We are investigating the utility of short-period, high-resolution surface-wave slowness maps for lowering detection thresholds and allowing for discrimination of explosions and earthquakes at lower magnitudes (3.0-4.8). We focus on the region of central Asia between 69 and 108 degrees east longitude and 29 and 54 degrees north latitude. We retrieved broadband waveform data from more than 1,100 events that occurred between January 1997 and May 2002. Waveforms were obtained from four different networks comprising 13 individual stations. Using multiple-filter and phase-matched filter techniques, we measured the dispersion characteristics of the signals between 6 and 30 seconds. These Rayleigh-wave group velocity dispersion curves were used to compute high-resolution, half a degree cell size, slowness tomographic maps for each period. We adopted a Bayesian tomography method to solve the equation that relates travel-time data with the slowness structure. We used a declustering technique to minimize the effect of event clusters on the results. Our model is similar, to some extent, to the a priori model, but contains more structure and the cell size is smaller (0.5 compared to 1 degree cell size for the a priori model). The tomographic patterns correlate well with known geologic and tectonic features in the area. Accumulations of relatively young sediments across Eurasia are greater than on any other continent due to the continuing rapid uplift across much of central Asia. The short periods are primarily sensitive to upper crustal structures. The tomographic images display low velocities associated with the known sedimentary basins - Tarim, Junggar and Quaidam basins - in the area of central Asia under study. High velocities are associated with mountainous tectonic features such as the Tien Shan. We validated our maps using Rayleigh group-velocity dispersion curves for 640 events that occurred on the region of interest between January 1993 and December 1996. We analyzed group velocity residuals between the new model and the a priori model using these independent measurements. The overall refined model predictions are good. More over, they show a significant improvement at short and intermediate periods (6 to 15 s) with respect to the a priori model. The refined model also shows a 15 percent improvement in the detection of surfaces waves with respect to previous 1D models. Therefore, these improved high-resolution, short-period tomography maps can be used to lower the Ms detection thresholds to be used for construction of regional mb:Ms discriminants.

S32B-0848 1330h POSTER

A Comparative Study of Intermediate-Period Surface Waves From Kiloton-Size Mining Explosions in Northeast China and Western United States

Rong-Mao Zhou[1] (1-214-768-2747; zhou@passion.isem.smu.edu)

Brian W. Stump[1] (1-214-768-1223; stump@passion.isem.smu.edu)

Yun-Tai Chen[2] (86-10-68415370; chenyt@cdsn.org.cn)

[1]Southern Methodist University, Dept. of Geological Sciences P.O. Box 750395, Dallas, TX 75275-0395, United States

[2]Institute of Geophysics, China Seismological Bureau, Beijing 100081, China

Kiloton size mining explosions are typically used to remove overburden or to fragment rocks for resource recovery. Large mining explosions are conducted with delays between individual charges in an array resulting in source durations as great as several seconds. The total size of the explosion, its time duration and spatial characteristics can generate short- to intermediate-period (2-20 sec) surface waves. These intermediate period surface waves provide the opportunity to constrain upper crustal shear structure and attenuation. We report on a comparative study using regional seismic data generated by mining explosions in Northeast China and Western United States. The regional surface waves from the Western US were generated by a large-scale cast blast in a Wyoming coal mine. The intermediate-period surface waves in Northeast China were generated by a mining explosion in an iron mine. Two seismic networks with STS-2 broadband seismometers were deployed around the coal-mine and close to the iron-mine at regional distances. Fundamental mode Rayleigh waves were generated by these two mining explosions and are utilized to constrain the crustal structure in each region regions. The group velocities of fundamental mode Rayleigh wave were determined by using the multiple filter analysis and refined by phase matched filtering technique. The surface wave dispersion curves covered the period range of 2 to 18 sec for the coal-mine explosion with group-velocities range from 1.3 to 3.0 km/sec and 1.5 to 10 sec from the iron-mine explosion with the group-velocities range from 2.6 to 3.3 km/sec, respectively. Station specific velocity models were determined for each station and are consistent with the known shallow crustal structure in each area.

S32B-0849 1330h POSTER

Site Effect for KNET Stations in Middle Asia: the Directional Dependence of P-Wave Energy From Results on Magnitude mb Residual

Vladislav G. Martynov[1] (1-858-822-0710; vladik@epicenter.ucsd.edu)

Frank L. Vernon[1] (1-858-534-5537; vernon@epicenter.ucsd.edu)

Deborah Kilb[1] (1-858-822-4607; dkilb@epicenter.ucsd.edu)

Jonathan Tytell[1] (1-858-534-9679; jtytell@epicenter.ucsd.edu)

[1]IGPP/SIO/UCSD, 0225, La Jolla, CA 92093, United States

We present results on site effects for the determination of magnitude mb. We collected data from teleseismic events ($30^\circ < \Delta < 80^\circ$) recorded by the Kyrgyz Digital Seismic Network (KNET) in northern Tien Shan from 1991 to 1998. Our results show mb residual with respect to reference data from PDE catalog has significant directional variation, from -0.1 to -0.8 unit of mb scale. We discuss the alternative sources of directional dependence of P-wave energy in terms of seismic attenuation and local bedrock topography structure beneath KNET.

S32B-0850 1330h POSTER

Investigation of crustal structure throughout Middle East, North Africa and Southern Europe using receiver functions and surface-wave dispersion

Minoo Kosarian[1] (1-814-865-3622; mkosarian@geosc.psu.edu)

Charles J Ammon[1] (814 865-2310; cammon@geosc.psu.edu)

Michael E Pasyanos[2] (pasyanos1@llnl.gov)

William R Walter[2] (walter5@llnl.gov)

Robert B Herrmann[3] (rbh@eas.slu.edu)

[1]Penn State, Department of Geosciences 503 Deike Building, University Park, PA 16802, United States

[2]Lawrence Livermore National Laboratory, Energy and Environmental Sciences, Livermore, CA 94551, United States

[3]Saint Louis University, Department of Earth and Atmos. Sci. 3507 Laclede Avenue, St. Louis, MO 63103, United States

Mapping Earth's structure remains an important, challenging problem. Although, considerable research has been devoted to map lithospheric structure with different data sets, less attention has been given to estimating Earth's structure using multiple data sets. The aim of this research is to estimate lithospheric structure of diverse tectonic environments by applying joint inversion of receiver functions and surface-wave dispersion methods to provide constraints on the character of the lithosphere (crustal velocities and thickness, crust-mantle transition velocity contrast). We included data from 49 more permanent and temporary three-component broadband seismic stations located in the research areas. We computed over 4900 receiver functions for 69 stations for the period of 1990-2003. Many of the sites have been carefully investigated by other researchers using receiver functions that provide good benchmarks for comparing our results. We first applied the thickness-Vp/Vs ratio estimation procedure of Zhu and Kanamori [2000] to estimate crustal thickness and Poisson's ratio. For most stations crustal thickness estimates are consistent with previous geophysical and or seismological work but several stations produce some differences from standard models. For the joint receiver-function surface-wave-dispersion inversions, we use localized group velocities for both Love and Rayleigh waves from tomographic analyses with a 2-degree resolution in the period of 10 to 100 seconds. We present results from the thickness-Vp/Vs stacking procedure and joint inversions for select stations.

URL: http://eqseis.geosc.psu.edu/~cammon/AGUF03B

S32C MCC: 3011 Wednesday 1340h

Splitting and Anisotropy II *(joint with T, MR)*

Presiding: **M D Long,** Massachusetts Institute of Technology**; S Y Schwartz,** University of California, Santa Cruz

S32C-01 1340h

Shallow Anisotropy in the Mediterranean Mantle From Surface Waves

Federica Marone[1] (federica@seismo.berkeley.edu)

Suzan van der Lee[2] (suzan@tomo.ig.erdw.ethz.ch)

Domenico Giardini[3] (giardini@seismo.ifg.ethz.ch)

[1]Berkeley Seismological Laboratory, University of California, 215 McCone Hall, Berkeley, CA 94720, United States

[2]Dept. of Geological Sciences, Northwestern University, 1850 Campus Dr., Evanston, IL 60208, United States

[3]Institute of Geophysics, ETH-Hönggerberg (HPP), Zurich 8093, Switzerland

In this study, we advance new evidence for the existence of the Love-Rayleigh discrepancy in the Mediterranean region and provide information on the average polarization anisotropic structure of the Mediterranean mantle. Using PWI (Nolet, 1990), we analysed about 1800 Rayleigh and Love waveforms from regional events recorded at 3-component broad band seismic stations of the MIDSEA and other networks in this region. Not one of the 3-component seismograms showing both Rayleigh and Love waveforms with an acceptable quality could be fit with a single 1D isotropic model characterized by a velocity smoothly varying with depth. However, satisfactory fits for individual Rayleigh and Love waveforms could often be obtained using realistic 1D velocity models. These 1D path-average velocity structures have been used in the framework of PWI to derive 3D S-velocity models for the Mediterranean region. The uppermost mantle velocity structure retrieved from Rayleigh waveforms is consistently slower than velocities obtained from Love wave data. We suggest that the observed Love-Rayleigh wave incompatibility is most likely caused by radial anisotropy. However, the Love wave data are not only incompatible with the Rayleigh wave data but are also internally less compatible than the Rayleigh wave data set. This difference in internal compatibility and the non-uniqueness of tomographic inversions prevent a meaningful quantitative comparison of the 3D SV- and SH-velocity models independently derived from Rayleigh and Love wave data, respectively. Instead we study the SH-SV velocity difference necessary to fit both Love and Rayleigh data with a smoothly varying velocity model, by inverting the Love wave data relative to the 3D SV-velocity model EAV03 derived from the Rayleigh wave data set. This procedure leads to remaining Love data residuals that are comparable to those obtained in an independent inversion of the Love wave data and to 3D SH-velocity models that have more similarities with the better constrained SV-velocity model EAV03. Our preferred 3D SH-velocity model has been obtained in a strongly damped inversion towards EAV03, which ensures that it shows only the minimum deviation from EAV03 and thus the simplest anisotropic structure necessary to fit all data. Our results show that Love waves require higher velocities (about 200 m/s) compared to Rayleigh waves in the sub-Moho mantle, between 30 and 120 km depth. Deeper anisotropy could exist, but is not necessary to explain our data. We relate the observed anisotropy to lattice-preferred orientation of crystallographic axes of elastically anisotropic minerals such as olivine, as suggested, throughout the Mediterranean region, by SKS splitting measurements. Due to the strongly heterogeneous upper mantle structure and to the complex lateral variation of the lithosphere-asthenosphere boundary in this region, it is not possible to discriminate between frozen-in preferred orientation of olivine in the lithosphere or alignment of olivine crystals in a present-day asthenospheric flow.

S32C-02 1355h

Lateral Variations in Radial Anisotropy Down to 1200 km Depth

Caroline Beghein[1] (+31 30 253 5145; beghein@geo.uu.nl)

Jeannot Trampert[1] (jeannot@geo.uu.nl)

[1]Utrecht University, Budapestlaan 4 PO Box 80021, Utrecht 3508 TA, Netherlands

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The presence of radial anisotropy in the upper mantle, transition zone and top of the lower mantle is investigated by applying the neighbourhood algorithm to degree 8 Rayleigh and Love wave phase velocity models constructed from fundamental mode and overtone measurements. Probability density functions are obtained for S-wave anisotropy (ξ), P-wave anisotropy (ϕ), intermediate parameter η, equivalent isotropic V_p and V_s anomalies and density perturbations. Shear wave anisotropy with $V_{SH} > V_{SV}$ is found down to the transition zone. The signal within continents is clearly age-related in the top 220 km, with platforms and tectonically active regions characterized by a rapid decrease in ξ with depth while cratons display a more constant signal, extending slightly deeper than the 220-discontinuity. A similar age dependence of S-wave anisotropy is also observed beneath oceans, with a strong and rapidly decreasing anisotropy for young oceans and a more constant anisotropy for older oceans. $V_{SH} > V_{SV}$ is also found in the transition zone, most likely occurring beneath oceans (and stronger for young oceanic areas than for old ones), but not beneath continents. This could indicate a possible deep origin for ocean ridges. In the uppermost mantle, η presents a similar depth dependence as ξ in various age-related regions, and perturbations in P-wave anisotropy are small and limited to the shallowest part of the continents. Both P-wave anisotropy and η change sign below 220 km depth beneath the oldest oceans and beneath continental regions, which might reflect a change in the mechanical behaviour of the materials in these regions. Below 400 km depth, no strong deviation from PREM for ϕ or η is required by the data. Likelihoods were also obtained for the ratios $d\phi/d\xi$ and $d\eta/d\xi$ in different regions. We find strong lateral variations in $d\eta/d\xi$ beneath continents in the top 100 km, with a clear change of sign between old cratons and younger continental areas. This could indicate age-related chemical variations in the continents or changes in the strain field that aligns crystals in the uppermost mantle. At larger depths the distributions are wide and they show that the data do not favour any particular relation between perturbations in the anisotropic parameters. Similar observations can be made for $d\phi/d\xi$, but the change of sign in the uppermost mantle is not as clear as the one found for $d\eta/d\xi$.

S32C-03 1410h

Development of Automated SKS Splitting Measurement - an Additional Parameter to be Provided by the ISC

Matthew S Evans[1] (+44 1635 861022; matt@isc.ac.uk)

John-Michael Kendall[1] (kendall@earth.leeds.ac.uk)

Raymond J Willemann[2] (ray@isc.ac.uk)

[1]School of Earth Sciences, University of Leeds, Leeds LS2 9JT, United Kingdom

[2]International Seismological Centre, Pipers Lane, Thatcham RG19 4NS, United Kingdom

We have implemented an automated system to measure shear wave splitting in SKS and SKKS arrivals for stations and networks where waveform data are freely available and archived. The ISC plans to include these measurements in its On-line Bulletin as an aid to studies of anisotropy in the Earth. We make automated measurements only for strong, clear signals, and at distances where there is no chance of contamination from S, ScS, Sdiff or other phases, as predicted by the IASP91 earth model. Phase onset is more accurately identified using a simple STA/LTA picker. When a polarised shear wave passes through an anisotropic medium, it is split into two perpendicular S-waves that are separated in time. In measuring splitting, we seek a polarisation angle and time shift that removes the effect of the anisotropy, minimising either the energy on the transverse component or the smaller of the two eigenvalues calculated from the covariance matrix. We report results from both methods, as we find differences between the two to appear to be systematic at some stations. Error estimates are calculated using both the methods of Silver and Chan (1991) and Sandvol and Hearn (1994). As well as the above error estimates, we include two other quality control parameters. We calculate the ratio of eigenvalues (min/max) calculated from the covariance matrix of both the uncorrected and corrected waveforms. For the uncorrected waveforms, if this ratio (min/max) is smaller than a set threshold, we conclude that there is insufficient initial energy on the transverse component for results to reliably measure splitting. Similarly, for the corrected waveforms, if this ratio is too high, then the splitting parameters that we computed are unreliable because they failed to transform the particle motion to expected linearity. We find good correlation between these automated results and manual measurements made on data from stations in the Canadian National Seismic Network, and plan to apply these methods to data from stations distributed globally in the near future.

S32C-04 1425h

Shear wave splitting and upper mantle anisotropy beneath Japan

Maureen D. Long[1] (617-253-3589; mlong@mit.edu)

Rob D. van der Hilst[1] (617-253-6977; hilst@mit.edu)

[1]Department of Earth, Atmospheric, and Planetary Sciences, Massachusetts Institute of Technology, 77 Massachusetts Ave., Cambridge, MA 02139, United States

Shear wave birefringence is a consequence of seismic anisotropy and is often used, with constraints from mineral physics, to characterize the pattern of upper mantle deformation. In the context of a subduction zone, however, the relationship between measured shear wave splitting parameters (ϕ, δt) and geodynamical processes is not straightforward. The three-dimensional pattern of anisotropy in a subduction zone may reflect processes such as corner flow in the mantle wedge, flow around the slab edge, back-arc extension, and motion of the overriding plate. This relationship may be further complicated by complex slab morphology, by the presence of frozen anisotropy in the slab itself, and by the presence of volatiles such as water. In this study, we take advantage of dense station coverage in Japan and use seismic phases covering a wide range of incidence angles, incoming polarization angles, and backazimuths. We take advantage of the good data coverage needed to consider complexities in structure such as multiple anisotropic layers, dipping symmetry axes, and small-scale lateral variations in anisotropic properties. We utilize data from the Japanese F-net network, which comprises 65 broadband seismic stations. We have compiled a database of approximately 1500 splitting measurements of S, SKS, and SKKS phases at F-net stations, and investigate the variations of measured splitting parameters with incoming polarization angle and incidence angle. In the southern part of the array, along the Ryukyu arc, we find that fast directions are consistently trench-parallel, with splitting times of 1 second or more. Moving northward along the array, the measured splitting patterns become more complicated, with significant variations in apparent splitting parameters that indicate complex anisotropic structure. Additionally, measured fast directions vary significantly over short length scales, and stations separated by less than 100 km often exhibit very different splitting behavior. This increase in complexity of anisotropic structure coincides geographically with the complicated slab morphology of the subducting Pacific plate. At stations on Hokkaido, to the north, and Kyushu, to the south, we see some evidence that the fast direction of anisotropy may rotate from trench-parallel close to the trench to subduction-parallel further away from the trench, which may correspond to a change in stress conditions and/or volatile content.

S32C-05 1440h

Analysis of teleseismic *P*, *S*, and *SKS* waves recorded in the Mediterranean region

Christian Schmid[1] (+41 1 633 2605; schmid@tomo.ig.erdw.ethz.ch)

Suzan van der Lee[2] (suzan@earth.northwestern.edu)

Domenico Giardini[1] (giardini@seismo.ifg.ethz.ch)

[1]Inst. of Geophysics, ETH Honggerberg, Zurich CH-8093, Switzerland

[2]Dept. of Geological Sciences, 1850 Campus Dr. Northwestern University, Evanston, IL 60208

The Mediterranean region comprises a large and highly complex part of the Africa-Eurasia plate boundary. The plate boundary deformation in this region has been dominated by compression accommodated by several zones of subduction. Other zones are characterized by extension. Consequently 3-D Mediterranean upper mantle structure is heterogeneous. We determined azimuthal anisotropy in the Mediterranean region by measuring splitting of SKS waves. The distribution of the fast axis is laterally consistent, and correlates with plate motion at many stations. We observe E-W alignment in the Western part of the Mediterranean, while N-S directions are observed farther east. The transition between these domains occurs over Italy, with the strongest anomalies over the Calabrian subduction zone. Here the largest splitting times in the Mediterranean are observed with values up to 2s. In contrast, stations associated with the Hellenic subduction show small splitting times with a fast axis that is not well defined. We have also measured delay times of teleseismic *P* and *S* waves from seismograms recorded by the MIDSEA and permanent seismic arrays in the region. The vertical and transverse components of recordings from about 90 events with a distance range from 30° to 100° were analyzed to derive delay times for *P* and *S* waves. We derived relative delay times by cross-correlating the recordings from different stations. The pattern of mean station delays for *P* resembles that for *S* and *S* delay times are about 3 times larger than those for *P*. As expected, most prominent early arrivals are observed around subduction zones such as the Hellenic one. Latest arrivals are observed near the Dead Sea Transform. Furthermore we determined the azimuthal dependence of the *P* delay times and compared the results with those from the splitting analysis, with the goal of determing the relative importance of anisotropy compared to lateral heterogeneity. We find that the influence of heterogeneity is several times that of anisotropy. From an observed slight dependence of the measured delay times on wave frequency, we estimate that heterogeneity on length scales of over 100 km is primarily responsible for the observed delay times.

URL: http://www.sg.geophys.ethz.ch/midsea

S32C-06 1455h

Vertical Distribution of Seismic Anisotropy Beneath the Western Flank of the Gulf of Suez.

Lucia Margheriti[1] (margheriti@ingv,it)

Vadim Levin[2] (vadim@ldeo.columbia.edu)

Silvia Pondrelli[3] (pondrelli@bo.ingv.it)

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

[2]Department of Geological Sciences, Rutgers University, 610 Taylor Road, Piscataway 08854, Italy

[3]Istituto Nazionale di Geofisica e Vulcanologia, Via D. Creti 12, Bologna 40128, Italy

We investigate the vertical distribution of seismic anisotropy beneath the site on the western flank of the Gulf of Suez. The area was affected by rifting during early stages of the Arabian-Nubian Shield breakup, but became quiescent at ~15 Ma when the locus of rifting shifted to the Gulf of Aqaba. We use two complimentary techniques sensitive to seismic anisotropy: birefringence in teleseismic SKS phases, and receiver function analysis focused on directional and epicentral systematics of SH-polarized converted waves. While the first method provides an integral measure of anisotropic properties, the second is sensitive to abrupt changes in them. Data used in the analysis were collected by the station KEG (Kottamya, Egypt) operated as a part of the MEDNET project from 1990 through 1999. Measurements of shear wave splitting yield fast directions in the range of 20°-40°NE for the majority of observed backazimuths. A significant minority of observations, clustered around backazimuths of 85°-90° and 260°-270°, displays more northerly fast directions. Such systematic variations in the value of fast direction are expected if the anisotropic fabric varies with depth. Indeed, numerous phases indicative of anisotropy are evident in the receiver functions. Most conspicuously, the crust-mantle transition displays characteristic traits of anisotropy, with transversely polarized pulses of opposite polarity observed from the northeast and from the west. The likely orientation of the symmetry axis for these phases is within 15° of south. Additionally, a shallow converted phase (2 s delay) exhibits polarity changes near backazimuths of 60° NE and 310° NW, while a deeper feature (~12 s delay) seen from the west change polarity around backazimuth of 300°. We construct a vertical profile of seismic properties (velocity and anisotropy) beneath station KEG by jointly modeling the receiver functions and the pattern of fast shear wave directions. Inferred depths, types and orientations of anisotropy-inducing fabrics are interpreted in the context of the tectonic history of the region.

S32C-07 1510h

The anisotropic seismic structure of the upper mantle beneath Mexico

Eric Matzel (925-422-0772; matzel1@llnl.gov)

Lawrence Livermore National Laboratory, 7000 East Ave L-206, Livermore, Ca 94551, United States

We present models for the P and S velocity structure of the upper mantle beneath Mexico, including measurements of radial anisotropy. The data are 3-component broadband seismograms from sources located in southern Mexico and Guatemala recorded at seismic stations located in the southwestern United States. From this we obtained a series of densely sampled SE-NW trending paths covering the major tectonic features of Mexico. Waveform data were inverted to obtain 1D models for each of these paths. The mantle beneath Mexico is characterized by a radially anisotropic seismic lid, which thickens from west to east, overlying a low velocity zone. Most of the variation between profiles occurs in the top 200 km, generally related to subduction. S anisotropy is high in the lid (6-8%), but the mantle is largely isotropic below that. P anisotropy is not well resolved, but P structure mimics the SH velocity structure, suggesting that P is also anisotropic within the lid. The VP/VSH ratio (1.86) is nearly constant as a function of depth from the Moho through the transition zone.

S32C-08 1525h

Anisotropic Parameter Estimation From PP and PS Waves in 4-Component Data

Bärbel Traub[1,2] (bt@bgs.ac.uk)

Xiang-Yang Li[1] (xyl@bgs.ac.uk)

Roger Scrutton[2] (Roger.Scrutton@ed.ac.uk)

[1] British Geological Survey, Murchison House, West Mains Road, Edinburgh EH9 3LA, United Kingdom

[2] University of Edinburgh, Grant Institute, West Mains Road, Edinburgh EH9 3JW, United Kingdom

In recent years we have seen that in many cases anisotropy cannot be neglected in seismic processing routines. Furthermore we know that sea-bed properties play an important role in marine seismics, particularly for sea-bed multicomponent seismic, because they significantly influence the amplitudes, phases and travel times of seismic waves.
In this work we investigate how reliably we can extract anisotropy parameters from P- and PS-wave data using near-surface layer multicomponent data from the Alba Field, North Sea. Near-surface data is affected by apparent anisotropy due to a vertical velocity compaction gradient. Furthermore, we can see phase reversals in the pressure wave data set which will lead to erroneous anisotropy parameter values. Thus, the imaging of the target area is affected. We extract the P-wave anisotropy parameter η (Alkhalifah and Tsvankin, 1995) which can be related to Thomsen's ϵ and δ formulation (Thomsen, 1986) by $\eta = (\epsilon - \delta)/(1 + 2\delta)$ from P-wave data and compare the result with reference values from a model, built according to well, VSP and surface data. As the parameters show differences up to an order of magnitude we use PS-wave data to estimate the effect of anisotropy. The effect of anisotropy on the converted waves in a single layer can be described by the parameter

$$\chi = (\gamma_0 - 1)\gamma_{eff}^2 \eta, \;\; with \; \gamma_{eff} = \frac{\gamma_2^2}{\gamma_0},$$

where γ_0 is the vertical velocity ratio, γ_2 the rms velocity ratio and $\gamma_{\rm eff}$ the effective velocity ratio. This equation is true for a single TIV layer. In this case η can be calculated from χ and vice versa. Thus, estimating χ from converted-wave data we can compute η for the near-surface events. The resulting parameters fit the reference values much better and show values of the same order of magnitude.

S32D MCC: 3009 Wednesday 1340h

Stress Transfer, Triggered Earthquakes, and Time-Dependent Seismic Hazard III *(joint with G, T, NG)*

Presiding: **I G Wong,** Seismic Hazards Group, URS Corporation**; G Anderson,** U.S. Geological Survey

S32D-01 1340h

Is earthquake triggering driven by small earthquakes?

Agnes Helmstetter (310 825 0961; helmstet@moho.ess.ucla.edu)

Institute of Geophysics and Planetary Physics, University of California Los Angeles, 3845 Slichter Hall, Los Angeles, CA 90095-1567, United States

Using a catalog of seismicity for Southern California, we show that the number of triggered earthquakes increases exponentially with the mainshock magnitude. The trade-off between this scaling and the distribution of earthquake magnitudes controls the relative role of small compared to large earthquakes. We show that seismicity triggering is driven by the smallest earthquakes, which trigger fewer aftershocks than larger earthquakes, but which are much more numerous. The magnitude of triggered earthquakes obeys the Gutenberg-Richter distribution, with the same b-value as other earthquakes, independently of the size of the triggering earthquake. We propose that the nontrivial scaling of the number of aftershocks with the mainshock magnitude emerges from the fractal spatial distribution of aftershocks. These observations highlight the importance of taking into account the effect of small earthquakes to model earthquake triggering.

S32D-02 1355h

Importance of direct and indirect triggered seismicity and derivation of Bath's law for the largest aftershock

Didier Sornette[1,2] (sornette@moho.ess.ucla.edu)

Agnes Helmstetter[1] (helmstet@moho.ess.ucla.edu)

[1] Department of Earth and Space Sciences and Institute of Geophysics and Planetary Physics, University of California Los Angeles, 3845 Slichter Hall, Los Angeles, CA 90095-1567, United States

[2] Laboratoire de Physique de la Matiere Condensee, Universite de Nice-Sophia Antipolis, Parc Valrose, Nice 06106, France

Using the simple ETAS branching model of seismicity, which assumes that each earthquake can trigger other earthquakes, we quantify the role played by the cascade of triggered seismicity in controlling the rate of aftershock decay as well as the overall level of seismicity in the presence of a constant external seismicity source. We show that, in this model, the fraction of earthquakes in the population that are aftershocks is equal to the fraction of aftershocks that are indirectly triggered and is given by the average number of triggered events per earthquake. Previous observations that a significant fraction of earthquakes are triggered earthquakes therefore imply that most aftershocks are indirectly triggered by the mainshock. For some values of the parameters, the ETAS model also reproduces Bath's law, which states that the average magnitude difference $\langle \Delta m \rangle$ between a mainshock and its largest aftershock is 1.2, regardless of the mainshock magnitude. We first point out that the standard interpretation of Bath's law [Vere-Jones, 1969] in terms of the two largest events of a self-similar set of independent events is incorrect, because it neglects the selection procedure entering the definition of aftershocks. We reconcile Bath's law with (i) the existence of a universal Gutenberg-Richter (GR) law for all earthquakes and (ii) with the empirical observation (productivity law) that each earthquake of magnitude m triggers other earthquakes at a rate $\sim 10^{\alpha m}$ with $\alpha \approx 0.8$.

S32D-03 1410h

Testing of hypotheses associated earthquake clustering features by using the stochastic reconstruction method

Jiancang Zhuang[1] (81+3-5421 8780; zhuangjc@ism.ac.jp)

Yosihiko Ogata[1] (81+3-5421 8744; ogata@ism.ac.jp)

David Vere-Jones[2] (dvj@mcs.vuw.ac.nz)

[1] Institute of Statistical Mathematics, Minana Azabu 4-6-7, Minato-Ku, Tokyo 106-8659, Japan

[2] Victoria University of Wellington, P.O.Box 600, Wellington 00000, New Zealand

Based on Ogata's ETAS model and the thinning procedure, we firt give an iterative approach to estimate the background occurrence rate, which is a function of locations but constant of time, and the parameters of the clustering struction, simultaneously. We then discuss the methods for sperating the seismicity in a given catalogue into a background component and a clustering component and for classifying the earthquakes into different clusters stochastically. The keys of these methods are the probabilities of one event being a direct offspring of another event or being a background event. Making use of these probabilities, we can reconstruct the functions associated with the characteristics of earthquake clusters, which enable us to test a number of important hypotheses about the earthquake clustering phenomena. In this paper, using the JMA catalogue for illustruction, the results show the following assertions: (a) The function forms provided on each clustering component in the formulation of Ogata's ETAS model are good enough as a first approximation in describing earthquake clusters; (b) the background events trigger offspring in a different ways from the triggered events; (c) The diffusion of the aftershock sequence is mainly caused by the cascades of individual trigger processes, while each individual process for triggering direct offspring is not diffusive; (d) the scales of the area of triggered events are mainly associated with the triggering ability of their direct ancestor.

S32D-04 1425h

Detection of Anomalous Seismicity as a Stress Change Sensor

Yosihiko Ogata (+81-3-5421-8744; ogata@ism.ac.jp)

Institute of Statistical Mathematics, Minami-Azabu 4-6-7, Minato-Ku, Tokyo, TKO 106-8569, Japan

Seismic quiescence has been attracting the attention as one of the precursors to a large earthquake. Also, it has been getting more attention than ever that the stress changes due to a slip can explain the mechanism of triggering another event. Likewise, seismic quiescence due to stress lowering transferred from a rupture or silent slip elsewhere can be discussed as a general phenomenon. Specifically, the quiescence in an active focal area could be found in the shadow zones where Coulomb stress change would be negative from a seismic or aseismic slip nearby. The seismicity rate lowering could be well seen in the regions where the activity has been high, including aftershock activity itself. To see the seismicity change explicitly, however, we need to fit a statistical model of either the modified Omori formula or its extension (the ETAS model [Ogata, 1992]), to the seismic activity before the suspected triggering time. Then, the activation and lowering of the seismicity relative to the predicted one by the model are of great concern to explore matching the pattern of Coulomb's stress changes due to a rupture or silent slip. A number of such examples from the recent activities in Japan will be shown. These lead us to a summarized observation that even a small size of negative ΔCFF down to the order of millibars can trigger such lowering, which is also supported by the Dieterich's seismicity rate equation [Dieterich, 1994; Toda and Stein, 2002]. Thus, we expect that aftershock and general seismic activity relative to the modeled rates is sensitive enough to measure a slight negative stress change. An earthquake prediction scenario from the implication of the relative quiescence is based on the asperity hypothesis in the sense that precursory slip around asperities applies more shear stress to the asperities, which in turn promotes the rupture of the main fault. However, on the other hand, aseismic slips in some region is not necessarily a precursor to a large event. Indeed, we have observed a number of aseismic slips (silent earthquakes; sometimes repeated in the same region) with no subsequent large events in the last decades. This is consistent with some empirical results that (relative) quiescence was not always followed by a large event. Therefore, distinguishing whether or not an aseismic slip leads to the rupture of asperity remains a further difficult research theme in earthquake prediction. At present, this issue can only be described in terms of probabilistic prediction [Ogata, 2001].

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URL: http://www.ism.ac.jp/~ogata/

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Bayesian Analysis of Aftershock Sequences

Yuh-Ing Chen[1] (886-3-4267227; ychen@stat.ncu.edu.tw)

Tsai-Hong Fan[1] (886-3-4227151ext5460; thfan@stat.ncu.edu.tw)

Jann-Yenq Liu[2] (886-3-4227151ext5763; jyliu@jupiter.ss.ncu.edu.tw)

[1] Institute of Statistics, National Central University, #300 Junda Road, Chung-Li 32054, Taiwan

[2] Institute of Space Science, National Central University, #300 Junda Road, Chung-Li 32054, Taiwan

The Reasenberg-Jones (1989) or RJ model describes the time-magnitude hazard of an aftershock sequence by combining the modified Omoris law (Utsu, 1961) and the Gutenberg-Richter (1954) rule. The parameters estimated separately from the power-decaying law and magnitude-frequency relation are then integrated for analyzing aftershock sequences in California. Wiemer (2000) further applied the RJ model to spatial grids over a possible aftershock area for evaluating the hazard or probability of a future aftershock. In this study, we propose a Bayesian analysis of the RJ model for a aftershock sequence with a non-informative prior or prior distributions based on previous aftershock sequences. Note that, under a non-informative prior, the Bayesian version of the RJ model based on posterior modes of the related parameters provides with an approximation to the estimated RJ model which maximizes the associated likelihood. The three versions of the RJ model, including the Bayesain, maximum likelihood and the integrated ones, will be applied to the Chi-Chi (M=7.6, 1999/9/20 UT) aftershocks for comparative purpose.

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