S41B-06 0930h

Heat Flow in the SAFOD Pilot Hole and Implications for the Strength of the San Andreas Fault

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As part of an investigation into the physical properties of the San Andreas fault (SAF) and adjacent crust, detailed thermal measurements have been acquired in the 2.2-km-deep pilot hole for the San Andreas Fault Observatory at Depth (SAFOD), located 1.8 km west of the SAF near Parkfield, California. Precision temperature logs have been combined with thermal conductivity measurements on drill cuttings in a detailed vertical profile of heat flow. The temperature at the bottom of the borehole is 92 ^{o}C, and heat flow from the basement section of the borehole (770 to 2160 m) is 91$\pm$2 mW m^{-2}. Within the resolution of the measurements, heat flow is constant across the identified faults that intersect the borehole, suggesting that any active fluid flow along these faults is at rates too low to alter the background conductive thermal regime. Heat flow in the SAFOD pilot hole is significantly higher than the 74 mW m^{-2} average for the Parkfield area reported by Sass et al. (JGR, v. 102, 1997) based on measurements in shallow holes but consistent with five measurements ranging from 84 to 100 mW m^{-2} near the SAF in Pancho Rico Canyon 20 km to the northwest. Reanalysis of the regional heat flow pattern indicates that high heat flow at the SAFOD site reflects an abrupt increase in heat flow along the SAF and within the Coast Ranges northwest of Parkfield. This transition corresponds to a shallowing of the base of seismicity on the SAF and may be related to a change in the mechanical behavior of the fault near the northern terminus of the M6 1966 Parkfield earthquake rupture. The persistence of elevated heat flow at sites more than 40 km west of the SAFOD pilot hole appears to rule out frictional heating on the SAF as a major source of the high SAFOD value. However, the correlation of along-strike variations in heat flow with changes in rupture patterns and fault characteristics may indicate a previously overlooked connection between laterally heterogeneous frictional properties and active thermal processes.

S41B-07 0945h

The Parkfield Stress Drop Controversy

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Nadeau *et al.* (1995) found that the seismicity on the San Andreas fault at Parkfield is highly clustered. Individual clusters consist of a sequence of near periodically repeating small earthquakes of similar seismic moment. Nadeau and Johnston (1998) compared the moments and timing of these repeating earthquakes ($M_W < 2$), and some larger events, with the surface creep rate on the fault to estimate the slip and stress drop ($\Delta\sigma$). They obtained conventional values (0.1 to 10 MPa) for the larger earthquakes, but $\Delta\sigma$ increased with decreasing M_W to extremely high values (> 1000 MPa) for the small earthquakes ($M_W < 2$). Such values are just about physically possible, but they are much higher than those estimated by seismic methods for small earthquakes elsewhere (e. g. Abercrombie 1995). These controversial high $\Delta\sigma$ estimates have sparked a number of theoretical and laboratory studies (e. g. Sammis & Rice 2000, Anooshepoor & Brune 2001, Beeler 2001) aimed at investigating whether the observations could result from earthquakes with more normal $\Delta\sigma$ occurring within the unusual tectonic setting at Parkfield. Lane & Nadeau (2000, 2002) considered whether localized patches of high $\Delta\sigma$ would be resolvable by standard seismic methods. However, to date nobody has used seismic methods to determine source parameters for these controversial small earthquakes at Parkfield. We use closely located earthquakes of different sizes (for example, the sub-clusters of cluster CL14, Nadeau *et al.*, 1995, M_W−0.2 to 1), recorded on the HRSN borehole network to analyse the source parameters. The smaller earthquakes are used as empirical Green's functions to resolve source processes of the larger events. Preliminary results from the earthquakes in cluster CL14 result in a source dimension of about 25 m and $\Delta\sigma$ of about 1 MPa for the M_W1 earthquakes, assuming that rupture velocity is the same as that for large earthquakes. We also resolve source-time functions for these earthquakes at most stations and so we can investigate the directivity and velocity of the rupture. Finally we compare the source parameter estimates from the seismic modeling, with those from recurrence and creep rate, and assess the validity of the various proposed models.

S41C MCC: Level 1 Thursday 0830h

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

Presiding: **J Lin,** Woods Hole Oceanographic Institution**; C Marone,** Pennsylvania State University

S41C-0083 0830h POSTER

Forward modelling of Coulomb stress: Does mu matter?

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The clear correlation between Coulomb stress perturbations and the spatial distribution of aftershocks suggests that it may be possible to make real time Coulomb maps delineating areas likely, or unlikely, to experience aftershocks. As part of the PRESAP project investigating this possibility, we have assessed the importance of the coefficient of friction in computing these maps. Although the static coefficient of friction measured in the laboratory is consistently between about 0.6 and 0.8; Coulomb modellers have suggested widely varying values of "effective friction" (i.e. including some unknown fluid effects) ranging from 0.0 to 0.8. Here we investigate the effect of mu on the spatial correlation between the Coulomb map and the aftershock distribution for a number of mainshocks and for varying assumptions of the planes upon which the stress should be resolved. For each model, we compute a Boolean correlation coefficient between the stress field and the aftershock distribution, a method that avoids the problem of nodal plane ambiguity. Preliminary results for the Landers earthquake show that the Coulomb maps are insensitive to the coefficient of friction and visual inspection of the maps support this assessment. If this result is supported by the remainder of the analysis, it will be very encouraging from a forward modelling perspective as it means that the predictive capacity of Coulomb maps is independent of the choice of a poorly constrained coefficient of friction.

S41C-0084 0830h POSTER

Effects of Variable Normal Stress on Shear Strength and Friction

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Previous work shows that dynamic and quasi-static variations in normal stress may play a key role in earthquake rupture dynamics and frictional stability. In order to improve our understanding of how normal stress changes influence frictional strength and stability we performed laboratory experiments using a servo-controlled, double-direct-shear testing apparatus. This assembly includes three rigid forcing blocks with two gouge layers sandwiched between grooved or smooth steel bounding surfaces. We sheared two 3-mm thick gouge layers of fine-grained quartz powder or smectite clay-quartz mixtures at constant load point velocity. Normal stress pulses and step experiments were carried out to investigate the shear strength response to an abrupt normal stress change. Normal stresses ranged from 10-45 MPa and we studied load point velocities in the range 1-1000 μm/s. Careful calibration of Poisson coupling within the testing apparatus and sample assembly was performed and these effects were removed from data prior to processing. Normal stress step tests involved a series of normal stress increases and decreases during steady sliding. For each step increase in normal stress, the parameter $\alpha = (\Delta\tau/\sigma)/\ln(\sigma/\sigma_0)$ was calculated, where $\Delta\tau$ is the amplitude of the change in shear strength due to a normal stress step, and σ and σ_0 are initial and final normal stress respectively. We find that α ranges from 0.28-0.35 for our range of experimental conditions, and that α does not change systematically with the variation of driving velocity. After exclusion of Poisson effects, there was generally no instantaneous change in shear strength in response to a step increase in normal stress. Our data show that step decreases in normal stress have the potential to destabilize steady sliding. For normal stresses of a few 10's of MPa, a normal stress reduction of >=1 MPa is sufficient to induce dynamic instability in our experiments. We compare our results to dynamic impact experiments on metals and other materials for which sliding velocity is of order 1-10 m/s. Those experiments consider only normal stress reductions and find that shear strength does not exhibit a sudden change in response to a step change in normal stress.

S41C-0085 0830h POSTER

The Effect of Dynamic Stress on Shear Strength and Stability in Laboratory Faults

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Recent studies show that earthquake-induced stress changes can trigger fault slip, change seismicity rates, and possibly cause additional damaging earthquakes. Investigations of stress transfer often focus on changes in the static stress state. However, dynamic stressing can lead to destabilization of creep motion and resonant behavior including stick-slip instability, both locally and at greater distances from the earthquake event. Studies of stress transfer commonly find that earthquake triggering occurs from small changes in stress and is delayed relative to the arrival of maximum stress. This phenomena cannot be explained by the Coulomb failure model, which predicts a constant failure threshold independent of stressing rate or time. We test the effects of dynamic shearing, using oscillations of shear loading rate and we compare results to theory. Using a double direct shear configuration, we sheared 3mm thick layers of glass beads (size distribution 105-149 microns) at room temperature. Glass beads are an ideal substance for these tests due to the repeatability of stick-slip events in terms of their magnitude and recurrence interval at constant velocity. The samples were loaded to quasi-periodic failure under a normal stress of 5 MPa (eliminating any changes in stick-slip behavior with displacement) and a background shear loading rate with a sinusoidal oscillation superimposed. Amplitude and frequency of the sine wave were varied, along with background shear loading rate, to determine any systematic shear stress response. We studied amplitudes ranging from 1-30 microns/sec, frequencies ranging from 0.01-10 Hz and load rates of 0.1-20 microns/sec. Although loading rate changes sign, shear stress remains positive throughout the experiment. Shear stress response was determined by studying systematic variations in stick-slip properties, e.g. amplitude of stress drop, frequency, and phase of the stick-slip stress drops compared to the imposed loading rate oscillations. Laboratory results of frictional response are compared to forward models of the rate and state friction laws. Preliminary results indicate that velocity oscillations lengthen the stick-slip recurrence interval and create generally larger instabilities; lower frequency oscillations create longer recurrence intervals than higher frequency oscillations. The phase of the stress drop relative to the velocity oscillation varies with oscillation frequency. During 0.1Hz oscillations, stress drops occur before the maximum loading velocity is reached whereas during 1Hz oscillations stress drops are delayed relative to the maximum velocity.

S41C-0086 0830h POSTER

The Role of Stress Interaction in Thrust and Subduction Earthquakes

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Key features of thrust earthquake triggering, inhibition, and clustering can be explained by Coulomb stress changes. Whereas slip on surface-cutting thrust faults drops the stress in most of the adjacent crust, slip on blind thrust faults increases the stress on some nearby zones, particularly above the source fault. Blind thrusts can thus trigger slip on secondary faults at shallow depth, and typically produce broadly distributed aftershocks. Short thrust ruptures are effective at triggering earthquakes of similar size on adjacent thrust faults. We calculate that during a progressive thrust sequence in central California during 1982-1985, the Mw=6.7 Coalinga earthquake brought the subsequent

1983 Mw=6.0 Nuñez and 1985 Mw=6.0 Kettleman Hills ruptures 10 and 1bars closer to Coulomb failure. On a larger scale, slip on major strike-slip faults modulates the stress acting on nearby thrust faults. We calculate that the 1857 Mw=7.9 Fort Tejon San Andreas earthquake and subsequent interseismic slip brought the Coalinga fault 1 bar closer to failure, and inhibited failure elsewhere on the Coast Ranges thrust faults. The 1857 event also promoted failure on the White Wolf thrust fault by 8 bars, which ruptured in the 1952 Mw=7.3 Kern County shock. The idealized stress-change calculations also explain key features of seismicity accompanying large subduction events. Subduction zone ruptures are calculated to promote normal faulting events in the outer rise, and to promote thrust faulting events on the periphery of the seismic rupture and on its downdip extension. These features are evident in aftershocks of the 1957 Mw=9.1 Aleutian and other large subduction earthquakes. We further examine stress changes on the rupture surface imparted by the 1960 Mw=9.5 and 1995 Mw=8.1 Chile earthquakes, for which detailed slip models are available. Calculated Coulomb stress increases of 2-20-bars correspond closely to sites of aftershocks and postseismic slip, whereas aftershocks are absent where the stress drops by more than 10 bars. We thus argue that stress transfer exerts a control on the seismicity of thrust faults across a broad spectrum of spatial and temporal scales.

URL: http://quake.wr.usgs.gov/research/deformation/modeling/refs/ross_refs.html

S41C-0087 0830h POSTER

An Independent Test of the Load/Unload Response Ratio Proposed Method of Earthquake Prediction

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It has often been hypothesized that earthquakes should occur more frequently during times of increasing tidal stress, yet the most careful studies suggest that the effect is very small and difficult to detect. However, as the tectonic stresses rise and approach failure, tidal stress variations might be more likely to raise the total stress to the failure level. Thus, the sensitivity of small earthquakes to the tidal stress before an impending large shock might be increased. This idea has been developed into the Load/Unload Response Ratio (LURR) proposed method of earthquake prediction (Yin et al., 1995). The LURR method involves looking at the ratio of the number or some measure of the size of small earthquakes that occur during loading of the tidal cycle to that measure of earthquakes that occur during unloading of the tidal cycle, and suggests this ratio should increase before an impending large shock. Smith and Sammis (2001, 2003) concluded that there was no predictive significance to the LURR method, and to our knowledge, this method has not been validated by any independent researchers. We calculated LURR values for several large earthquakes in southern California, using the methods and parameters described by Yin et al. (2000) and estimates of the other necessary methods and parameters that were not published. We employed tidal stresses, both from the solid earth tides alone and together with tidal ocean loading, using programs provided by Agnew (1996). Increases in the LURR value do occur, but they do not occur more often prior to large earthquakes than at any other time. We also calculated LURR values for altered datasets in which we randomized the times of each small earthquake before calculating the tidal stresses, theoretically eliminating any real influence of the tides on LURR. There is no statistically significant difference between preliminary results from the calculations utilizing the actual earthquake times and calculations utilizing the randomized times. After considering our results and those of Smith and Sammis (2001, 2003), we conclude that the LURR method is not a useful tool in earthquake prediction.

S41C-0088 0830h POSTER

Seismic Hazard Assessment for Large Aftershocks

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Coulomb static stress changes provide a promising way to short term probabilistic prediction of spatial occurrence of aftershocks. Main aim of this work is proposing method for seismic hazard assessment due to large aftershocks. Strong-ground motion estimation for the aftershocks has a number of uncertainties, namely aftershock magnitude and location since the Coulomb static stress changes give us only probabilistic information about the next aftershock hypocenters. First we discuss how to treat with such uncertainties. In cases when independent information about fault structure in the area under study is available, we can estimate maximum magnitude of the likely aftershock and its location. Then, we can use any strong motion prediction technique to estimate ground-shaking characteristics (e.g., PGA, PGV, etc.) in the near source region for a number of various scenarios (with varying position of the nucleation point and asperity) and compute mean strong-motion map of each of the characteristics and their standard deviation. After the local conditions (site effects) are taken into account, the possible impact on urban areas can be estimated. We propose a new method based on probabilistic seismic hazard assessment. This method is suitable for cases when 1) not only a single fault is designated to produce likely aftershocks and/or 2) their possible magnitude is unclear and/or 3) the seismogenic zone is known to be capable to produce aftershocks on blind faults. For each given magnitude and fault the strong-motion map is estimated. Presented approach represents a general tool to combine all the strong-motion maps obtained for all magnitudes and faults into a single probabilistic map. The method differs from the commonly used probabilistic seismic hazard methods in the point that the weights for particular epicentral zones are based on the Coulomb stress changes. The output of the method is either the maximum values of ground motion characteristics that have a specified probability of not being exceeded during fixed time period (e.g., one year) or the probability of non-exceedence of given ground motion level for each of the stations. The reliability of the method is shown on the example of Izmit aftershock No. 25 ($M_w = 5.8$).

URL: http://karel.troja.mff.cuni.cz/students/gallovic/

S41C-0089 0830h POSTER

Rationalizing Hybrid Earthquake Probabilities

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An approach to including stress transfer and frictional effects in estimates of the probability of failure of a single fault affected by a nearby earthquake has been suggested in Stein et al. (1997). This hybrid' approach combines conditional probabilities, which depend on the time elapsed since the last earthquake on the affected fault, with Poissonian probabilities that account for friction and depend only on the time since the perturbing earthquake. The latter are based on the seismicity rate change model developed by Dieterich (1994) to explain the temporal behavior of aftershock sequences in terms of rate-state frictional processes. The model assumes an infinite population of nucleation sites that are near failure at the time of the perturbing earthquake. In the hybrid approach, assuming the Dieterich model can lead to significant transient increases in failure probability. We explore some of the implications of applying the Dieterich model to a single fault and its impact on the hybrid probabilities. We present two interpretations that we believe can rationalize the use of the hybrid approach. In the first, a statistical distribution representing uncertainties in elapsed and/or mean recurrence time on the fault serves as a proxy for Dieterich's population of nucleation sites. In the second, we imagine a population of nucleation patches distributed over the fault with a distribution of maturities. In both cases we find that the probability depends on the time since the last earthquake. In particular, the size of the transient probability increase may only be significant for faults already close to failure. Neglecting the maturity of a fault may lead to overestimated rate and probability increases.

S41C-0090 0830h POSTER

27 january 2003 Pulumur (Mw:6.1) and 01 may 2003 Bingol (Mw:6.4) earthquakes: triggered events in the westward-escape tectonic regime, eastern Turkey

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Two moderate earthquakes occurred in the Bingol-Karlýova-Erzincan 300 angle (BKEA), at the eastern corner of the Anatolian block, which is characterized by westward escape. The BKEA is located between North (NAF) and East (EAF) Anatolian faults west of the Karlýova triple junction. It is bounded by large stepover structures: the Erzincan basin on the NAF and Gokdere stepover on the EAF. A conjugate active fault pattern includes NE and NW trending faults parallel to the NAF and EAF. The NW and SE trending faults are right-lateral and left-lateral, respectively. The January 27, 2003 Pulumur Earthquake (Mw:6.1) occurred at the northwest corner of the BKEA. Ten years ago, 13 March 1999, the Erzincan earthquake (Ms: 6.8) occurred at the east of the Erzincan basin and triggered, two days later, the Pulumur Earthquake (Mw:5.8) on Dagyolu fault, which is parallel to the NAF. The 27 January 2003 Pulumur earthquake occurred on the Pulumur fault, which is conjugate to the Dagyolu fault. The Pulumur fault is a left-lateral, north-east trending, and 20 km in length. The January 2003 event might be triggered by 1992 Erzincan earthquake. The 01 May 2003 Bingol earthquake occurred at the south-eastern corner of the BKEA. Before the last event, the May 22 1971 Bingol earthquake (Ms:6.8) occurred on the Goynuk segment of the EAF and produced surface rupture. The Bingol-Karakocan and Sudugunu faults are conjugate to the 1971 rupture of EAF. The earthquake in the region, the 01 May 2003 Bingol earthquake, was generated by the Sudugunu fault but did not rupture the surface. However, many landslides and lateral spreading were observed along this fault 20 km-long and N500 W trending fault. The 2003 Pulumur and Bingol earthquakes were close in time and space to the 1992 Erzincan and 1971 Bingol earthquakes, respectively. The series of earthquakes during the last 30 years suggest that triggering is common in the conjugate fault pattern of the BKEA. Therefore, it can be speculated that the 2003 events raised the earthquake potential on the adjacent faults.

S41C-0091 0830h POSTER

Lessons on Seismic Hazard Estimation from the 2003 Bingol, Turkey Earthquake

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In a 2002 paper the stress state along the East Anatolian Fault Zone (EAFZ) was estimated by the addition of long term tectonic loading to the static stressing effect of a series of large historical earthquakes. The results clearly indicated two areas of particular concern. The first extended along the EAFZ between the cities of Kahraman Maras and Malatya and the second along the trend of the EAFZ between the cities of Elazig and Bingol. The Bingol (M6.4, 1 May 2003) earthquake occurred within this second area with a focal mechanism which was consistent with left lateral rupture of a buried segment of the EAFZ, prompting suggestions that this represented a success for the idea of using Coulomb Stress Modelling to assess seismic hazard. This success, however, depended on the confirmation of the orientation of the earthquake fault; in the event, and in the absence of surface ruptures, aftershock distributions unambiguously showed that the event was a right lateral failure on an unmapped structure conjugate to the EAFZ. The Bingol earthquake was, therefore, not encouraged by the stress field modelled in the 2002 study. Here we reflect on the lessons learned from this case. We identify three possible reasons for the discrepancy between the calculations and the occurrence of the Bingol earthquake. Firstly, historical

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earthquakes used in the 2002 study may have been incorrectly modelled in either size or location. Secondly, earthquakes not included in the study, due to either their size or occurrence time, may have had a significant effect on the stress field. Or, finally, the secular stress used to load the faults was inappropriate. We argue that it is through a combination of historical seismology guided and constrained by structural geology, directed paleoseismology and coupled with stress modelling which has been informed by detailed GPS data that an integrated seismic hazard program might have the best chance of success.

S41C-0092 0830h POSTER

Variations in GPS strain rate and their relationship to seismic hazard variables in western Turkey

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Interrelationships between seismic hazard variables (epicenter distribution (Dq), the Gutenberg-Richter b value) and GPS-derived strain fields (shear and normal) are examined in the western Turkey region. This analysis was conducted in three tectonic subdivisions corresponding to regions dominated by shear, extensional, and compressional deformation. The region of shear coincides with the Northern Anatolian Fault Zone; the region of extension, the Hellenic back-arc region; and the region of compression lies along the Hellenic subduction zone between the African and Anatolian plates. Along the NAFZ a significant positive correlation is observed between D and b. However, a clear relationship between D and b does not appear in regions deformed in response to extension and compression. The relationship between D and b along the NAFZ may also be an indicator of increased seismic hazard since the positive relationship between D and b is a recent characteristic of the NAFZ observed only in the 20-year period preceding the Izmit earthquake. The relationship between D and b became increasingly positive compared to earlier analysis conducted over the 1975 through 1988 time period. Interrelationships between D and b to GPS derive shear and normal strains in the region are currently being evaluated.

S41C-0093 0830h POSTER

Stress Interaction and Triggering of Aftershocks Associated With the 1999 Chi-Chi, Taiwan, Earthquake

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We employed the models of Coulomb stress changes to investigate the features of the 1999 Chi-Chi earthquake on fault interactions and earthquake triggering. The seismicity examined by Z-map shows a butterfly shape of increased of seismicity consistent with the pattern for Coulomb stress changed associated with a thrust event. Due to the surface-cutting thrust fault, the Coulomb stress change show relief of stress near the surface of the fault, consistent with less amount of the aftershocks along the fault surface. The correlation of the aftershocks occurrence is significant at deeper depth (>12 km), especially in the off-source region. The lobe with positive Coulomb stress change tends to be broader at deeper depths. It explains the occurrence of large amount of aftershocks at deeper depth. Most of the aftershocks occurred in the positive Coulomb stress changes region. The six large aftershocks, which occurred within a week of the mainshock, located near the boundary of the positive and negative Coulomb stress changes in off source region. The positive stress changes associated with these events are of about 2-7 bars, suggesting that only little change of the Coulomb stress could yield the triggering of large aftershocks. The examination on stress interaction shows that at deeper depths (>6 km) significant increases of Coulomb stress changes were found beneath the Chelungpu nearby active faults, namely Shuangtung and Shuilikeng faults, suggesting the activation of the faults after the Chi-Chi earthquake. The Chunghua fault, to the west of the Chelungpu fault, as the frontal thrust of the Taiwan fold and thrust belts the Coulomb stress change beneath it shows significant increase of stress up to 50 MPa. Long term monitoring of the stress flow might be necessary to investigate the future behavior of the Chunghua fault. In additions, our study shows that variable of slips in dip direction has significant influence on the pattern of Coulomb stress change. It suggests the importance of accurate fault slip model in both strike and dip direction toward stress triggering study.

S41C-0094 0830h POSTER

Spatial and scale-dependent friction parameter derived from earthquake rate changes after a stress step by the 1999, Chi-Chi, Taiwan, earthquake

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Dieterich's fomulation for earthquake clustering derived from stability analysis of a spring-slider system with slowness law suggests that earthquake rate changes can be used as a stress meter for near-surface deformation and a tool for evaluation of the probability for the future large earthquakes. While employing this theory, most studies implicitly assumed friction parameters are spatially and magnitude independent. This assumption, however, needs to be justified. We conduct genetic-algorithm inversion to simultaneously obtain the spatial variation of long-term stressing rate and friction parameter based on the earthquake rate changes before and after the 1999, Chi-Chi, Taiwan, earthquake. We found that the long-term stressing rate from this inversion agrees well with GPS observations. Our results also suggest that the rupture characteristics of the Chi-Chi earthquake may be attributed to the spatial variation in Aσ (rate constitutive parameter and normal stress). Moreover, we found that Aσ systematically decreases with earthquake magnitude, which implies that Dieterich's fomulation for earthquake clustering is implicitly magnitude-dependent. Since stress drop derived form seismic moment release does not strongly correlate with earthquake magnitude, the magnitude-dependent friction parameter derived from this method may reflect the friction behavior of characteristic asperities only instead of the entire rupture area.

S41C-0095 0830h POSTER

Spatio-Temporal Distribution of Aftershocks and Stress Changes After the 1999 Chi-Chi, Taiwan, Earthquake

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Numerous aftershocks followed by the 1999 Chi-Chi, Taiwan, Earthquake (Mw=7.6) provided us valuable data sets for studying aftershock occurrence and crustal structure in Taiwan. In this study, we focused on the role of stress changes in triggering aftershocks. This mainshock occurred on September 20, 1999 (UT) with a 100-km-long surface rupture along the Chelungpu fault with fault slips of up to about 10 m. The area that aftershocks occurred was as broad as 150 km long and 100 km wide, which was almost half of the Taiwan Island and much larger than faulted area [e.g. Nagai et al., 2003]. The aftershocks were separated into 7 clustered activities concentrated in space, each of which also had different characteristics in temporal distribution. And their distribution had changed as compared with that of past seismicity. Aftershocks have various focal mechanisms, which indicate the complex crustal structure and the regional stress distribution originated by the relative motion between the Eurasian and the Philippine Sea plates. We calculated static stress change by the mainshock on objective fault planes, inferred from each clustered aftershock distribution and their focal mechanisms. We adopted the finite source dislocation model [Okada, 1992] to calculate the static stress change in an elastic half-space by the main shock. And we assumed crust was homogeneous with a shear modulus of 3×10^{10} Nm^{-2} and employed a Poisson's ratio of 0.25 and an effective friction coefficient of 0.4. The results showed positive correlations between aftershock areas and positive stress changes in the Chi-Chi aftershock sequence approximately. However static stress triggering is one of many factors to influence the occurrence of earthquakes, which include such as pore pressure, dynamic stress triggering by seismic waves passage, and tectonic loading. Indeed, Taiwan is located in the arc-continent collision zone between the Eurasian and the Philippine Sea plates with a convergent rate of about 7-8 cm/yr. We will discuss the relationship among the occurrence of the Chi-Chi aftershock sequence, the effect of static and dynamic stress changes by the mainshock and the larger aftershocks, and other effects such as tectonic loading and crustal structure in Taiwan.

S41C-0096 0830h POSTER

Tidal Triggering of Earthquakes in and Around the Locked Zone of the Philippine Sea Plate in the Tokai Region, Japan

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We investigated statistical correlation between the earth tide and earthquake occurrence in and around the locked zone, 80 km $\times$ 60 km, of the plate interface in the Tokai region, central Japan, where a large interplate earthquake may be impending. The data we used are the origin times, hypocenter coordinates and focal mechanisms of M $\geq$ 1.5 earthquakes occurring in the subducting Philippine Sea plate that were observed by the seismic network of the National Research Institute for Earth Science and Disaster Prevention for the period from June 1986 to February 2003. Clustered events were removed from the data set. For each earthquake, we assigned the tidal phase angle at the origin time by theoretically calculating the tidal shear stress on the fault plane. Based on the distribution of the tidal phase angles, we statistically tested whether they concentrate near some particular angle or not by using the Schuster's test. In this test, the result is evaluated by p-value, which represents the significance level to reject the null hypothesis that the earthquakes occur randomly irrespective of the tidal phase angle. As a result of analysis, no correlation was observed for the data set including all the earthquakes (p = 29%). However, we found a characteristic pattern in the temporal variation of tidal effect. There were four M $\geq$ 4.5 earthquakes in the investigated period. The p-value significantly dropped before the occurrence of these earthquakes and recovered after that. The frequency distribution of tidal phase angles in the pre-event period exhibited a peak at the phase angle where the shear stress is at its maximum to accelerate the fault slip, which indicates that the observed small p-value is a physical consequence of the tidal effect. We also investigated the spatial distribution of p-value. The most remarkable low-p region was found to coincide with a strongly locked portion of the plate interface, which was inferred from seismicity change in the past few years.

S41C-0097 0830h POSTER

Estimation of the strength of faults in the region of the 2000 Western Tottori Earthquake

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To study the strength of the faults that caused large earthquakes, we tried to determine the stress state near the faults prior to and after the 2000 Western Tottori Earthquake using the focal mechanism data of the Joint Group for Dense Aftershock Observation. We investigated the spatial distribution of strikes of the nodal planes from the focal mechanisms of aftershocks. There are some aftershocks that have the nodal planes consistent with the fault strike of the mainshock (N132E) distributed near the mainshock hypocenter (35.2847N, 133.3459E), and these aftershocks are aligned in a N132E direction. To investigate the distribution of the P axis orientations of the aftershocks, the aftershock area was divided into four areas; the northern end of fault (area 1), the northern half of the rupture area

(area 2), the southern half of the rupture area (area 3), the southern end of fault (area 4), based on the differences of the characteristic distributions of the P axes orientations and the principal axis of stress change due to the mainshock. P axes are mostly oriented in a northwest-southeast direction in areas 1 and 2. Around the large slip zone in area 3, the direction of the P axes vary widely, and in area 4, the P axes are mostly oriented in a east-west direction. Next we calculated the stress changes due to the slip distribution of the mainshock, estimated by Iwata and Sekiguchi (2002), using the formulas of Okada (1992). The direction of the maximum compressive stress axis calculated from the stress change was compared with that of the P axis. In area 1, the directions of the maximum compressive stress axes were almost consistent with those of the P axes. In the area 2, however, they were not consistent with those of the P axes, though the stress change was large (10-20 MPa.). Around the large slip zone in the area 3, the stress change was large (10-50 MPa.) and the directions of the maximum compressive stress axes were not consistent with those of the P axes. In the area 4, they were consistent with those of the P axes oriented in an east-west direction. From the results of the direction of the nodal planes, it is inferred that a weak plane with a direction consistent with the strike of the mainshock fault pre-existed near the hypocenter, and that these aftershocks occurred on this weak plane. From the comparison between the directions of the maximum compressive stress axes and the P axes, it is expected that the directions of the P axes were not affected by the stress change in areas 1 and 2, because they are not consistent with the maximum compressive stress axes, and almost oriented in a northwest-southeast direction. Thus, it is inferred that the maximum compressive stress axis prior to the mainshock was oriented in a northwest-southeast direction and the magnitude of the stress was large so that the direction of the maximum compressive stress was not modified by the stress change. Around the large slip zone in area 3, it is possible that the stress state became heterogeneous by the mainshock slip distribution. Finally, in area 4, it is possible that the magnitude of initial stress prior to the mainshock was smaller than that in areas 1 and 2, because the direction of the P axes was consistent with the maximum compressive stress axes, although the stress change was only a few MPa.. We can also explain these results, by the assumption that the magnitude of the maximum compressive stress was about 10 MPa. and was oriented in an east-west direction.

S41C-0098 0830h POSTER

3D model of dip slip faults loaded by tectonic stress

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A numerical 3D finite element model is used to study the effects of the tectonic stress field and lithostatic loading on the dislocations of dip-slip faults. Special contact elements are employed to deal with the fault surfaces, and a Coulomb friction criterion is adopted. The model has been tested with known solutions based on simple fault models embedded in an elastic halfspace. We are able to predict the slip distribution and other quantities such as the moment tensor, which can reproduce data inferred from observed earthquakes. We study both single faults and fault systems focusing on the coseismic stress and postseismic stress diffusion associated with the relaxation of the ductile lower crust. The model is applied to the Umbria Marche sequence (1997) in order to study the interaction between the main shocks fault planes and the spatio-temporal migration of the earthquakes distribution.

S41C-0099 0830h POSTER

The Apparent Stress Profile for Normal-Fault Earthquakes Across Subduction Zones

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The behavior of apparent stress for normal-fault earthquakes across the various tectonic regimes of a subduction zone complex is derived by examining the apparent stress ($\tau_a = \mu E_S/M_0$, where E_S is radiated energy and M_0 is seismic moment) of 139 large global earthquakes with depth <70 km that occurred from 1987 to 2001. Using accurately determined hypocenters to delineate Wadati-Benioff zones in fine detail, we are able to ascribe the hypocenters to specific tectonic features. The highest and most anomalous values of τ_a (up to 5 MPa) are found in the depth range 35-70 km. These events are characteristically intraslab and in proximity to zones of intense deformation such as a sharp slab bend or the juncture of multiply convergent slab systems. Events with high τ_a (> 1 MPa) at shallow depths between 10-35 km are generally intraslab, in cold slabs, and near plate boundaries with oblique convergence or local contortion. Low τ_a (<1 MPa) is associated with events occurring between the outer rise and the trench axis, as well as with intracrustal events behind the trench axis. The average apparent stress of intraslab normal-fault earthquakes is considerably higher than that of interplate thrust-fault earthquakes. This suggests that lower stress drops are needed to rupture plate interfaces that have been made smoother by cumulative total displacements (from hundreds to thousands of kms). In contrast, intraslab normal-fault earthquakes generally occur in cold and intact lithosphere along which total fault displacements have been much less (from hundreds of meters to a few km). We have identified earthquake pairs in which an interplate-thrust and an intraslab-normal earthquake occurred remarkably close in space and time. The intraslab-normal member of each pair radiated anomalously high amounts of energy compared to its thrust-fault counterpart. These earthquakes are dramatic examples in which M_e (energy magnitude) is a better estimate of the potential for earthquake damage than M_W. This discovery may help explain why loss of life due to intraslab earthquakes was greater in the 20th century in Latin America than the fatalities associated with interplate thrust events that represented much higher total moment release.

S41C-0100 0830h POSTER

The Dynamics of Strike-Slip Faults with Stepovers and Linking Dip-Slip Faults

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One of the most important issues in seismology is the potential size of future earthquakes. Dynamic models of strike-slip faults with stepovers have shown that under certain circumstances, rupture can jump from segment to segment, increasing the size of potential earthquakes beyond that which would be expected from the size of the individual segments. Studies of offset thrust faults have shown that linking tear (strike-slip) faults can greatly increase the distance over which rupture can jump. Using the 3-D dynamic finite element method, we extend this line of research to study parallel strike-slip fault segments linked by either a thrust or normal fault, depending on the whether the stepover is compressional or dilational. We find that in all cases, a linking fault greatly increases the distance over which rupture can jump, and increases the size of the final event. However, slip on the strike-slip segments increases the compressive normal stress on a thrust fault in a compressive stepover, and decreases the compressive normal stress on a normal fault in a dilational stepover. This effect causes the dilational/normal faulting stepover to be more conducive to multi-segment events than the compressive/thrust stepover. This result is consistent with studies of systems with no linking faults. Additionally, the orientation (dip direction) of the linking dip-slip fault leads to the effect that jumping rupture is more likely for ruptures that approach the stepover from a certain direction. Interaction between the static and dynamic stress fields in the stepover region leads to further complications. The results may lead to more accurate forecasts of earthquake size and seismic hazard in places where linked stopovers occur, such as the San Francisco bay region.

S41C-0101 0830h POSTER

Fault Jumping and Bilateral Propagation as a General Mechanism of Backward Branching: Case Study of Transition from the Kickapoo to the Homestead Valley Fault in the 1992 Landers Earthquake

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To unravel the directivity of past large earthquakes along complex fault systems, with offsets and branches, we address the mechanics of "backward" branching (*Dmowska et al., EOS*, 2002). In the 1992 Landers earthquake, such a 4-km long backward branch formed along the southeastern end of the Homestead Valley Fault (HVF), after transfer of slip to it from the Johnson Valley Fault (JVF) via the Kickapoo Fault (KF) (Sowers et al., BSSA, 1994); the main Landers rupture continued to the north along the HVF. Direct bending of a right-lateral rupture path through a strongly obtuse angle, to form a backward branch, is disallowed by the stress field at a dynamic rupture front (*Poliakov et al., JGR*, 2002). An alternative mechanism must be identified. We propose that rupture arrests at the termination of one fault segment, allowing a *Harris-Day* (*JGR*, 1993) jump to an adjoining segment which then ruptures bilaterally; the end propagating oppositely to the arrested rupture forms the backward branch. Using a 2D elastodynamic BIE formulation incorporating slip-weakening rupture (*Kame et al., JGR*, 2003), we numerically reproduced backward branching for the JVF-KF to HVF geometry. When the rupture stopped at the northern termination of the KF, it jumped to the HVF and then evolved bilaterally, most extensively to the north in continuation of the main rupture, but also along the southeastern HVF, which curves away from the KF to form the backward branch. A 2D rupture model such as we use may often be justified when length scales of phenomena modeled are small compared to the thickness of the seismogenic zone, as in this case here. We showed that stresses radiated to the curved HVF, while the rupture tip was still propagating along the JVF-KF system, would be unlikely to nucleate rupture on the HVF. Rather, the jump was made possible by the much higher stresses radiated when the rupture stopped at the northern termination of the KF. Those stresses succeeded in nucleating on the HVF because the two fault traces are close to parallel there; the less parallel orientation of the curved HVF further to the southeast would not have allowed jumping. Evidence for the termination of the KF and for the lack of its direct connection with the HVF, hence for the necessity of a jump to transfer rupture, is provided by the following: Detailed surface slip mapping (*Sowers et al., BSSA*, 1994) which showed a gap, relative relocations of aftershocks which projected fault planes to seismogenic depths (*Felzer and Beroza, GRL*, 1999), and fault zone trapped wave studies (*Li et al., JGR*, 1994) which showed non-communication between the JVF-KF and HVF. Such a jump followed by bilateral propagation provides a general mechanism of forming rupture segments running backwards by comparison with the general direction of propagation. During the Landers 1992 event two other such cases followed the JVF-KF to HVF transition just discussed, namely one from the northern HVF to the southeastern Emerson Fault, and then another from the northwestern Emerson to southeastern Camp Rock Fault.

S41C-0102 0830h POSTER

An attempt to directly monitor stress buildup and triggered earthquakes within one fault distance in South African deep gold mines

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Mining takes place at depths of 2-3km, thereby frequently inducing events with $M > 2$ in the close vicinity of stopes. So, with sensors installed ahead of time in seismogenic areas, we can directly observe temporal change in stress, deformation and material (e.g. *SeismogenicProcessMonitoring*, 2002, Balkema). At Bambanani mine, we could successfully record strain change up to 10^{-4} with 25 Hz 24 bit sampling associated with $M \sim 2$ events at a ~100m distance with an Ishii strainmeter (see Takeuchi's poster). However, our previous experiments had a lot to be desired: only single strainmeter or only remote (>200m) geophones with less dynamic range available, no insitu stress measurement, no a priori or afterward material investigation and so on. To solve these, we deployed new experimental sites at Tau Tona and Mponeng with significant contrast in geology and current stress, where we carry out in situ stress measurement, install two Ishii strainmeters, two strong ground motion meters and multiple thermometers within 10 - 20 m from faults. The site at Tau Tona is within a pillar with a fault 2.9km deep, where an $M > 2$ event is anticipated with mining advance. Geology is simply Quartzite, and the fault consists of intensely fractured quartzite ~30cm thick with 0.5-1cm thick claylike gouge at both boundaries. The fault is well exposed at adjacent stopes and tunnels, enabling investigation of fault material property. In four boreholes already drilled 7-15m long, significant borehole breakout is seen associated with active mining near the site. A direction of maximum stress has changed since June as mining has advanced, currently being 20-30 degrees oblique to the fault. The site at Mponeng mine (3.1km deep, $(\sim 200m)^3$ in volume) has a fault zone several tens of meters thick in a planned pillar. The fault zone was originated by ancient, large lateral fault movement, and now is characterized by complex geology consisting of chopped various-sized surrounding country rock (Basalt and Quartzite), filled with solidified fault gouge and accompanying some weak planes. In five holes 18-30m long already drilled, we don't see so significant borehole breakout as those at Tau Tona site because mining is not yet active near the site. Regardless of complex geology, weak planes were well located by logging with a borehole camera. In addition to the mine's seismic network (~500m spacing), adjacent high-resolution temporary geophone network (~200m spacing) and our own additional wide-dynamic-range network (~200m spacing) covers the fault zone 3-dimensionally.

S41C-0103 0830h POSTER

Coseismic strain changes of 10^{-4} and 7×10^{-5} recorded with Ishii strainmeter by continuous 24bit 25Hz monitoring on seismogenic fault of M 3 in deep gold mine, South Africa

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We will report on coseismic strain step ranging 10^{-5} to 10^{-4} recorded with 24bit 25Hz continuous monitoring, associated with seismic events with M 2 at a distance about 100m at Bambanani mine, Welkom, South Africa. We have been observing mine tremors of -1.2<M<3 at a hypocentral distance of near dozens of meters since September 2000 at the mine. We installed an Ishii multi-component borehole strainmeter several meters from a potential seismogenic fault to monitor normal and slip-driving shear strains on it. It accommodates as large strain as 10^{-4}, and detects as subtle strain as 10^{-9}. To record rock mass behavior just before and after a tremor, data are continuously recorded with a 24bit 25Hz monitoring system. Recently, the strainmeter recorded two big coseismic steps up to 10^{-4}, which can be recorded only within a seismogenic volume. On 2003 February 14, an event of magnitude 2.5 at a distance of about 70m from the strainmeter and it produced maximum coseismic strain change of $\pm10^{-5}$. Its foreshocks were recorded by the strainmeter from 36.5 seconds before the main shock. The last big foreshock was M1.4 just 2 seconds before the main shock, which was followed by a significant strain change. At this moment, we don't know if that is just a postseismic change of the M1.4 foreshock or preseismic change of the main shock. On 2003 April 12, the biggest coseismic strain change of 10^{-4}, amoung those we have ever recorded by the strain meter, occurred by an M2.5 event at a distance of about 100m from strainmeter. No foreshocks were recorded with the event of 2003 April 12. Although the non-causal effects of a recording system are successfully removed with minimum phase filter, a precursor strain change larger than 10^{-8} was not seen until the onset (0.1 s just before the event). During a period with significant postseismic change, the directions of principal strainchange axes were stable, suggesting that each channel worked consistently. However, it should be noted that duration of coseismic step was much longer than that is derived from seismograms. We have been investigating whether that is caused by strainmeter's instrumental response or a real rock mass behavior.

S41C-0104 0830h POSTER

Scenario Earthquake in the Moyenne Durance, Southeastern France

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The fault system of the Moyenne Durance, southeastern France, is a segmented fault system characterized by a moderate instrumental seismicity. Nevertheless, repeated historical events (M=5-5.5 every century since 1509) and paleoseismological evidence of a possible strong earthquake between 27 ky and 9 ky underline the importance of seismic hazard in this region. Recent studies have revealed a fault system characterized by a complex geometry of fault segments. A critical question for hazard assessment is which segments (or how many segments) are able to break at the same time during an earthquake. This may give a physical constraint on seismic hazard assessment and strong ground motion prediction in this region. The complexity here is the existence of different fault kinematics, a mixture of inverse and left-lateral strike-slip faulting as well as a 3D fault geometry. For this purpose, we simulate spontaneous rupture process along a geometrically complex fault system using a 3D boundary integral equation method (BIEM). Two fault segments are considered: a roughly E-W north dipping structure that meets a NE-SW almost vertical fault. As a preliminary case, we suppose uniform frictional parameters for all segments in the fault system, a uniform tectonic stress with the maximum principal stress σ_1 NNW oriented and the minimum principal stress σ_3 vertical, and a fixed fault geometry. The parameters controlling these simulations are the coefficient of friction (static and dynamic), the direction and magnitude of the principal stresses and the distance between the fault segments. Assuming that the value of the dynamic friction is 20-30% less than the static one (0.6), rupture propagation from one segment to the next is only observed when the magnitude of σ_2 is sufficiently close to σ_3 and when fault separation is less than 2 km. Future work will consider scenarios along other fault segments as well as considering the possibility that the stress regime may change spatially along the fault system.

S41C-0105 0830h POSTER

Interpreting Focal Mechanisms in a Heterogeneous Stress Field

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There is evidence that slip in earthquakes is spatially heterogeneous (with possibly a fractal distribution). This implies stress that is highly heterogeneous. In addition, there is evidence that the small-scale spatial heterogeneity is significantly larger than any uniform component of stress. Strain resulting in local stress changes of 100 MPa or more have been reported (McGill and Rubin, 1999), whereas GPS observations in Southern California indicate regional stress changes of 1 MPa per century, and energy estimates of large earthquakes predict average shear stress changes of less than 10 MPa (Kanamori and Heaton, 2000). Additional support for stress heterogeneity, has been shown in work by Rivera and Kanamori (2002) and Aagaard et al. (2001), Widely used techniques for determining the orientations and relative magnitudes of principal stresses (Gephart, 1990; Gephart and Forsyth, 1984; Michael, 1991; Michael, 1984, 1987) invert focal mechanisms from earthquakes. The objective is to find a spatially uniform component of the deviatoric stress field in hopes that it is indicative of the background stress. These techniques work only if the uniform component of stress is sufficiently large with respect to random spatial heterogeneity. We hypothesize that stress is very heterogeneous and the heterogeneity is large in comparison to uniform background stress. We also hypothesize that inversion results, which are intended to reveal uniform background stress, are actually characterizing secularly increasing tectonic stress. In other words, earthquakes are a biased sample of points brought closer to failure by tectonic stress. If these hypotheses are correct, they could have major implications for how stress inversions are interpreted for crustal stress studies and hazard analysis. Therefore, our plan is: 1) generate suites of synthetic focal mechanism from a variety of stress fields. Specifically, a random number generator with a Gaussian distribution will create an initial 3-D stress field. Various smoothing filters will be applied to create the different spatial heterogeneities, including some with fractal distributions. A uniform background component of stress will be applied. Then last, spatially uniform tectonic stress that linearly increases with time will be added to bring points to failure. A Hencky-Mises yield condition will determine the time to failure. 2) invert the focal mechanism suites using the Gephart and Forsyth (1984) technique and the Michael (1987) technique, 3) then compare the inversion results to the original focal-mechanism generating stress fields. This will give us a direct numerical test of the inversion methods. Our three main objectives are: 1) determine how the degree of spatial heterogeneity affects the inversion, 2) compare the effects of different types of heterogeneity, 3) determine to what degree inversions reflect spatially uniform, external tectonic stress.

URL: http://www.gps.caltech.edu/~desmith/research.html

S41C-0106 0830h POSTER

Seismicity Surveying in Central and North Mexico Regions

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The seismic nature of Central Mexico is poorly understood due to insufficient sampling. We carried out a seismic survey in part of the TransMexican Volcanic Belt (TMVB) and the Central Altiplano. These regions are characterized by a very low deformation rates. Seismic activity is variable and ranges from microseismicity to large earthquakes, but no large historic earthquake has been instrumentally recorded. Only few direct observations such as intensity reconstructions and recent paleoseismic studies (e.g. the Acambay-Tixmadejé earthquake of 1912) are available. Large earthquakes have occurred but their recurrence period is unknown; structural studies show this recurrence could range from hundreds to thousands of years. In order to understand the regional seismic behavior, we installed a temporal network. This network consists of 3-5 short period instruments, consisting of 16-bits triaxial digital velocity recorders (0.01-4.5 Hz). We registered several seismic sequences over a period of several months. One of them took place in Guanajuato within a graben structure in the TMVB and lasted for 2 weeks. Another sequence occurred at the northern limit of the TMVB in the Sierra Gorda. Over five weeks, several micro-earthquakes $M < 2$ were felt with anomaously high intensity. Relocated seismicity shows very shallow (< 10km) activity. Even though the seismicity varied significantly, the regional crustal conditions appear to be roughly uniform. In some areas like Arroyo Seco, in the Sierra Gorda, the event distribution is aligned along a small valley, but perpendicular to the main structural grain imposed by the Sierra Madre Oriental range. In no instances have surface ruptures been observed; those seismogenic structures could be blind ones. A challenge is to locate this structures which are may be too old to be still active. Increased seismotectonic knowledge of this region will yield further insight into the details of the interaction between surface structures driven by the regional stress field. Our results provide evidence that the region requires more intensive seismic surveying, and in some cases that some structures have been reactivated recently.

S41C-0107 0830h POSTER

Major Existence of Very Low Frequency Earthquakes in Background Seismicity Along Subduction Zone of South-western Japan

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The condense, high quality and equalized broadband seismic network provided us to recognize the variety of seismic sources. The active volcanoes excite seismic waves with various frequency characteristics. Some cases show the long period seismic waves greater than 10 sec associates with volcanic activities. The tectonic seismic events originated at the close to trench zone are frequently lack of high frequency, greater than 1 Hz, seismic wave component. Meanwhile, the many low frequency earthquakes and tremors whose sources are not explicated are occurred in lower crust and subcrustal region. The subduction zone of Philippine Sea plate in south-western Japan is actively genetic area of low frequency earthquake group. The broadband seismic array of Japan region observed unknown long period ground motions. The seismograms are higher amplitude between 10 and 30 sec period than ground noise level. The earthquake JMA and USGS catalogues don't list about these long period seismograms. The arrival order of wave packet means that these events locate subduction zone around Japan. The hypocenters of unknown events are estimated by arrival times of vertical peak amplitude using the assumption that the ground motion dominates Rayleigh wave. The more detailed determination of major events is performed by combined technique for moment tensor inversion and grid search. The moment magnitude of uncatalogued event is greater than 3.5 because of the detection limitation. The largest event is distributed to about 4.5 Mw level and special event is greater than 5.0. The frequency characteristics show that source time is 7 to 20 sec by comparison with synthetic seismograms. We call these uncatalogued events very low frequency earthquake. The hypocenters are located to two kinds of zones along the Philippine Sea subducting plate in south-western Japan. The one zone is very close to the trough. The seismicity listed by earthquake catalogues is low level in the zone and hypocenters are distributed in island arc side. The very low frequency earthquakes occur in outer area of seismic generation zone. The other zone is coincided with extended zone generating low frequency seismic events. Very low frequency earthquake occurs intermittently in limited area. Frequently, activity increases for some days and swarm type activity generates occasionally. To evaluate integrated seismicity for anomalous events, same class magnitude, greater than 3.0, events occurred in same and surrounding area are picked up from JMA earthquake catalogue. The analysis shows that seismicity of very low frequency earthquakes is comparative with one of normal earthquakes in background activity. We concluded that very low frequency earthquake is one of factors playing seismically important role.

S41D MCC: Level 1 Thursday 0830h

Subduction and Lithospheric Deformation in South America II Posters *(joint with T)*

Presiding: **S L Beck,** University of Arizona**; A Krabbenhoeft,** GEOMAR Research Center for Marine Geosciences

S41D-0108 0830h POSTER

Low Vp/Vs Ratio in the Archean Crust of the Southern Sao Francisco Craton, SE Brazilian Shield, by Slant Stacking of Receiver Functions.

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The composition of the lower crust in Archean cratons is a matter of debate. Felsic to intermediate granulites (with relatively low Vp and low Vp/Vs ratio) have been proposed by Mooney and Durheim (1991) based on seismic refraction profiles. On the other hand, worldwide estimates of Vp/Vs from receiver functions (Zandt et al., 1995) seem to show high Vp/Vs ratios in Precambrian regions (>1.78). It is not yet clear if the Archean crust has any typical value or not (Ni and James, 2003). Determination of Vp/Vs ratios from receiver functions tend to have high uncertainties due to the weak amplitudes of the multiple reflected phases and interference effects after the first Ps conversion, and this difficulty may have prevented the determination of a "typical" value for the Archean crust. A new method is presented here for enhancing the multiple reflected phases (P2ps and Pp2s) in receiver function seismic sections. Slant stacking of receiver functions is carried out in the time x slowness-squared domain (instead of the usual time x distance domain) which allows a better alignment of the converted phases and improves the identification of their arrival times. Phase weighted stacking is also used to remove uncoeherent noise. The picked arrival times can then be used to estimate the average crustal Vp/Vs ratio. Several stations located in the Archean block of the southern Sao Francisco craton and adjacent fold belts yielded Vp/Vs ratios ranging from 1.66 to 1.77 with an average value of about 1.72. This is consistent with the regional average value of 1.71 determined by a Wadati diagram from small local earthquakes. The low Vp/Vs values found for the Sao Francisco craton favour a less mafic composition for the lower crust, more in agreement with the Archean/Proterozoic crustal evolution proposed by Mooney and Durheim (1991).

S41D-0109 0830h POSTER

Surface Wave Group Velocity Tomography and Lithospheric S-velocity Structure of South American Continent

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A new group velocity tomography is presented for the South American continent including additional stations deployed in the northern and northeastern part of the continent, which had not been covered by previous works. More than 10,000 seismograms were examined with paths principally propagating across the continent of South America. 4000 Rayleigh- and 2270 Love-wave dispersion curves with good quality were retrieved in the period range of 10-150s for Rayleigh wave and 20-70s for Love wave. Single-station group velocities were determined using multiple filtering techniques. 2D group velocity tomography was applied to fundamental-mode Rayleigh and Love waves on a regular geographical grid using a conjugate gradient method. Checkerboard tests showed that our data set permits a lateral resolution of about 300km in the central part of the continent with denser paths coverage. Regionalized dispersion curves have been then inverted for 1D S-velocity profiles inside each block, which have been used to construct the final 3D S-velocity model. Both the 2D group velocity and the 3D S-velocity maps showed good correlation with the major geological provinces like cratons, Andean range, shields and sedimentary basins etc. The lowest velocities are found in the Andean region and the highest velocities in the Amazon craton. The two flat subduction slabs in the western coast of South America were well resolved. Our 3D shear-wave velocity model not only showed general similarity to the results from Partitioned Waveform Inversion and body-wave traveltime tomography, but also improved the resolution in the northern and northeastern part of the continent not covered by previous works.

S41D-0110 0830h POSTER

An investigation into crustal structure of South America; the continent that is missing some of its Moho

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Knowledge of the large-scale crustal structure of the South American continent is currently very sparse. In order to improve this situation we collected data from available permanent broadband seismometers in the GSN, GTSN, and Geoscope networks in South America to learn about crustal structure at each station. Data was obtained from 15 stations spanning South America from as far north as Venezuela to southern Argentina, and across the entire east-west extent of the continent. Five stations are located along the western coast of South America near the subduction zone in the forearc region west of the high cordillera of the Andes. Seven stations are located in the non-deformed shield part of the South American continent. Three stations are located in the actively deforming region of the Andes. The stations in the nearby Galapagos and Falkland Islands were also studied. We collected data from each of these stations for a time period between 1996 and 2002 and calculated nearly 1000 high quality receiver functions with the amount of data at each station ranging from less than ten to over 150. The receiver functions from these stations were investigated as a function of ray parameter and backazimuth to identify P-to-s conversions from the Moho and crustal multiples. The most striking observation we find is that we do not detect a clear Moho arrival at any of the five stations in the forearc region. This observation may be due to pervasive hydration of the forearc mantle resulting in the reduction of the shear velocity contrast at the base of the crust. We do however find a strong conversion that appears to occur at a depth corresponding to the top of the subducting slab in the range of 60-80km at these stations. The Moho under the stations in the cratonic crust can be clearly seen in the depth range of 34-47 km and Vp/Vs values are in the range of 1.63 to 1.88. We do not detect a clear geographic pattern in changes in crustal thickness and Vp/Vs across the continent, but we are currently comparing crustal properties and surface geology to find additional correlations.

S41D-0111 0830h POSTER

Constraints on South American crustal evolution and composition from crustal Poisson's ratio and thickness measurements

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Using a receiver function stacking procedure and data from 37 broad-band seismic stations installed along a 3000-km EW profile across central South America, we have determined crustal Poisson's ratio (σ) and thickness across the entire continent along 20-degree South. Similar to previous studies using various techniques/datasets, we have found a thick crust beneath the central Andes. In addition, we have found that the crustal Poisson's ratio in this area is higher-than-normal (0.27), suggesting a mafic average crustal composition. In contrast, the two sites located on the immediate east of the surface expression of the Andes are found to have low σ (about 0.23) and normal crustal thickness (36 km), suggesting a felsic composition. Under the assumption that the pre-shortening crust beneath the present-day Andes was similar to that beneath those two sites, the dramatic contrast in σ suggests underplating of mantle-derived mafic materials. Such an underplating could be achieved by thermal thinning of a weak basal lithospheric layer. Obviously, simple tectonic shortening of the felsic crust would not be able to form the inferred mafic Andean crust. This conclusion is consistent with geothermal and geochemical observations, which suggested the existence of mantle-derived rocks in the crust. Crust beneath the Parana basin and the Sao Francisco craton are found to have a normal thickness (38-44 km) with a medium-to-high σ (0.26). Possible correspondence between the observed spatial variation of crustal thickness and σ with the occurrence of the extensive flood basalt and other major tectonic events will be presented.

S41D-0112 0830h POSTER

Seismic attenuation and electrical resistivity beneath the southern Altiplano plateau

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