1 Noji Higashi, Kusatsu 525-8577, Japan

[4]Department of Earth and Planetary Science, Graduate School of Science, the University of Tokyo, 7-3-1, Hongo, Bunkyo-ku, Tokyo 113-0033, Japan

Analyses of rupture velocities of earthquakes are important to investigate characteristics of fracture energies, initiations, and arresting mechanisms. But it is especially difficult to resolve rupture velocities of small earthquakes because close station spacing near the hypocenter and high sampling rates are necessary. Such observations are being carried out in a South African gold mine for mining induced earthquakes. Nine triaxial borehole accelerometers were installed within 200 m along a 2,650-m-deep haulage tunnel in the Mponeng gold mine. More than 25,000 seismic events (-2.7 < M < 3.3) were recorded with a sampling frequency of 15 kHz from February to October, 1996. We carefully picked 10 events with magnitudes between 0.0 and 1.5 having good azimuthal coverage and analyzed the waveforms to try to determine rupture velocities.

The events studied have rather complicated waveforms and individual subevents could be identified. Arrival times of the subevents were picked relative to the initial arrival. These differential arrival times were used to locate the subevents relative to the initial hypocenter. Approximate rupture velocities could be obtained by dividing the distance to the subevent by the delay time.

We obtained results that showed rupture velocities ranging from 2.34 to 2.70 km/s for earthquakes of magnitude from 0.0 to 1.5. These values are about 70 % of the shear-wave velocity and consistent with those of larger natural earthquakes. This result suggests that if the static stress drops of these earthquakes are the same as those of natural earthquakes, the ratios of fracture energies to radiated energies of small earthquakes in a South African gold mine are not particular large and almost the same as those of larger natural earthquakes.

S72B-1144 1330h INVITED POSTER

Energy-Moment Scaling in the Eastern and Western Alps

Luca Malagnini[1] (+39 0651860538; malagnini@ingv.it)

Kevin Mayeda[2] ((925) 423-5913; mayeda2@llnl.gov)

Paola Morasca[3] (+39 0103538343; alpocc@dipteris.unige.it)

[1]Istituto Nazionale di Geofisica e Vulcanologia , Via di Vigna Murata, 605 , Rome, RM 00143, Italy

[2]Lawrence Livermore National Laboratory, P. O. Box 808, L-205, Livermore, CA 94550, United States

[3]Universita' di Genova, Viale Benedetto XV, 5, Genova, GE 16132, Italy

Energy-moment scaling is examined in the Alps using high quality digital three-component waveforms for local events ranging between $M_w \sim 2$ to 5. The method we employ for energy and moment estimates is based on stable, coda-derived moment-rate spectra. This method has been previously applied to the western United States and the eastern Mediterranean where it was shown that energy and moment estimates are significantly more stable than those derived from direct P and S waves. Furthermore, these studies have suggested that for larger events the energy-moment ratio increases with increasing seismic moment for events ranging between $M_w \sim 0.5$ to 7. Results from this study will be compared against previous studies with the hope of better understanding the energy-moment scaling. Recently, there has been renewed debate and interest on whether or not the energy-moment ratio is constant or is size-dependent. We believe our approach takes into account all the effects of frequency-dependent path attenuation and site response leaving a stable, unbiased estimate of the radiated source spectrum.

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S72B-1145 1330h POSTER

The Effect of a Shallow Thrust-Fault Reflecting Boundary Condition on Teleseismic Radiated Energy: Study Using Dynamic Finite-Element Rupture Models and Synthetic Body Wave Seismograms

Deborah Elaine Smith[1] (626-395-6932; desmith@its.caltech.edu)

Brad T Aagaard[2] (baagaard@caltech.edu)

Thomas H Heaton[1] (626-395-4232; heatont@caltech.edu)

[1]Caltech, 252-21 Seismolab Caltech, Pasadena, CA 91125, United States

[2]USGS, 525 S. Wilson Ave., Pasadena, CA 91106, United States

It has been suggested that dislocation models of teleseismic waves may seriously underestimate seismic moments of shallow thrust-fault events (Brune, 1996). Dislocation models allow seismic waves, such as reflected phases, to propagate through the fault boundary unimpeded, i.e., they are transparent to seismic radiation. Brune hypothesizes instead that the two sides of the fault separate during rupture creating a reflecting boundary condition that is opaque to seismic radiation. If so, then energy becomes trapped in the overhanging wedge, radiated energy to teleseismic distances is reduced, and the moment is underestimated.

We tested this by producing and comparing synthetic P and SH seismograms for earthquakes with and without a reflecting or opaque fault boundary condition. We used friction laws in dynamic, three-dimensional finite-element models to create slip-histories for models with partially to completely reflecting faults in the Mode II and Mode III directions. The inclusion of gravity created sufficient lithostatic stress that any Mode I opening was negligible. We have three opaque models in order of most to least opaque: crack-like (slip-weakening) with zero sliding friction, crack-like with constant sliding friction, and pulse-like (slip- and rate-weakening). The slip-history of our dislocation model with a transparent fault boundary condition (Haskell-like model), is the integral of Brunes (1970) far-field time function. Slip-histories for these opaque and transparent models are normalized such that they have the same potency. In addition, the Haskell-like model slip-history is designed to have the same final slip, peak slip-rate, and slip start times as the pulse-like model at each location on the fault for a close comparison.

Synthetic seismograms were calculated for the above four models at a variety of azimuths and epicentral distances, and the peak-to-peak amplitudes were numerically evaluated. Note that we normalized the peak-to-peak amplitudes of the three "opaque" models by the Haskell-like model. Therefore, a peak-to-peak value < 1 indicates that dislocation theory would underestimate the seismic moment of the opaque model and a value > 1 indicates that dislocation theory would overestimate the seismic moment of the opaque model. Our results for the P wave peak-to-peak amplitudes are: 1.64 for crack-like with zero sliding friction, 0.96 for crack-like with constant sliding friction, and 1.09 for pulse-like. For SH waves the values are: 2.02 for crack-like with zero sliding friction, 1.02 for crack-like with constant sliding friction, and 1.05 for pulse-like. Interestingly, two out of the three models (constant sliding friction and pulse-like) have peak-to-peak amplitudes either very close or slightly larger than the transparent, Haskell-like model. The somewhat unrealistic, zero sliding friction model (which is opaque to all Mode II and Mode III sliding) has a larger peak-to-peak amplitude than the Haskell-like, but this can be explained by the fact it oscillates about the equilibrium, zero frequency solution. Thus, it appears that a reflecting boundary condition has little to no effect on the radiated energy to teleseismic distances. If anything, a completely reflecting boundary increases the radiated energy. Hence, we do not find any problem with standard dislocation theory in estimating seismic moment.

S72B-1146 1330h POSTER

Seismic Energy Distribution From Strong Motion Models

Xyoli Pérez-Campos[1] ((650) 723-6658; xyoli@pangea.stanford.edu)

Gregory C. Beroza[1] ((650) 723-4958; beroza@pangea.stanford.edu)

Satoshi Ide[2] (ide@eri.u-tokyo.ac.jp)

[1]Department of Geophysics, Stanford University, 397 Panama Mall, Stanford, CA 94305, United States

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

The total seismic energy can be estimated directly from seismograms; however, this approach does not allow us to study spatial variations in how seismic energy is radiated during the earthquake rupture process. In this study we use the method of Ide [2002] to estimate the radiated energy distribution on the fault plane. We analyze three California earthquakes, the 1984 Morgan Hill (M=6.2), the 1992 Landers (M=7.2), and the 1999 Hector Mine (M=7.1) earthquakes. We find that the radiated energy distributions from these earthquakes have their highest concentration at the main asperities, and that these asperities have energy absorbing regions (sinks) at their edges. We estimate the apparent stress distribution on the fault plane using the moment density, the energy density, and the shear modulus. This distribution shows that the apparent stress is highest at the center of the high slip regions and negative, i.e. showing a stress increase, at regions of energy absorption, primarily the edges of the high slip regions. The seismic energy estimated from the rupture models for these earthquakes is underestimated by a factor of 2 to 10, suggesting that much of the true radiated energy is not accounted for in this formulation. Our results suggest that much of the slip in these earthquakes occurred in areas where energy was dissipated and that fault segmentation plays a strong role in limiting the extent of earthquake rupture.

S72B-1147 1330h POSTER

Using Macroscopic Seismological Parameters to Understand the Dynamics of Faulting

Anupama Venkataraman[1,2] (650 7252234; anupamav@pangea.stanford.edu)

Hiroo Kanamori[1] (626 3956914; hiroo@gps.caltech.edu)

[1]California Institute of Technology, 252-21, Seismo Lab, Caltech, Pasadena, CA 91125

[2]Stanford University, Department of Geophysics, Mitchell Bldg, Stanford University, Stanford, CA 94305-2215

We computed teleseismic estimates of radiated energy (E_R) for 23 large subduction zone earthquakes recorded between 1992 and 2001; most of these earthquakes have a magnitude $M_w > 7.5$, but we also included some smaller ($M_w \sim 6.7$) well-studied subduction zone earthquakes and 6 crustal earthquakes. For these 29 earthquakes, we compiled the static stress drop estimates ($\Delta\sigma_s$) from published literature. We then determined radiation efficiency ($\eta_R = \frac{E_R}{(E_G+E_R)} = \frac{2\mu\tilde{e}}{\Delta\sigma_s}$, where $\tilde{e} = E_R/M_0$, and M_0 is the seismic moment) of these earthquakes using a simple slip-weakening stress relaxation model that relates measurable and macroscopic seismological parameters to the physical processes on the fault zone via fracture energy. We also determined the rupture velocity (V) of these earthquakes from published literature.

Most crustal, interplate, downdip, intraplate and deep earthquakes have radiation efficiencies between 0.5 and 1 and are thus efficient in generating seismic waves. In these earthquakes, only a small fraction of the energy is dissipated in mechanical processes on the fault zone. Also, most earthquakes propagate at velocities close to the shear wave velocity (β). We observe that the radiation efficiencies are smaller for smaller V/β and larger for larger V/β, a relationship that we could expect from crack theory and from simple energy considerations. Since rupture velocity is an independently determined quantity, this consistency in the observed relationship between radiation efficiency and V/β on the one hand, and the calculations from crack theory on the other suggest that most earthquakes propagate as shear cracks with low fracture energy and that the simple slip-weakening model used is probably good for most earthquakes.

S72B-1148 1330h POSTER

Strain Energy Flow and the Accumulation of Large Earthquake Energies in the Island Arc-Trench Dynamics (NE Japan Arc)

Shozaburo Nagumo (81-3-3724-6780; nagumo-shozaburo@oyonet.oyo.co.jp)

OYO Corporation, 43 Miyukigaoka, Tsukuba 305-0841, Japan

A gravitational shear flow of the island-arc rock-mass was newly revealed under the Japan trench inner slope on the artifact-free and distortion-free seismic reflection profiles (Nagumo and Tsuru (2001), Eos. Trans. AGU82(47), Fall.Meet. Suppl. Abstract T12D-0934). Based on such a shear flow phenomena, I envision a picture of the island arc-trench dynamics as below. The hot upper mantle under the volcanic arc generates buoyancy, and uplifts the volcanic arc. The uplifted island arc rock-mass gains excess gravitational potential energy. The surface inclination from the central arc towards the trench axis generates horizontal driving force within the arc mass, and generates shear stresses, shear deformations, and shear strain energies.

In the deep part of the crust, such shear stresses exceed the critical value, and the rock-masses are in a state of shear flow. Because of rather hot thermal regime, such a shear flow of rock-masses predominates within the ductile intermediate zone of the crust, which ranges from the basal granitic layer to the upper part of the basaltic layer.

The shear flow carries the whole island-arc mass towards trench axis from the central volcanic arc and transports the strain energies, which are involved within the deformed rock-mass, and forms a flow of strain energy. Such a gravitational flow of the rock-mass is a behavior of viscous fluids in a long time scale.

When the strain energy flow is obstructed by some mechanism, a part of the strain energy flow is trapped, and stored around the obstacles. The stored energies accumulate with elapse of time, and results in an occurrence of large earthquake.

I postulate that the occurrence condition of a large earthquake is such that the average density of the accumulated strain energy within the volume of the self-adjoined domain attains a certain critical level. Then, we can estimate the earthquake radiation energy by the product of the critical strain energy and the volume of the self-adjoined domain. The gravitational potential energy is sufficient enough to generate the large earthquake energies in the forearc region. The energy supply by the subducting oceanic plate is not required.

Such a view of strain energy accumulation process may relate to the variety of the asperity, repetition interval of occurrence, and the types of earthquakes, such as main shock type, swarm type and etc. The above picture of the island arc-trench dynamics does not require subduction-accretion tectonics.

S72B-1149 1330h POSTER

Source Characteristics of Shallow Intraslab Earthquakes from Strong Motion Data

Kimiyuki Asano[1] (k-asano@egmdpri01.dpri.kyoto-u.ac.jp)

Tomotaka Iwata[1] (iwata@egmdpri01.dpri.kyoto-u.ac.jp)

Kojiro Irikura[1] (irikura@egmdpri01.dpri.kyoto-u.ac.jp)

[1]DPRI, Kyoto University, Gokasho, Uji, Kyoto 611-0011, Japan

Large shallow intraslab earthquakes, occurring within subducting slabs at 30-100km depths, generate earthquake damages by strong ground motions (e.g. the 1993 Kushiro-oki earthquake, the 2001 Geiyo earthquake, and the 2001 Nisqually earthquake). Source characteristics of intraslab earthquakes have been pointed out to have some different features compared to those of inland crustal earthquakes and interplate earthquakes by some researchers. We examined six shallow intraslab earthquakes that recently occurred around Japan ($M_{JMA}5.1-7.0$) using dense strong motion network data.

The observed peak ground accelerations at K-NET stations for the 2001 Geiyo earthquake in near distance are about 3 times larger than those expected from the attenuation relation based on inland crustal earthquakes proposed by Fukushima and Tanaka (1992). For other intraslab events, the observed peak ground accelerations are also larger than the expected values. These seem to be related with high stress drop in source as well as low attenuation along the propagation path in case of intraslab earthquakes.

We carried out strong motion simulation based on the empirical Green's function method to investigate the source characteristics of intraslab earthquakes. Using the empirical Green's function method, we can construct the source model to explain observed waveforms in broadband frequency range (Irikura, 1986; Miyake et al., 1999). We used the observed waveforms of a small event occurring at each source region as the empirical Green's function, and estimated the number, size, and location of asperity (strong motion generation area), rise time, and rupture propagation velocity of target events by forward modeling.

Since the combined area of asperities obtained for each earthquake is about 14-66% of values predicted by the empirical relation for inland crustal earthquakes proposed by Somerville et al. (1999), the stress drops on asperity of shallow intraslab earthquakes are higher than those of inland crustal earthquakes. The ratios between the combined area of asperities obtained in this study and the value predicted from the empirical relation decrease with focal depth. The stress drops on asperity of shallow intraslab earthquakes increase with focal depth.

We used the strong motion data from K-NET, KiK-net, and F-net operated by the National Research Institute for Earth Science and Disaster Prevention (NIED) and the CMT solutions by F-net and Harvard University. We also used the hypocentral information provided by the Japan Meteorological Agency (JMA).

S72B-1150 1330h POSTER

Calibration for Coda Derived Moment Magnitude Using Berkeley Complete Waveform Moment-Tensor Solutions

Fumiko TAJIMA[1] ((0824) 24-7463; fumiko@geol.sci.hiroshima-u.ac.jp)

Kevin M MAYEDA[2] ((925) 423-5913; kmayeda@llnl.gov)

Douglas S DREGER[3] ((510) 643-1719; dreger@seismo.berkeley.edu)

Gilead WURMAN[3] ((510) 643-1719; gwurman@seismo.berkeley.edu)

[1]Hiroshima University, Department of Earth and Planetary Systems Science, Kagamiyama 1-3-1, Higashi Hiroshima Ci 739-8526, Japan

[2]Lwrence Livermore National Laboratory, P.O. Box 808, L-205, Livermore, CA 94550, United States

[3]University of California at Berkeley, Department of Earth and Planetary Science, 283 McCone Hall, Berkeley, CA 94720, United States

The method of seismic moment-tensor determination using complete waveforms (Dreger and Helmberger, 1993; Pasyanos et al., 1996) provides stable solutions for local and regional events if the data propagation paths are well-calibrated to calculate Green's functions. However, this waveform modeling approach has a limitation to apply to smaller events with the cut-off magnitude of approximately 3.5 due to reduction of S/N ratios in the passband employed. We carried out an experiment to extend the moment magnitude scale to smaller events (M<3.5) in northern California using an empirical method of coda derived moment magnitude (M_w(coda)) calibration (Mayeda et al., 2002). The basic assumption of this approach is that the coda spectra are the results of scatters from randomly distributed inhomogeneities in the crust and represent seismic energy propagation, independent of the source radiation pattern, as a function of propagation distance with a specific attenuation rule. In practice we found that when the data propagation paths cross a wide range of different structural areas, the standard deviation of the parameters is large and the parameter estimation is less coherent. Thus, in the course of calibration the entire northern California is divided into several tectonic subregions, in each of which the calibration parameters are relatively coherent. The present study suggests a conservative application of the coda envelope calibration method to estimate M_w(coda) that avoids ambiguities.

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S72C MCC: 133 Sunday 1330h

Plumes, Hot Spots, and Calderas II

(joint with G, GP, OS, T, V, DI)

Presiding: **U Achauer,** Institute de Physique du Globe (IPG)**; G Ito,** University of Hawaii

S72C-01 1330h

En Echelon Volcanic Ridges Along Seamount Chains Result from Episodic Changes In Stress Orientations That Open Cracks to the Asthenosphere and Permit Magma Ascent: They do not Require Plumes

Edward L. Winterer[1] (858-534-2360; jwinterer@ucsd.edu)

Mary Ann Lynch[2] (LynchMaryAnn@netscape.net)

[1]Scripps Institution of Oceanography, 9500 Gilman Dr., La Jolla, CA 92093-0220, United States

[2]Professional Services, P.O. Box 4032, Warren, NJ 07059, United States

An alternative to the plume/hotspot hypothesis for seamount chains is formation via cracks through the lithosphere. Many Pacific Cenozoic seamount chains comprise intermittently spaced volcanic ridges aligned en echelon to the overall trend of the chain, a pattern that reflects tensional stresses in the lithospheric plate at angles to the trend. The overall trend is a line of incipient cracking close to the average direction of plate motion in the fixed-Antarctica reference frame. The ridges mark episodic, relatively local deviations in the orientation of the stress field, permitting the incipient tensional cracks to open through the lithosphere to the asthenosphere. The upper parts of the asthenosphere are at the solidus temperature, as manifested in lower seismic velocities indicating the presence of small fractions of melt, such that through-going cracks allow magmas to form and ascend toward the surface where they erupt to form the volcanoes and en echelon ridges. High fertility of the source region favors increased volumes of magma. Cracks typically break though in the younger parts of the lithosphere, which is thinner and weaker than older lithosphere, but cracking is possible anywhere along the volcanic trend where the lithosphere is thin or weak. Cracking is common, for example, along the thinned lithosphere of the boudinage-like structures imaged on regional gravity maps, as in the Pukapuka chain, which follows one of the regional gravity lows. There, the time sequence of volcanic ridges is not progressive. The markedly different orientation of the youngest parts of the Hawaiian chain, compared to the long-term average trend of the chain, may record a change in regional stress orientations in the Pacific plate beginning about 3-4 Ma, reflected also in the Marquesas and younger parts of the Society Islands.

The en echelon crack mechanism requires no excessive "hotspot" temperatures and no plumes.

S72C-02 1345h INVITED

Seismic Evidence for a Plume Beneath the Galápagos Hotspot

Douglas R Toomey[1] (drt@newberry.uoregon.edu)

Emilie E E Hooft Toomey[1,2] (emilie@newberry.uoregon.edu)

Sean C Solomon[2] (scs@dtm.ciw.edu)

David E James[2] (james@dtm.ciw.edu)

Minard L Hall[3] (geofisico@accessinter.net)

[1]Dept. of Geol. Sci., Univ. of Oregon, Eugene, OR 97403, United States

[2]DTM, Carnegie Institution of Washington, Washington, DC 20015, United States

[3]Instituto Geofisico, Escuela Politecnica Nacional, Quito 1701-2759, Ecuador

The Galápagos hotspot and Galápagos Spreading Center system provide a promising environment for testing further the plume hypothesis and for developing a comprehensive model of hotspot magmatism and hotspot-ridge dynamics. The near-ridge setting of the Galápagos hotspot and its location with respect to seismic sources provide unparalled opportunities to image upper-mantle anomalies associated with hotspots and ridges. Here we report on a reconnaissance, land-based seismic experiment designed to image the structure of the crust and upper mantle beneath the archipelago. The data comprise broadband, three-component seismograms recorded at twelve sites; the aperture of the seismic network is 300 km.

Initial results indicate that the Galápagos hotspot is underlain by an anomalously thin transition zone and by an upper-mantle low-velocity anomaly consistent with a mantle plume. The transition-zone structure of the Galápagos region in general is similar to that of the Pacific basin in areas removed from hotspots and to sites within the western U.S. However, a subset of data that sample a region centered to the west-southwest of Isabela indicates a 45-km thinning of the mantle transition zone. To produce this thinning by a plume that penetrates the transition zone requires a temperature anomaly of as much as 300 K relative to the average Pacific basin or tectonically active North American sites. This value is similar to the temperature anomaly inferred by others for the Hawaiian plume and is twice as large as the thermal anomaly inferred for Iceland. Tomographic inversion of body-wave delay times reveals a pronounced low-velocity anomaly centered near the southwestern corner of Isabela, above the area of thinned transition zone. This anomaly, which we interpret to be the axis of the plume, is narrower than the anomaly imaged beneath Iceland. At depths less than 150 km the region of lowest seismic velocities, inferred to be plume-derived material, is deflected first to the northeast beneath the central archipelago and then to the north-northwest along the Wolf-Darwin

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