the time the hypocenter and magnitude are determined (minutes to an hour) and the time that onsite information is available through the media and other organizations (typically several hours to days). When complete, the system will provide an assessment of the situation based on estimated and any observed ground motions, total population exposed to varying degrees of shaking, and fragility of the impacted region. We expect that an automatic summary impact statement and associated alarms can be made within seconds of computing the ground-motion estimates, well before onsite damage estimates arrive. Development of the system is proceeding in stages, with each stage adding an increased level of detail and robustness to the impact statements. The initial system will be basic and empirical. It will issue alarms when an earthquake occurs where historical earthquakes of similar magnitude and depth have seriously impacted human life or infrastructure. This basic system will miss some significant events, but it will be relatively easy to implement and it will provide a baseline for further enhancements. Subsequent enhancements will include estimates of ground motion, population exposure, and regional fragility. Ground motion estimates will initially use regionally specific, empirical ground-motion attenuation relations. As details about the source are recovered, the estimated motions will evolve from point-source-based empirical to finite-fault-based empirical and to finite-fault-forward modeled synthetic amplitudes, augmented with empirical predictions. To this end, we are working collaboratively with C. Ji and D. Helmberger (Caltech) to expedite and automate the finite-fault inversion process (see abstract this meeting). Any ground motion observations (strong motions stations or Community Internet Intensities) will be used as constraints. Site amplification will be simple at first. We will use soil classification where known; otherwise, generic site terms will be used. The use of topography as a proxy for site conditions will also be investigated. Worldwide population databases in gridded form (e.g., LandScan developed by Oak Ridge National Laboratory) will be used to determine the total population exposed to various levels of shaking. For events not having significant populations at risk (e.g., off-shore or very deep earthquakes), it will be easy to determine when no response is warranted. However, when a large population is exposed to potentially damaging levels of shaking, the fragility of the region will be evaluated to constrain the likely overall impact. Fragility can be addressed in a several ways, but we will initially derive regionalized estimates based on the NEIC database of historical damaging earthquakes. We will later use socioeconomic considerations, as well as a qualitative assessment of construction and engineering practice.

S42B-0171 1330h POSTER

Quick Finite-Fault Inversion and Strong Motion Prediction: Feasibility, Process, and Developments

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As part of a larger, concerted effort to rapidly assess the impact of major earthquakes globally and to provide input into other post-earthquake analyses (e.g., ground motions, stress changes, tectonic implications, etc.), we are developing and testing a new system to automatically determine finite-fault characteristics by inversion of teleseismic body waveforms. Although initially constrained from teleseismic data alone, which currently are the only rapid and reliable available data after major events worldwide, additional data will be used (either directly or as constraints) as they become available, including aftershock locations, geodetic displacements, and regional waveforms. Our ultimate goal is to provide well-constrained, estimated peak ground motions for input into a global ShakeMap, which in turn will allow automatic, reliable estimates of losses and overall impact. To evaluate the feasibility of such a system, we inverted for slip variations on a single plane for the 1999 ChiChi (M7.6) earthquake using only teleseismic data and then compared the 2-sec peak ground velocity map predicted by this model with the observations (constrained by over 400 stations). Even though the fault geometry of this earthquake was more complex than our simple approximation, as would be the case for our initial, automated solution, the predicted map matches the overall observed amplitude variations. While successful in that case, a fully automated system requires overcoming additional, significant hurdles, many of which we are discovering and addressing as we develop the processing system. One such hurdle addressed was the choice of the causative rupture plane from the two nodal planes of a moment tensor solution. We simply conduct finite fault inversions on the two planes simultaneously, and select the solution with a smaller error function. This approach worked well for recent the 2003 Carlsberg Ridge earthquake (M7.6), for which the inverted result matches the trend and extent of its aftershock sequence. Among the more challenging hurdles is compensating for travel time anomalies within an automated system. Using the 2002 Denali earthquake as an example, we show the importance of this correction and how we calibrated the teleseismic path effects with proximal fore- or aftershocks. We also show how an improved fault geometry based on a high-resolution DEM map enhanced the solution. Finally, we discuss ongoing developments, further results, and plans for this system.

S42C MCC: Level 1 Thursday 1330h

The Energy Budget of the Earthquake Machine III Posters *(joint with G, T, NG)*

Presiding: **R E Abercrombie,** Boston University**; A McGarr,** U.S. Geological Survey

S42C-0172 1330h POSTER

Constraints on the Energy Budget of Deep Earthquakes

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Processes such as melting and thermal shear instability have been suggested as mechanisms for deep earthquake generation, which is still not understood. If such displacement-driven processes are important in deep earthquake rupture, then an effect on the energy budget may be expected. Therefore, we determine seismically-radiated energies and stress drops (from corner frequency), and examine these for moment-dependence of the seismically-radiated energy to moment ratio and seismic efficiency estimates. We calculate source spectra for 111 globally-distributed earthquakes with depths from 100 to 650 km and Mw from 6.3 to 8.3. The spectra are computed from teleseismic broadband P waves recorded by the GSN. We correct for instrument response, depth-dependent attenuation, radiation pattern, geometrical spreading, and near-source velocity. Squared velocity spectra are integrated and scaled to yield the seismically-radiated energy. The ratio of radiated seismic energy to moment times rigidity gives the apparent stress. For these earthquakes, this parameter has more than an order of magnitude scatter. A modest change in apparent stress over this moment range could occur, but is not resolvable in the scatter. Apparent stresses appear to increase by about a factor of two with depth. Static stress drop can be estimated from the spectral corner frequency, but it is well to bear in mind that this requires the assumption of a rupture velocity. Static stress drops estimated from corner frequencies vary more than two orders of magnitude for these events. An upper bound on the seismic efficiency can be computed from twice the apparent stress divided by the static stress drop. This bound, the Savage-Wood efficiency, is found to be greater than 0.25 for all events, and may increase slightly with moment. The Savage-Wood efficiency of events in the 350 to 550 km depth range is about three times higher than that of events above and below, mainly because static stress drops are smaller. Our previous studies have found events from 350 to 550 km depth to rupture longer with measurably more complexity, and with far fewer aftershocks. In these results, independent, but scarce, evidence that rupture velocity may differ significantly from 0.8 of shear velocity (such as for the 1994 Bolivian earthquake) was not taken into account. The difficulty in separating static stress drop from rupture velocity using only durations or corner frequencies remains. In some ways seismically-radiated energy is more reliably estimated than static stress drop, unless independent information on the spatial extent of rupture is available from surface rupture or aftershocks. To the extent that rupture velocity does not vary systematically with moment, our preliminary assessment is that the effect on the energy budget of displacement-driven processes such as melting or thermal shear instability does not change markedly and systematically for deep earthquakes over the magnitude range studied here.

S42C-0173 1330h POSTER

Quantifying properties of seismic spectra: an examination of 100's of spectra from southern California earthquakes recorded by the ANZA seismic network

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Unraveling earthquake source properties from seismic spectra requires an understanding of the inherent uncertainties that can be introduced from site and path effects. Here, we quantify properties of hundreds of earthquake spectra, and the associated uncertainties, from 0<Ml< 3 earthquakes in southern California recorded by the ANZA seismic network. From the spectrum that meet our data-quality and data-fit requirements we: (1) Determine the influence of site effects on the spectral decay characteristics; (2) Estimate the distance that site effects can be reliably extrapolated using data from small aperture arrays; and (3) Investigate the hypothesis that earthquakes behave as partial stress drop events. For each seismogram with an analyst-identified S-wave arrival, we test a range of viable corner frequencies and identify the one that minimizes the squared error fit of the data spectrum to the synthetic spectrum, which is computed assuming a Brune (1970) omega-square fall off. From this we can then compute the associated stress drop, seismic moment and AH-kappa, where AH-kappa is the residual slope to an omega-squared spectrum (Anderson & Humphries, 1991). Small values of AH-kappa indicate a greater percentage of high frequency energy. Using our highest quality data, we find that AH-Kappa measurements from sites on hard-rock can, in general, be 20 ms smaller than those from sites on unconsolidated rock. The uncertainty in AH-Kappa at a single station is 10 ms; assuming the site effect is constant for common source-receiver paths, we attribute this variability to deviations in the seismic source. Based on the theory of Brune (1970), we then used an iterative method that makes spectral corrections to account for potential partial stress drop events. Because the spectral shape of the partial stress drop model is less than omega-square model we expect the AH-kappa values to increase, and indeed we find this to be true. For an assumed full stress drop of 100 bars, our results typically show an increase of 10 ms in AH-kappa measurements, a value that is consistent with the 10 ms observed scatter. If variable stress drops are responsible for the 10 ms scatter in AH-kappa measurements, then, for engineering purposes, an additional 10 ms should be added to the mean observed AH-kappa values. Using AH-kappa to summarize small-scale site effects shows a +/-10 ms variation in AH-kappa measurements from individual event recordings at stations that are only 10s of meters apart. This implies that small-scale (10s of meters) heterogeneous site properties play a key role in a seismogram's frequency content.

S42C-0174 1330h POSTER

Relation between Corner Frequency and Seismic Moment for Shallow Earthquakes in Japan

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Strong motion records for three groups of shallow earthquakes in Japan (20 Kagoshima events with $M_w = 3.6 \sim 6.1$, 47 Tottori events with $M_w = 3.3 \sim 6.6$, and 16 Miyagi events with $M_w = 3.4 \sim 6.1$) are analyzed to investigate the similarity of earthquakes. A lot of high-quality close-in records at K-NET and KiK-net stations operated by the National Research Institute for Earthquake Science and Disaster Prevention, Japan (NIED) are available for these events. Spectral ratio of transverse component accelerograms observed at the same station is calculated between the largest event and each one of the other events in the same group to remove the station site response and the attenuation effect along the wave propagation path. Spectral ratios at stations around the epicenters of the events are averaged to remove the effect of small differences in the hypocenter location and the focal mechanism. The source spectrum is assumed to have omega-squared decay in the frequency range higher than the corner frequency, f_0. The seismic moment, M_0, determined by NIED is used in this study. Fitting the theoretical source spectral ratio to the observed spectral ratio, f_0 is estimated for each event. The rela-

tionship, $M_0 \propto f_0^{-3}$, is expected from the similarity of earthquakes. However, the present result shows $M_0 \propto f_0^{-(3+\epsilon)}$, where ϵ is positive. Although the location and the focal mechanism of the three groups are different (Kagoshima and Tottori events are strike-slip and Miyagi events are reverse faulting.), the results for the three groups are very similar. The seismic energy is calculated from the estimated source spectra. The energy-to-moment ratio increases with the earthquake size. This scale-dependence is very similar to that found earlier for earthquakes in Southern California.

S42C-0175 1330h POSTER

High-frequency seismic energy radiation from the 2003 Miyagi-Oki, JAPAN, earthquake (M7.0) as revealed from an envelope inversion analysis

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The 2003 Miyagi-Oki earthquake (M 7.0) took place on May 26, 2003 in the subducting Pacific plate beneath northeastern Japan. The focal depth is around 70km. The focal mechanism is reverse type on a fault plane dipping to the west with a high angle. There was no fatality, fortunately. However, this earthquake caused more than 100 injures, 2000 collapsed houses, and so on. To the south of this focal area by about 50km, an interplate earthquake of M7.5, the Miyagi-Ken-Oki earthquake, is expected to occur in the near future. So the relation between this earthquake and the expected Miyagi-Ken-Oki earthquake attracts public attention. Seismic-energy distribution on earthquake fault planes estimated by envelope inversion analyses can contribute to better understanding of the earthquake source process. For moderate to large earthquakes, seismic energy in frequencies higher than 1 Hz is sometimes much larger than a level expected from the omega-squared model with source parameters estimated by lower-frequency analyses. Therefore, an accurate estimation of seismic energy in such high frequencies has significant importance on estimation of dynamic source parameters such as the seismic energy or the apparent stress. In this study, we execute an envelope inversion analysis based on the method by Nakahara et al. (1998) and clarify the spatial distribution of high-frequency seismic energy radiation on the fault plane of this earthquake. We use three-component sum of mean squared velocity seismograms multiplied by a density of earth medium, which is called envelopes here, for the envelope inversion analysis. Four frequency bands of 1-2, 2-4, 4-8, and 8-16 Hz are adopted. We use envelopes in the time window from the onset of S waves to the lapse time of 51.2 sec. Green functions of envelopes representing the energy propagation process through a scattering medium are calculated based on the radiative transfer theory, which are characterized by parameters of scattering attenuation and intrinsic absorption. We use the values obtained for the northeastern Japan (Sakurai, 1995). We assume the fault plane as follows: strike=193a, dip=69a, rake=87a, length=30km, width=25km with referrence to a waveform inversion analysis in low-frequencies (e.g. Yagi, 2003). We divide this fault plane into 25 subfaults, each of which is a 5km x 5km square. Rupture velocity is assumed to be constant. Seismic energy is radiated from a point source as soon as the rupture front passes the center of each subfault. Time function of energy radiation is assumed as a box-car function. The amount of seismic energy from all the subfaults and site amplification factors for all the stations are estimated by the envelope inversion method. Rupture velocity and the duration time of a box-car function should be estimated by a grid search. Theoretical envelopes calculated with best-fit parameters generally fit to observed ones. The rupture velocity and duration time were estimated as 3.8 km/s and 1.6 sec, respectively. The high-frequency seismic energy was found to be radiated mainly from two spots on the fault plane: The first one is around the initial rupture point and the second is the northern part of the fault plane. These two spots correspond to observed two peaks on envelopes. Amount of seismic energy increases with increasing frequency in the 1-16Hz band, which contradicts an expectation from the omega-squared model. Therefore, stronger radiation of higher-frequency seismic energy is a prominent character of this earthquake. Acknowledgements: We used strong-motion seismograms recorded by the K-NET and KiK-net of NIED, JAPAN.

S42C-0176 1330h POSTER

Seismic Energy of Small Earthquakes Using Hi-net Data

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Seismic energy is a fundamental parameter of the earthquake source. The seismic energy of large earthquakes is well determined, but large earthquakes occur infrequently, so it is critical to develop accurate methods to study the more numerous smaller earthquakes as well. Additionally, a key question in earthquake source dynamics is whether there is something fundamentally different in the physics of the rupture process of small and large earthquakes. To answer this question, we need accurate estimates of the seismic energy for events of all sizes. The low signal to noise ratio of smaller earthquakes makes their seismic energy difficult to measure. Fortunately, there are high signal-to-noise ratio borehole recordings of small earthquakes available. Data from the high sensitivity borehole network in Japan (Hi-net) should be particularly useful for this purpose. Using these data and using techniques based on empirical Green's functions under the assumption of an omega-square source spectrum, we estimated seismic energy for 6 small earthquakes in the Ishikawa prefecture.Our results suggest that the scaling of seismic energy may break down with earthquake size; i.e., small earthquakes have smaller energy than is expected from a simple similarity scaling. The lower energies we observe appear to be explained by a change in the scaling of earthquake duration with size. In other words, we observed a change in corner frequencies, and hence inferred static stress drops, with earthquake magnitude. The ratio of apparent stress to stress drop yields an apparent radiation efficiency that differs from the true radiation efficiency depending on the degree of dynamic overshoot. While our observations of the apparent radiation efficiency do not vary with earthquake size, the results of other studies suggest that this quantity decreases for very small earthquakes. Under the assumption that rupture velocity is not different for such small earthquakes, we find that these small values may require unreasonably large overshoot.

S42C-0177 1330h POSTER

Determination of Fault Planes and Rupture Velocities of Small Earthquakes in a South African Gold Mine: Constraints on Radiation Efficiency

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Analyses of source processes of small earthquakes are important for investigating whether or not there are dynamic differences between small and large earthquakes. However, it is difficult to resolve details of the source of small earthquakes because close station spacing near the hypocenter and data with high sampling rates are necessary. Such observations of mining induced earthquakes are being carried out in a South African gold mine. Nine tri-axial borehole accelerometers were installed within 200 m along a 2,650-m-deep haulage tunnel in the Mponeng gold mine. Many seismic events (-2.7 < M < 3.3) were recorded with a sampling frequency of 15 kHz from February to October, 1996. In this study we focused on the rupture velocity, which is important for investigating characteristics of initiations, arresting mechanisms, and radiation efficiency of earthquakes. We carried out kinematic waveform inversions for three larger events (M1.4, 1.1, and 0.8) that occurred within 200 m of the stations. First, we determined the velocity structure using arrival time data. Velocities of P and S waves were estimated to be 6.00 km/s and 3.83 km/s, respectively. Next, we determined focal mechanisms from amplitudes of P, SH, and SV waves. Finally we carried out kinematic wave-form inversions for both nodal planes of focal mechanisms assuming various rupture velocities to distinguish the fault plane and the best-fitting rupture velocity. We could determine the fault plane for all events because the model fit to the data for the fault plane was significantly better than for the auxiliary plane. Also, the deduced fault planes were consistent with the results of sub-event locations for these events by Yamada et al. (2002). On the other hand, we could not determine the rupture velocities with complete confidence. One problem is that in general, residuals are likely to be smaller by assuming higher rupture velocities. However, we can conclude that rupture velocities were not less than 50% of the S-wave velocity, on the basis that the slower rupture velocities could not explain wave-forms very well. Therefore, we conclude that rupture velocities of small earthquakes in the South African gold mine are almost the same as those of larger natural earthquakes. The radiation efficiency can be written as a function of the rupture velocity and becomes greater with increase of the rupture velocity. This study indicates that radiation efficiencies of small earthquakes in the South African gold mine are almost equal to those of larger natural earthquakes.

S42C-0178 1330h POSTER

Source Parameters of Reservoir-Induced Small Earthquakes: Can We Resolve Rupture Velocity?

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Abercrombie and Leary (1993) noted that the average stress drops of induced earthquakes appear to be lower than those of tectonic earthquakes. This difference may result from different tectonic setting or the shallow depth of induced earthquakes. Alternatively, it may reflect uncertainties resulting from single station recording, and assumption of rupture velocity and source model. We analyze earthquakes induced by the Açu reservoir, NE Brazil for comparison with tectonic and mining earthquakes. Do Nascimento (2002) located 286 earthquakes (M≤2.8) recorded between 1994 and 1997 on a closely spaced network of 8 3-component seismometers. The locations and focal mechanisms are consistent with activity on NE trending right-lateral faults. The short source-to-receiver distances (<5km) and shallow hypocentral depths (<3km) of the earthquakes, and the low attenuation of the Precambrian basement rock allowed energy at frequencies up to the Nyquist (100 and 250 Hz) to be well recorded at the surface. Starting with the largest earthquakes we search for groups of collocated events. We use 3 different approaches to calculate the source parameters of the largest 2 earthquakes in the first cluster ($M2.2$ and $M1.8$), at 4 stations with good azimuthal distribution. We fit the individual spectra using an ω^{-2} source model to find corner frequency (f_c), frequency-independent Q, and long period amplitude. We use the small earthquakes as empirical Green's functions (EGF) and calculate the spectral ratios of the largest earthquake to the smaller events in the cluster. Using the ω^{-2} model we fit the ratios solving for the f_c of the largest earthquake. We then determine the relative source time functions using the EGF method. We will also measure radiated energy. The various estimates of source duration and f_c imply stress drops in the range of 1 to 10 MPa. These are similar to tectonic earthquakes suggesting hypocentral depth and strain rate do not affect stress drop. The source-time functions vary systematically with azimuth and imply rupture toward the NE, with rupture velocity consistent with that of large tectonic earthquakes.

S42C-0179 1330h POSTER

Rate dependence of acoustic emissions generated during granular shear

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Earthquake systems are commonly described using rate and state dependent fault models. The parameters in these laws describe the microphysics of slip, however a detailed understanding of the connection between friction parameters and specific micro-processes remains a challenge. We present new laboratory observations using state of the art ultrasonic techniques to gain insights into dynamic processes operating during frictional sliding. Granular layers were sheared under constant normal stress for a range of loading rates in a direct shear apparatus. During experiments, we monitored high frequency acoustic emissions (AE)

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generated by grain fracture and friction using an array of piezoelectric transducers mounted around the sliding layers. Complete waveforms and event information (AE events/s) were collected for thousands of micro-earthquakes. Perturbations in load point velocity (V) were imposed periodically to determine the friction response and acoustic activity. For a given V, we observed that AE event rate decreased systematically with accumulated slip suggesting sensitivity to gouge layer evolution. Step increases in V induced immediate and sustained increases in acoustic activity; the converse was true for V decreases. Friction response to a velocity perturbation was consistent with previous work. The positive rate dependence of acoustic activity is unsurprising since more slip is covered per unit time at higher V, however our data on the number of events/μm exhibit a decrease with increasing V indicating a deficit of acoustic activity per unit slip at larger V. Assuming that AE result mainly from grain contact sliding, the acoustic activity is proportional to the real area of contact between sliding particles. Our results qualitatively agree with previous experiments carried out on bare rock surfaces and support ideas that frictional contact junction area is reduced at increased sliding velocity. Our data represent unique, direct observations of micro-mechanical contact processes important in friction mechanics and hence are fundamental to earthquake physics.

S42C-0180 1330h POSTER

Attempting to Bridge the Gap Between Laboratory and Seismic Estimates of Fracture Energy

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The elastic strain energy released during an earthquake is partitioned into energy radiated by the seismic waves, work expended to overcome frictional resistance, and the fracture energy consumed as the rupture surface expands. Of these three components, the fracture energy G_c is perhaps the least understood and, in particular, attempts to relate laboratory estimates of this component to counterparts measured seismically for earthquakes have been controversial. Because of its important role in the development of dynamic rupture models of earthquakes, it is important to be able to understand the behavior of G_c, especially its dependence on the state of stress and the scale of rupture. Encouraged by success at scaling fault slip and slip rate from biaxial stick-slip friction laboratory experiments to those for earthquakes (McGarr and Fletcher, Bull. Seismol. Soc. Am., in press, 2003), we propose a similar approach for extrapolating G_c measured in the laboratory to investigate its behavior for earthquakes. Fracture energy is commonly represented as the area of a right triangle whose height represents the difference between the yield stress and the dynamic frictional stress (dynamic stress drop) and whose base is the slip-weakening distance D_c. Fracture mechanics analysis suggests that D_c may scale as the dimension of the seismic rupture and the dynamic stress drop is determined by the state of stress in the seismogenic crust. The dimension of rupture is often taken to be the size of the entire earthquake. Slip models developed for major earthquakes, however, indicate that the distribution of slip is quite inhomogeneous, consisting of patches of high slip separated by zones of relatively little offset. This suggests that G_c and D_c scale more appropriately with either the dimension of an asperity or its associated slip; slip turns out to be a more straightforward scaling parameter. Thus, using slip as the parameter to scale from laboratory friction experiments to major well-studied earthquakes typically yields estimates of G_c and D_c that are less than those used in most dynamic rupture models of earthquakes. This new approach to estimating G_c appears to resolve a problem involving calculations of seismic energy radiation from dynamic rupture models of earthquakes; that is, these energies tend to be less than other types of estimates (e.g., teleseismic). We suggest that the high values of D_c used in some recently-published dynamic rupture models resulted in overestimates of the fracture energies at the expense of the seismic energies. We find that distributions of G_c and D_c that are constrained by laboratory results and the distribution of fault slip yield lower fracture energies and higher seismic energies that are in better accord with independent estimates.

S42C-0181 1330h POSTER

Stress Drop and Stiffness for the 1992 Landers, 1994 Northridge, and 1995 Kobe Earhquakes

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The new method of computing seismic energy and apparent stress of McGarr and Fletcher (2002) provides a means for computing the static stress drop on each sub fault from slip models by

$$\Delta\sigma = 2\tau_a(E_{nf}/E_a - 1)$$

where $\Delta\sigma$ is the stress drop, τ_a is the apparent stress, E_{nf} is the seismic energy in the nearfield, and E_a the seismic energy propagated to the farfield. From this we can determine a local stiffness using the definition from Walsh (1971) of

$$K_e = \Delta\sigma/u$$

where K_e is the stiffness, and u is slip. Using this method we determined stress drop and stiffness for slip models of 1992 Landers, 1994 Northridge, and 1995 Kobe earthquakes. Although the depth dependence of stress drop is weak for Kobe, it is clear for both the Northridge and Landers events. Maximum values range from about 40 MPa at a depth of 17 km for the Northridge event to 6 MPa at a depth of 14 km for the Kobe event. Stiffnesses are much more constant with depth and range from a high value for Northridge of about 16 MPa/m to a low value for Kobe of about 4 MPa/m. The depth dependence of the maximum value of stress drop at each interval in depth is similar in shape to estimates of crustal strength versus depth.
The slope of stress versus slip from dynamic modeling of the Kobe earthquake has units of stiffness and following peak stress have values that are similar to that obtained from our method (about 7 MPa/m for the dynamic modeling at deeper points on the fault). This implies that the value of slip corresponding to the distance from peak stress to the frictional sliding stress obtained from the dynamic modeling is related to the amount of slip on the subfaults and not to the critical slip distance in the Dieterich (1981) slip-weakening model of friction. Further, if the slip is larger than the critical slip distance then the area under the stress unloading curve inferred from dynamic modeling following peak stress is probably an overestimate of the true fracture energy.
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S42C-0182 1330h POSTER

Mechanisms of hydrodynamic fault rock fluidization and liquification and their effects on fault strength evolution

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Coseismic entrainment and transport of fragmented fault rock in moving fluid has previously been inferred to explain layering and sorting of cataclastic fault rocks and their injection into connected fractures. I distinguish two mechanisms of fault rock entrainment with different impacts on the local stress state in the fault zone and on fault rheology: 1.Fault rock fluidization results from the entrainment of wear particles or fault breccia in rapidly upward moving fluid following the coseismic rupture of a pressure seal. Fault rock fluidization requires that fluid contained within the fault, as well as in the surrounding host rock, is at super-hydrostatic pore fluid pressure prior to rupture. 2. Fault rock liquification results from the coseismic suspension of wear particles in fluid that is contained within fracture and pore space of the fault zone at nominally hydrostatic pressure. In this case, particles are suspended due to turbulent fluid flow induced by viscous drag along the slipping fault surfaces and by local fluid pressure gradients resulting from the creation and reduction of fracture space along the fault. Liquification will be aided by an overall coseismic fault zone dilatancy and subsequent transient influx of pore fluid into the fault zone. The coseismic pressure evolution within the fault zone will be different for both mechanisms: For fault rock fluidization, a rapid initial pressure drop will be followed by a slower pressure decline as fluid migrates from the fault into a sink at higher structural levels and as suspended material settles out of the fluid. For fault rock liquification, an initial drop due to coseismic fault dilatancy will be followed by a transient increase in fluid pressure due to the load of suspended material within the fluid column contained in the fault, reverting to the initial pressure as suspended material settles out. The transient increase in fault fluid pressure due to liquification would result in an equally transient reduction in effective fault normal stress potentially promoting seismic or aseismic afterslip. While the fluid pressure evolution is different for both mechanisms, they have similar effects on fault rock rheology. In both cases, entrainment of solid wear particles and breccia would increase the fluid volume contained in the fault, reducing frictional contact area along the fault surface, and thus resulting in coseismic slip weakening. In contrast to fault rock fluidization, slip weakening by fault rock liquification does not require super-hydrostatic fluid pressures prior to rupture enabling this mechanism in tectonic regimes that lack efficient mechanisms of interseismic pore pressure buildup.

S42C-0183 1330h POSTER

Fault Zone Drainage, Heating and Melting During Earthquake Slip

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The expansion of pore water caused by frictional heating during large crustal events provides a powerful weakening mechanism (Sibson, 1973; Lachenbruch, 1980). It may explain the magnitude of seismically inferred fracture energy and aspects of its variation with increased slip (Abercrombie and Rice, 2003; Rice *et al.*, 2003; Rice, this section, 2003). The weakening is mediated by the effects of fluid transport, which are sensitive to the permeability structure of the fault zone and its modification by damage induced by the passing rupture front (Poliakov *et al.*, 2002), as well as by the increase in pore pressure itself. Higher permeabilities allow partial drainage to occur, so that enough strength remains for the heat generated to cause partial melting of the fault gouge at large enough slip. We use recent field and laboratory data for fluid transport through pressurized fault gouge (e.g. Lockner *et al.*, 2000; Wibberley and Shimamoto, 2003) to motivate models for drainage and melting during earthquake slip. A dramatic illustration of the role of drainage is provided by an idealized model in which we assume that a freshly damaged, highly permeable region extends right up to a localized shear zone of thickness h_o = 5 mm, with fixed porosity n and much lower permeability k. At 7 km depth, for n = 0.02 and $k = 10^{-19}$ m^2, the slip distance required to reach the onset of melting at 750°C is approximately 0.4 m for a constant friction coefficient of f = 0.6. At 14 km depth, for n = 0.01 and $k = 10^{-20}$ m^2, the same temperature is reached after only 0.1 m of slip. Yet more efficient drainage might occur due to the permeability increases that accompany reductions in the effective stress, so that even more rapid temperature increases would be predicted. For example, with ten times higher k, melting begins after 0.1 m slip at 7 km depth and just 0.05 m at 14 km. At onset of melting the high melt viscosity impedes further drainage and, with increasing melt fraction, interparticle contact is soon eliminated (Jacques and Rice, 2002). Then all of the fault-normal stress is supported by pressure in a slurry fluid which, when the normal stress exceeds the least principal stress, can inject into the bordering damage zone. Remaining dissipation in fault slip is dominated by fluid lubrication between the still-solid gouge particles rather than inter-particle friction. The slurry viscosity is thermally activated and reduces dramatically with increasing temperature and decreasing solids fraction. We quantify these effects approximately, and compare our predictions to records of slip behavior as preserved in pseudotachylytes (e.g. Otsuki *et al.*, 2003).

URL: http://www.deas.harvard/~rempel

S42C-0184 1330h POSTER

Field Evidences for Fault Surface Lubrication by Friction-Induced Melts During Coseismic Slip

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Lubrication by friction-induced melts has been proposed as a mechanism for fault weakening during earthquakes. Field evidence for melt lubrication of the

fault surfaces is lacking, however, although the andesitic/basaltic composition (i.e. low-viscosity melts) of the matrix of many tectonic pseudotachylytes (solidified friction-induced melts) suggests low dynamic shear strength during coseismic slip. The Gole Larghe Fault Zone is an exhumed seismic source crosscutting the Adamello tonalites (Italian Southern Alps) and is exposed in a glacially polished area. In the fault zone, displacement is partitioned in more than 100 subparallel faults. Fault rocks are an association of pseudotachylytes and cataclasites produced at 6-8 km depth and 250-300 ^{o}C. Given the large extent of the outcrop and the large number of structural markers within the tonalites, it has been possible to reproduce the 2D profile (i.e. intersection of the fault surface with the outcrop surface) of 25 different pseudotachylyte-bearing faults and to relate the fault profile with the displacement accommodated by each fault. Two lines of field evidence suggest that shear strength is low during coseismic slip: 1) A maximum shear stress of only 20 MPa has been estimated from the amount of mechanical work converted to heat during coseismic slip to produce the measured volume of pseudotachylyte in single-jerk faults. Although a shear strength of 20 MPa is a minimum estimate since part of the displacement has been accommodated without production of pseudotachylytes, such strengths are very small considering the depth where seismic faulting has occurred. 2) The fractal dimension (measured with a box-counting method) of the 2D profile of pseudotachylyte-bearing faults increases from 1.0 to a constant value of 1.15 with increasing displacement. In experimentally generated friction melts, the fractal dimension of molten surfaces increases from 1.0 to 1.1 when, with increasing slip, a steady state value for the friction coefficient of 0.5 is achieved. The increase of fractal dimension with displacement from field studies could be evidence of steady state friction during coseismic slip in the presence of melt. Thus, field evidence suggests that melts might lubricate fault surfaces during coseismic slip.

S42C-0185 1330h POSTER

Characterization of Natural Slip Surfaces Relevant to Earthquake Mechanics

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The Punchbowl fault, an ancient trace of the San Andreas, displays extreme localization of displacement to a meters-thick fault core containing an ultracataclasite layer with mesoscale slip surfaces. New maps of the Punchbowl fault slip surface and ultracataclasite produced using optical and electron microscopy document that extreme localization of slip also occurred at the microscopic scale. The prominent mesoscopic scale slip surface is a thin (mm thick), texturally distinct layer of ultracataclasite with a crystal-lattice preferred orientation, as evidenced by uniform birefringence, within which distinct microscopic slip surfaces are evident. Thin sinuous seams and possible injection-like structures of opaque, ultrafine material and thin zones of cataclastic flow occur at the microscopic slip surface. Evidence for multiple episodes of synfaulting mineral alteration and cementation in the surrounding ultracataclasite documents chemical processes likely were important to strength recovery. Overall, microstructural features are consistent with the inference that repeated slip occurred on the mesoscopic-scale slip surface, and that older slip-surfaces are present throughout the ultracataclasite layer. Diffraction-contrast TEM imaging, micro-electron diffraction, quantitative elemental mapping and energy dispersive spectroscopy (EDS) are being used to determine relative abundance and types of crystalline phases, glass, or other friction-induced amorphous phases (e.g., silica gel). Preliminary TEM observations indicate that the ultracataclasite consists almost entirely of ultrafine particles (4 to 400 nm diameter), with rounded relict grains of the host rocks, faulted and unfaulted veins, sheared and kinked clay minerals, and new, euhedral grains. Low permeabilities are implied by the fine grain size and corresponding nm-scale pores. Although rapid slip on mesoscopic scale slip surfaces would be expected to have produced thermal transients, we have not, as yet, found any direct evidence of frictional heating. While most of the ultracataclasite is made of nano-particles and specific surface areas of the material are large, micro-diffraction of individual particles reveals their crystalline nature. We have not ruled out the possibility of alteration of glass to zeolites, but to date, amorphous glass has not been imaged, and clays have not been found with textures that suggest devitrification of glass; rather, clays exhibit evidence of shear during and after growth at low temperature. Zeolites locally are abundant and occur in intact, offset and fragmented veins, and as nanometer to micrometer size particles.

S42C-0186 1330h POSTER

EXAMINING MECHANISM DEPENDENT SEISMIC RADIATION IN 3D SPONTANEOUS RUPTURE MODELS

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The mechanism-dependence of radiated seismic energy generated by earthquakes is investigated by modeling dynamic ruptures for three different fault mechanisms in three dimensions: a 30° dipping reverse fault, a 60° dipping normal fault and a vertical strike-slip fault. All three faults have the same area and are subjected to the same stress conditions in a homogeneous half-space. Except for the geometry and the mechanism, all other conditions are identical. Following the work of Favreau and Archuleta (2003) both the work distribution on the fault and the work done by seismic waves against distant surfaces enclosing the source for the three different mechanisms are calculated using a 3D finite element method. In a recent study Perez-Campos and Beroza (2001) examined the far field energy radiation from previous earthquakes. Even though there is a large scatter in the results, they found that the radiated seismic energy is strongly mechanism-dependent: the average apparent stress for strike-slip earthquakes is 4.8 times higher than for reverse events and 1.8 times higher than for normal events (0.7 MPa for strike-slip events and 0.15 and 0.25 MPa for thrust and normal faults, respectively). These results are opposite to what is expected for the state of stress. In 2D dynamic simulations (Ma and Archuleta, 2002) we show that the three faults have almost the same seismic moment and radiate nearly the same amount of seismic energy for strike-slip and normal with a 50 percent increase for thrust. The apparent stress is 0.45 MPa, 0.29 MPa and 0.31 MPa for the reverse fault, normal fault and strike-slip fault, respectively. By looking at the energy distribution on a surface surrounding the fault we found most energy is confined near the free surface, i.e., most radiated energy propagates out as surface waves. The energy associated with small takeoff angles, i.e., energy that goes to teleseismic distance, is very small. We are doing simulations in three dimensions to investigate the mechanism-dependent radiated energy in a more realistic environment and to check possible 3D effects on our previous results.

S42C-0187 1330h POSTER

Tests of the Accuracy of the *Dc'* Estimate of Earthquake Slip-Weakening Distance

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Mikumo *et al.* (2003) and Fukuyama *et al.* (2003) have proposed a parameter they call *Dc'* which might be a useful estimate of slip weakening distance *Dc*. At each point on a fault, *Dc'* is defined to be the slip at the time of the peak slip speed at that point. We test the accuracy of the *Dc'* estimate by calculating it in unfiltered and low-pass filtered versions of models A and B of Guatteri and Spudich (2000). Models A and B are two different rupture models for a hypothetical M6.5 earthquake, and they have nearly identical rupture time, slip, and stress drop distributions, as well as nearly identical predicted seismograms, but *Dc'* for model B is about twice that for model A. *Dc'* calculated for these models tends to underestimate *Dc*. By low-pass filtering slip models A and B at 1.0 Hz or 0.2 Hz, we simulate the blurring effects, on these slip models, of band-limited waveform inversions. In these filtered slip models, *Dc'* usually overestimates *Dc* for subfaults in which *Dc* is less than half the total slip, but *Dc'* is approximately correct for subfaults having *Dc* greater than half the total slip. Low-pass filtering the slip models causes an artificial correlation between *Dc'* and the total slip. Spatial variations of *Dc'* in filtered slip models do not necessarily correlate with spatial variations of *Dc*. These biases should be considered when interpreting *Dc'* derived from band-limited slip models of real earthquakes.

S42C-0188 1330h POSTER

The Energy Budget of Earthquake Rupture: a View From Spontaneous Rupture Modeling and Finite-Source Models

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It is a common and frustrating experience of many dynamic modelers to initiate spontaneous rupture calculations that subsequently abort before rupturing to the desired earthquake size [*Nielsen and Olsen*, 2000; *Oglesby and Day*, 2002]. Source parameters in such dynamic source models are strongly correlated, but stress drop is the main factor affecting the distribution of the other dynamic rupture parameters. Additionally, the position of the hypocenter exerts a strong influence on the dynamic properties of the earthquake, and certain hypocenter positions are not plausible as those would not lead to spontaneous rupture propagation. To further investigate this last statement, we analyze the energy budget during earthquake rupture using spontaneous dynamic rupture calculations and finite-source rupture models.
In describing the energy budget during earthquake rupture, we follow *Favreau and Archuleta* [2003]. Each point on the fault contributes to the radiated seismic energy $E_{rs} = E_{el} - E_{fr} - E_{rx}$, where E_{el} denotes the elasto-static energy and E_{fr} the fracture energy. In this study we neglect for simplicity the relaxation work E_{rx} spent during the stopping of the earthquake. A rupture can be characterized by locally negative seismic energy density values, but its integral over the fault plane must be positive. The fundamental condition for rupture growth is therefore that the integral of E_{rs} on the rupture area remains always positive during rupture propagation.
Based on a simple energy budget calculation, we focus on identifying those target slip/stress distribution in dynamic rupture modeling that for a given hypocenter location fail to rupture spontaneously. Additionally, we study the energy budget of finite-source rupture models by analyzing the integrated seismic energy for the inferred slip maps using also hypocenter positions other than the network location. These results indicate how rupture was promoted for the true hypocenter while randomized hypocenters may not have been able to sustain a large earthquake. Our approach helped us both to speed up the computation of successful spontaneous rupture models, as well as to construct dynamically consistent rupture models for strong motion prediction.

S42C-0189 1330h POSTER

Asymmetric Structural Properties Across the San Jacinto Fault, Anza and the San Andreas Fault, Gorman: A Possible Indication of Preferred Rupture Direction

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We studied the structure and asymmetry properties of gouge and damage zone along the San Jacinto fault near Anza, CA. The NE side of the Principal Shear Zone (PSZ) expresses higher fracture density (FD) and more fault-parallel shear fractures with respect to the SW. In a road-cut exposure 2 m below the original ground surface, where the fault juxtaposes middle and late Pleistocene alluvial deposits, the gouge is 1.6 m wide and can be divided into distinct fracture domains. On the SW side of the recently active PSZ, the gouge is massive and dark, with a FD of 0.08 (cumulative fracture length, cm/cm2). Immediately to the NE of the PSZ, the gouge is highly sheared and foliated, with a FD of 0.82. The next gouge layer to the NE is shattered but shows no evidence of shearing and has a FD of 0.58. The SW wall-rock shows near-zero FD while the NE wall-rock has a FD of 0.17, higher than that of the massive SW gouge layer. We exposed the same gouge zone in a trench, 3.5 m below the road-cut and 5 m away from the original ground surface where it is only 15 cm wide; its face was moistened, than carefully scraped to preserve the natural fabric. This narrow gouge expresses similar division and asymmetry as the

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exposure above it, except that it is more compressed. Artificial exposures on two additional slopes with opposing exposure directions, located 100 and 140 m SE of the road-cut, respectively, were excavated to a depth of several meters. The sheared gouge layer adjacent to the PSZ from its NE side and within it has, respectively, 1.8 and 2.2 higher FD than that of the massive gouge layer on the SW side. The general fracture pattern is similar to the one of the road-cut exposures. We are now in the process of studying additional exposures along the Anza section of the San Jacinto fault and the Gorman area of the San Andreas fault. Our observations show several manifestations of asymmetry in gouge and fracture properties that are compatible overall with theoretical predictions for a wrinkle-like rupture pulse along an interface between different elastic materials (Ben-Zion, JMPS, 2001, and references therein). The wrinkle-like pulse has a preferred propagation direction that is the same as the loading direction on the slower side of the fault, and dynamic dilation at the rupture front with large fault-normal motion on the slower side. If such ruptures occur repeatedly on a fault that separate different media, we expect the following signals on the slower side: 1. higher FD in the gouge and in the host rock, 2. fault-parallel tension fractures with increasing density towards the PSZ, 3. higher morphological degradation driven by the increased FD, 4. reasonable consistency of items 1-3 along the fault. Our initial observations agree with these expectations, assuming that the slower side of the faults in our study areas is on the NE and the preferred direction of rupture propagation is to the SE. If these signals indeed represent the mechanical behavior of wrinkle-like rupture pulses, continuing studies can provide improved understanding of earthquake behavior and refined estimates of ground shaking associated with large faults separating different media. Updated results will be presented in the meeting.

S42C-0190 1330h POSTER

Examining tendencies of in-plane rupture to migrate to material interfaces

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Recent work indicated that rupture along a material interface has remarkable dynamic properties, which may be relevant to a number of geophysical problems, and that material interfaces are mechanically favoured locations for rupture propagation. Here we examine tendencies of 2D in-plane rupture to migrate spontaneously to material interfaces by performing a numerical parameter-space study in a model consisting of 3 media with 9 possible faults, 2 of which are material interfaces. The calculations employ a generalized version of the second-order finite-difference code used by Andrews (1973) and Andrews & Ben-Zion (1997). The faults are governed by Coulomb friction, and in some cases also Kelvin-Voigt viscosity. In general, a rupture along a material interface governed by Coulomb friction does not have a continuum limit (e.g., Adams, 1995; Ranjith & Rice, 2001). A Kelvin-Voigt viscosity provides regularization of the problem for a limited range of propagation distances and grid-refinements. Ruptures in our work are nucleated by a symmetric bilateral expanding pore pressure source, and may then continue to propagate (or not) along one or more faults. Using different nucleation locations (fault 1-9), different rheological parameters and initial stress, and different velocity contrasts, we examine the range of conditions for which ruptures migrate spontaneously to material interfaces and continue to propagate there in a self-sustaining manner.

S42C-0191 1330h POSTER

The Magnitude and Energy of Large Earthquakes

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Several magnitudes were introduced to quantify large earthquakes better and more comprehensive than M_s: M_W (moment magnitude; Kanamori, 1977), M_E (strain energy magnitude; Purcaru and Berckhemer, 1978), M_t (tsunami magnitude; Abe, 1979), M_m (mantle magnitude; Okal and Talandier, 1985), M_e (seismic energy magnitude; Choy and Boatwright, 1995). Although these magnitudes are still subject to different uncertainties, various kinds of earthquakes can now be better understood in terms or combinations of them. They can also be viewd as mappings of basic source parameters: seismic moment, strain energy, seismic energy, stress drop, under certain assumptions or constraints. We studied a set of about 90 large earthquakes (shallow and deeper) occurred in different tectonic regimes, with more reliable source parameters, and compared them in terms of the above magnitudes. We found large differences between the strain energy (mapped to M_E) and seismic energy (mapped to M_e), and between M_E of events with about the same M_w. This confirms that no 1-to-1 correspondence exists between these magnitudes (Purcaru, 2002). One major cause of differences for "normal" earthquakes is the level of the stress drop over asperities which release and partition the strain energy. We quantify the energetic balance of earthquakes in terms of strain energy E_{st} and its components (fracture (E_g), friction (E_f) and seismic (E_s) energy) using an extended Hamilton's principle. The earthquakes are thrust-interplate, strike slip, shallow in-slab, slow/tsunami, deep and continental. The (scaled) strain energy equation we derived is: $E_{st}/M_0 = (1+e(g,s))(E_s/M_0)$, $e(g,s) = E_g/E_s$, assuming complete stress drop, using the (static) stress drop variability, and that E_{st} and E_s are not in a 1-to-1 correspondence. With all uncertainties, our analysis reveal, for a given seismic moment, a large variation of earthquakes in terms of energies, even in the same seismic region. In view of these, for further understanding of earthquakes behaviour we introduce energy classes, and present first results.

S42C-0192 1330h POSTER

The Energetics of Gravity Driven Faulting

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Tectonic stress is reasonable attributed to gravity acting on the earth's density structures. The gravity collapse seismic mechanism assumes the earthquake fault fails and slips in direct response to the gravitational tectonic stress. Gravity collapse is simple but it involves some unusual energetics. In particular, gravitational potential energy is released from the stress-causing density structures. This energy is split between the seismic wave energy and an increase in locked-in elastic strain energy. In classic elastic rebound, the change in the locked-in elastic strain field drives slip on the fault. In gravity driven faulting, it stops slip on the fault. A change in gravitational potential energy implies a change in the density structure. The gravitational body force is directly dependent on density so a change in the density structure implies a change in the body force field. If the body force field changes, there must be volumetric body-force displacements. These are in addition to the displacements generated by slip on the fault surface. Their nature and significance remain largely unexplored. The gravity collapse mechanism provides a simple explanation for the occurrence of deep focus earthquakes in temperature/pressure environments that preclude the gradual accumulation of locked-in elastic strain energy. It also accounts for the dual-plane character of some Wadati-Benioff zones, post-seismic regional displacements that resemble the co-seismic regional displacements, and induced tectonic activity at a distance from the epicentral region. To the extent that tectonic stress originates from gravity acting on the Earth's density structures, the gravity collapse mechanism is fundamentally simple. It does not require the creation of a locked-in elastic strain field prior to the earthquake.

S42D MCC: Level 1 Thursday 1330h

Coda the Destroyer: Rupture Kinematics and Dynamics II Posters *(joint with T)*

Presiding: **D Lavallee,** Institute for Crustal Studies**; A M Rubin,** Princeton University

S42D-0193 1330h POSTER

Rupture Propagation for Stochastic Fault Models

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The inversion of strong motion data of large earhquakes give the spatial distribution of pre-stress on the ruptured faults and it can be partially reproduced by stochastic models, but a fundamental question remains: how rupture propagates, constrained by the presence of spatial heterogeneity? For this purpose we investigate how the underlying random variables, that control the pre-stress spatial variability, condition the propagation of the rupture. Two stochastic models of prestress distributions are considered, respectively based on Cauchy and Gaussian random variables. The parameters of the two stochastic models have values corresponding to the slip distribution of the 1979 Imperial Valley earthquake. We use a finite difference code to simulate the spontaneous propagation of shear rupture on a flat fault in a 3D continuum elastic body. The friction law is the slip dependent friction law. The simulations show that the propagation of the rupture front is more complex, incoherent or snake-like for a prestress distribution based on Cauchy random variables. This may be related to the presence of a higher number of asperities in this case. These simulations suggest that directivity is stronger in the Cauchy scenario, compared to the smoother rupture of the Gauss scenario.

S42D-0194 1330h POSTER

Stochastic Model of Complexity in Earthquake Slip Distributions

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Finite-fault source inversions reveal the spatial complexity of earthquake slip or prestress distribution over the fault surface. The basic assumption of this study is that a stochastic model can reproduce the variability in amplitude and the long-range correlation of the slip spatial distribution. The model is tested for the 1992 Landers earthquake and the 1994 Northridge earthquake and the results are compared with the stochastic model derived for the 1979 Imperial Valley earthquake. For the three earthquakes, we show that the average power-spectra of the raw, i.e., non-interpolated, data follow a power law behavior with scaling exponents close to unity. For the three earthquakes, we have found that non-Gaussian distributions, i.e., the Levy distributions, are better suited to describe the spatial variability of slip over the fault. The values of the Levy parameters differ from one earthquake to the other. We discuss the variation in parameter values from one earthquake to another and its signification for earthquake properties. We also show that a stochastic characterization of the slip amplitude based on a Gaussian distribution fails to reproduce the spatial variability observed in the original slip distribution. Especially, the "extreme" large slip valuesfrequently defined as asperitiesare present in the synthetic slip amplitude based on a Levy distribution but are missing in their Gaussian counterpart. The results obtained for the Imperial Valley, Landers and Northridge earthquakes suggest that some features of the slip spatial complexity are universal and can be modeled accordingly. If this is proven correct, this will imply that the spatial variability and the long-range correlation of any slip or stress distribution can be described with the help of five parameters: a scaling exponent controlling the spatial correlation and the four parameters of the Levy distribution constraining the spatial variability.

S42D-0195 1330h POSTER

The dynamic rupture process of the 2001 Geiyo, Japan, earthquake

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Dynamic rupture simulation of the 2001 Geiyo earthquake (Mw = 6.7) was carried out based on the kinematic model. The space-time distribution of slip of the earthquake i.e., the kinematic mode, was investigated by inverting the nearfield strong ground motion data and teleseismic waveform data(Yagi and Kikuchi, 2001). Two asperities are identified. The rupture mainly propagated 20 km to the south. In constraint of the above source model, we have constructed a dynamic