critical for the development of the region especially in the ongoing and planned major engineering structures such as large dams and oil and gas pipelines.

S61D-08 1055h INVITED

Active Tectonics of the Iran Plateau and South Caspian Basin

K. Priestely[1] (44-1223-337195; keith@esc.cam.ac.uk)

J. Jackson[1] (jackson@esc.cam.ac.uk)

A. Maggi[1] (maggi@madingley.org)

M. Talebian[1] (talebian@esc.cam.ac.uk)

R. Walker[1] (rwalker@esc.cam.ac.uk)

[1]Bullard Laboratories University of Cambridge, Madingley Rise Madingely Road, Cambridge CB30EZ, United Kingdom

We use observations of surface faulting, well-constrained earthquake focal mechanisms and centroid depths, and velocity structure to investigate the present-day deformation and kinematics of the region. Current deformation is primarily concentrated in three seismically active belts: the Zagros Mountains of southwest Iran,the Talesh-Alborz-Kopeh Dag Mountains of northern Iran, and the Apsheron-Balkhan Sill in the central Caspian Sea. These belts are separated by seismically inactive regions that act as semi-rigid blocks. The extent to which the active shortening is divided between the three belts is still uncertain. Earthquake locations in the region, particularly their focal depths which are determined from teleseismic arrival times, are poor, and reported subcrustal earthquakes have been cited as evidence for present-day subduction beneath the Zagros. A detailed analysis of earthquake focal depths in the Zagros and elsewhere in the region confirms that no substantial subcrustal earthquakes occur in this part of the Middle East except beneath the Makran subduction zone in the south and the Apsheron-Balkhan Sill in the north. The present-day N-S deformation across the Zagros is partitioned with right-lateral, strike-slip motion on the NW-SE striking Main Recent Fault, and NE-SW shortening across the Zagros. Shortening in the Zagros is accommodated by folding in the sediments (0-10 km depth), moderate earthquakes on high-angle reverse faults striking parallel to the surface folds (∼10-20 km depth), and aseismic thickening of the lower crust (∼20-45 km depth). The south Caspian basin is essentially free of earthquakes and acts as a rigid block which strongly influences the nature of the deformation in the surrounding active belts. No significant subcrustal earthquakes occur in the Talesh, Alborz, or Kopeh Dag Mountains which bound the northeast, south and west sides of the south Caspian basin, but substantial subcrustal seismicity occurs beneath the Apsheron-Balkhan Sill on the north side of the basin. Earthquakes in the Kopeh Dag occur primarily on reverse or right-lateral strike-slip, NW trending faults. The Kopeh Dag structures continue to the NW towards the Apsheron-Balkhan Sill but become increasingly buried by sediment. Focal mechanisms of earthquakes in the Alborz show either reverse motion or left-lateral strike-slip motion on faults parallel to the regional strike of the belt. Earthquakes in the Talesh indicate thrusting on almost flat faults at depths of 15-26 km with slip vectors directed towards the Caspian. We believe that the subcrustal earthquakes occurring beneath the Apsheron-Balkhan Sill indicate the onset of subduction of the high velocity (high density) south Caspian crust beneath the continental crust of the central Caspian. The conjugate right-lateral and left-lateral components in the Kopeh Dag and eastern Alborz suggest that the South Caspian Basin has a westward component of motion relative to both Eurasia and Iran. This motion enhances westward underthrusting of the basin beneath the Talesh Mountains of Iran and Azerbaijan.

S61D-09 1115h

Integrated Studies of Seismic Q and Velocity Structure in the Tethysides Belt of Southern Eurasia

Brian J Mitchell[1] (mitchbj@eas.slu.edu)

Goran Ekstrom[2] (ekstrom@seismology.harvard.edu)

Alemayehu L. Jemberie[1] (jemberie@eas.slu.edu)

[1]Saint Louis University , Department of Earth Atm. Sci. Saint Louis University 3507 Laclede Avenue , St. Louis, MO 63103, United States

[2]Harvard University , Department of Earth Plan. Sci. Harvard University 20 Oxford Street, Cambridge, MA 02138, United States

Tomographic maps of Lg coda Q that pertain to the crust, Rayleigh-wave phase velocites, and inferred shear-wave velocities in the upper mantle, are now available for nearly the entire Eurasian continent. In addition, models of the depth distribution of shear-wave Q, obtained from the inversion of fundamental-mode Rayleigh-wave attenuation are available for the Middle East and for China and peripheral regions. The most striking feature of Q maps for Eurasia is the broad band of low values that stretches through the Tethysides belt, a young collision zone in southern Europe, the Middle East and most of southern Asia. The mapped band of low Q values correlates strongly with maps of low values for shear velocity in the upper mantle. Measured values of Lg coda Q, shear-wave Q, and shear velocities also vary laterally along that band. Lowest values for Lg coda Q (about 200) occur in Turkey and southern Tibet.

Rayleigh-wave path coverage in southeastern Asia is sufficiently dense to allow the development of tomographic maps of shear-wave Q structure in three depth intervals, 0 10 km, 10 30 km, and 30 60 km. For the shallowest layer shear-wave Q attains lowest values (about 40) in the southern part of the Tibetan Plateau and the Tarim Basin and is highest in southeastern China. Shear-wave Q in the 10 30 km deep layer is lowest (about 50) in Tibet and the Pamir thrust system and highest in central China and parts of the Sino-Korean platform. Resolution of crustal variations is significantly poorer for the deepest layer than for the others, but results indicate that shear-wave Q is highest (about 180) beneath southern Mongolia and the Tarim Basin and lowest under the Pamir thrust system.

Lateral variations in Q at crustal depths can be interpreted in terms of variable densities of fluid-filled cracks and permeable material in the crust. Such fluids might originate from hydrothermal reactions in regions of high temperature in the upper mantle that might also cause reduced upper mantle velocities.

S61D-10 1130h

Improved images of the Tibetan upper mantle to test hypotheses of its dynamic origin

Nikolai M Shapiro[1] (303 735 1850; nshapiro@fignon.colorado.edu)

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

Michael H Ritzwoller[1] (ritzwoll@merckx.colorado.edu)

Peter Molnar[3] (molnar@cires.colorado.edu)

Jeffrey Park[2] (jeffrey.park@yale.edu)

[1]Center for Imaging the Earth's Interior, Department of physics University of Colorado Campus Box 390, Boulder, CO 80309-0390, United States

[2]Department of Geology and Geophysics, Box 208109, Yale University, New Haven, CT 06520, United States

[3]Department of Geological Sciences, CIRES, Benson Earth Sciences Building, Campus Box 399 University of Colorado, Boulder, CO 80309, United States

Uncertainties in current models of the upper-mantle beneath Tibet prohibit choosing among the variety of competing hypotheses that have been proposed to explain its genesis. These hypotheses include large-scale convective downwelling; the northward subduction of Indian lithosphere beneath Tibet; the southward subduction of the Tarim (or other Eurasian) lithosphere beneath Tibet; and small scale convective instabilities, or "deblobbing", of thickened mantle lithosphere beneath Tibet. To discriminate among these competitors, therefore, requires focusing current models of the Tibetan mantle and reducing uncertainties. We discuss our attempts to improve upon our earlier tomographic models of the Tibetan crust and upper mantle that have been derived exclusively from surface wave data. Monte-Carlo error analysis indicates that a large share of the uncertainty in the mantle derives from trade-offs between crustal and mantle structures. To reduce mantle uncertainties requires tighter constraints on crustal structures, which we apply based on receiver function analyses of broad-band data at both permanent and portable seismic observatories in the region. Models resulting from the joint inversion of surface wave dispersion and body-wave reverberations are considerably more reliable than from either alone. We discuss how the improved model compares with our earlier models, which display low wave speed anomalies immediately beneath the crust in northern and central Tibet which, in turn, are underlain by high speed mantle material to depths exceeding 200 km. Finally, we consider how the resulting model may be used to discriminate between mantle structures that are consistent with each of the dynamical hipotheses.

S61D-11 1145h

Himalayan Nepal Tibet Broadband Seismic Experiment (HIMNT)

Anne F. Sheehan[1] (303-492-4597; afs@cires.colorado.edu); Francis T. Wu[2]; Roger Bilham[1]; F. Blume[1]; G. Monsalve[1]; R. Bendick[1]; H. Gilbert[1]; T. de la Torre[1]; V. Schulte-Pelkum[1]; C. K. Wilson[1]; G. C. Huang[2]; M. R. Pandey[3]; H. B. Liu[4]

[1]University of Colorado at Boulder, CB 399, Boulder, CO 80309, United States

[2]SUNY Binghamton, P.O. Box 6000, Binghamton, NY 13902

[3]Department of Mines and Geology, National Seismological Centre, Kathmandu KTM, Nepal

[4]Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing 100101, China

Our project aims at the understanding of the mountain building processes through earthquake source and crust and mantle structure imaging. It involves the deployment of 28 broadband seismometers throughout Eastern Nepal and Southern Tibet, using broadband instrumentation from the IRIS PASSCAL facility. The stations were in place for one year from Fall 2001 to Fall 2002. The current studies with this data and their purposes are: (1) P to S converted waves (receiver functions) and teleseismic P and S arrival times will be used to decipher the general crustal and upper mantle structures under the Himalaya: to determine the presence of subduction zone and other structures under the Himalaya, (2) the arrival times and waveforms of hundreds of earthquakes under the orogen will be used to image the 3-D crustal structures underneath the Himalaya and relocate earthquakes using double difference and 3-D tomographic techniques: to determine possible major dislocation surfaces and the internal structure and rheology of the orogen, (3) seismic anisotropy under the Himalaya will be measured using shear wave splitting and P wave polarization analysis: to map upper mantle flow and lithospheric deformation, (4) focal mechanisms from regional moment tensor inversion: to determine kinematics of orogenic deformation. We seek to determine the geometry of fault ramps, where seismic events with characteristic focal mechanism concentrate, and whether the decollement can be detected through seismicity or material differences. Using teleseismic data we expect also to map features in the upper mantle underneath the orogen, such as the subducted Indian lithosphere and products of delamination. We will report on the results to date on these projects. The geometry of the source zones, the nature of the seismic slip and kinematics derived from this experiment will also help constrain the interpretation of ongoing geodetic surveying in the area.

URL: http://cires.colorado.edu/people/sheehan.anne/nepal_project.html

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S61E MCC: 121 Saturday 0830h

Slip Sliding Away: Earthquake Process *(joint with NG, G, T)*

Presiding: **J Gomberg,** U.S. Geological Survey**; J E Ebel,** Weston Observatory, Boston College

S61E-01 0830h

A Primer on Seismicity Rate Change Models

Joan Gomberg[1] (901-678-4858; gomberg@usgs.gov)

Maria Elina Belardinelli[2] (39-051-20-95018; elina@ibogfs.df.unibo.it)

Massimo Cocco[3] (39-06-51860401; cocco@ingv.it)

[1]U.S. Geological Survey, 3876 Central Ave., Suite 2, Memphis, TN 38152, United States

[2]Dipartimento di Fisica, Universita' di Bologna, Viale Berti-Pichat 8, Bologna 40127, Italy

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

Numerous physical models explaining the temporal response of seismicity to changes in loading, particularly the decay rate of aftershocks, have been proposed over the years. Among the most recent is that proposed by Dieterich (1994) in which earthquake failure is modeled as a frictional process obeying a particular set of empirical rate-state frictional relations. The Dieterich model predicts a simple analytic description of the change in seismicity rate due to a static stress step and/or change in loading rate, such as might result from a large earthquake affecting a population of

faults in the surrounding volume. The model continues to grow in popularity and is being applied by some to make time-dependent earthquake forecasts, which may be used to make decisions affecting public safety. For these reasons, the framework, assumptions and limitations of the model must be thoroughly understood by both those who apply it and those interested in their results. We have attempted to examine all these aspects of the model in detail, and to illustrate them in an easily understood manner. We would like to understand and explain how the rate of earthquake production is affected by variations in the initial mechanical conditions of the faults as well as the variability of frictional constitutive parameters. We do so using synthetic earthquake catalogs that are analogous to the real ones that the Dieterich model might be invoked to explain, and offer a general simple theoretical framework in which the Dieterich model fits as a special case. One example of a key assumption of the Dieterich model we test is that a steady-state background seismicity rate exists due to failure of different faults in an essentially infinite population of faults affected by tectonic (constant-rate) loading. Another is that seismicity rate increases occur because loading perturbations advance the failure times of faults that would have eventually failed anyways as part of the background seismicity, rather than resulting from new failures on faults not part of the background population. We show that the Dieterich model derivation and simplicity relies on specific frictional behavior, as embodied in the choice of rate-state frictional laws, which in turn has implications for the range of variability in properties of the faults comprising the affected population. Our hope is that this primer provides simple guidelines for use of the Dieterich and other similar models when interpreting observations of seismicity rate change and in predictive analyses.

S61E-02 0845h

1997 Kagoshima, Japan Earthquake Couplet as a Test of a Rate/State Stress Transfer Model to Forecast Time-dependent Seismicity

Shinji Toda[1] (81-298-61-2480; s-toda@aist.go.jp)

Ross S Stein[2] (1-650-329-4840; rstein@usgs.gov)

[1]Active Fault Research Center, GSJ/AIST, Higashi 1-1-1 AIST C7, Tsukuba 305-8567, Japan

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

Two large earthquakes struck 48 days apart within 4 km of each other, permitting us to study how seismicity responds to sudden changes in the sign of the applied stress. The stresses in some off-fault areas are calculated to have increased in the first shock and decreased in the second; elsewhere the opposite occurred. Using well-recorded data provided by Kagoshima University network, we find that rate/state friction of Dieterich (1994) can explain such seismic time series caused by such toggling between sudden stress increases and decreases. The first M=6.5 mainshock was produced by left-lateral slip on a 15-km-long striking fault. The succeeding M=6.3 shock involved near-simultaneous rupture of two conjugate strike-slip faults, forming an O'L.OL Because the epicenter of the May event was located at the junction of two fault planes, it is unclear which part of the O'LOL ruptured first, and thus whether the May event was triggered by the March event. Instead, using the variable slip models of Horikawa (2001), we calculate the Coulomb stress changes for each rupture. Rather than add the stress changes caused by both events, we consider the evolution of the state variable in rate/state friction in each stress perturbation. For example, the lobe of stress increase off one end of the March event, a site of numerous aftershocks, was suddenly subjected to a smaller stress decrease by the May event. Although for the two earthquakes there was thus a net stress increase, seismicity all but ceases after the second event. It is clear that seismicity is not proportional to the stress change but to the state, which depends strongly on the stressing and seismicity rate before each perturbation. We thus argue that in order to forecast seismicity from stress perturbations, the time-dependent behavior of seismicity described by rate/state friction leads to more accurate estimates.

S61E-03 0900h

Modeling the 1992 Landers Earthquake with a Rate and State Friction Model.

Hamdane Mohammedi[1] (Hamdane.MOHAMMEDI@ifp.fr)

Raul Madariaga[2] (madariag@geologie.ens.fr)

Gilles Perrin[1] (Gilles.PERRIN@ifp.fr)

[1]Institut Francais du Petrole, 1-4 Avenue du Bois Preau, Rueil Malmaison 92852, France

[2]Ecole Normale Superieure, Laboratoire de Geologie 24 Rue Lhomond, Paris Cedex 05 75231, France

We study rupture propagation in realistic earthquake models under rate and state dependent friction and we apply it to the modeling of the 28 June 1992, Landers earthquake. In our simulations we use a modified version of rate and state proposed by Perrin, Rice and Zheng, the so called PRZ law. Full inversion with PRZ is not yet possible because of the much higher numerical cost of modeling a fault under rate and state than with slip weakening friction laws (SW). Also PRZ has a larger number of independent parameters than slip weakening. We obtain reasonable initial models through the use of the ratio κ between available strain energy and energy relase rate. Because in PRZ friction there are more parameters than in SW we have not yet been able to identify all relevant non-dimensional numbers that control rupture in this model, but a very important one is a logarithmic map that controls whether instable slip may occur or not. This map has the form $\log \dot{D}/v_0 = \lambda \dot{D}/v_0$, where λ is a nondimensional number akin to κ. It includes the parameters of the friction law and the characteristic length of the initial stress, velocity or state fields. $\dot{D}$ is slip velocity and v_0 a reference speed that defines the initial stress field. Using the results of dynamic inversion from Peyrat et al, we find reasonable rupture models for the initiation of the Landers earthquake. The slip weakening distance in rate and state D_c, as defined by Bizarri and Cocco, is of the order of a few tens of cm. D_c is determined from L, the relaxation length in rate and state, as a subproduct of the logarithmic map cited above.

S61E-04 0915h

Numerical simulation of seismic cycles on a 2D planar fault with nonuniform frictional property

Naoyuki Kato (nkato@eri.u-tokyo.ac.jp)

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

To examine the effect of nonuniform distribution of friction parameters, I perform a numerical simulation of seismic cycles on a two-dimensional fault in an infinite uniform elastic medium. The fault is driven by steady plate motion and the frictional stress obeys a rate- and state-dependent friction law. I solve quasi-dynamic fault motion adopting radiation damping approximation, using 2D FFT technique in calculating quasi-static shear stress due to fault slip. Spatial nonuniformity in constitutive parameters a, b, and L or effective normal stress σ_n^{eff} on the fault is introduced in the simulation. When a patch with velocity-weakening friction ($a - b < 0$) is embedded in velocity-strengthening friction ($a - b > 0$) region, episodic slip events repeatedly occur in the patch. The critical patch radius r_c can be defined by $(7\pi/24)[GL/(b-a)\sigma_n^{eff}]$, where G is rigidity. If the patch radius is much larger than r_c, the events become normal earthquakes, and if the patch radius is comparable with r_c, the events become silent earthquakes. This indicates that the constitutive parameters may be estimated from the observations of silent earthquakes. Similar results are also obtained for nonuniformity in the characteristic slip distance L or the effective normal stress σ_n^{eff}. Introducing two or more patches in this model I can simulate more realistic unsteady slip behavior including postseismic slip, multiple events, and delayed multiple events. Stressing by propagation of aseismic sliding tends to trigger seismic rupture. The present simulation study is useful for understanding interaction between asperities and mechanism of complicated unsteady slip behavior on plate boundaries. Nonuniform distribution of constitutive parameters or effective normal stress may be estimated from the comparison of the simulation with the observed slip histories estimated from seismic and geodetic data.

S61E-05 0930h

Nucleation of Rate and State Frictional Instability Under Non-Uniform Loading

Nadia Lapusta[1] (617-496-8135; lapusta@esag.harvard.edu)

James R Rice[1,2] (617-495-3445; rice@esag.harvard.edu)

[1]Division of Engineering and Applied Sciences, Harvard University, Cambridge, MA 02138, United States

[2]Department of Earth and Planetary Sciences, Harvard University, Cambridge, MA 02138, United States

We consider the nucleation of frictional instability on a 2-D fault governed by rate and state friction under locally peaked stress. The stress increases linearly in time to mimic tectonic loading. It is important to study the nucleation process under such conditions because common sense as well as simulations of earthquake sequences suggest that earthquakes might nucleate in the areas of elevated stress produced by ends of creeping regions or by previously arrested earthquakes. The rate and state frictional stress τ for the case of constant in time normal stress σ is usually written as $\tau = \sigma\,[f_o + a \ln V/V_o + b \ln V_o\theta/L]$, $\partial\theta/\partial t = 1 - V\theta/L$, where V is slip velocity, θ is a state variable, and L is the characteristic slip distance. Two existing simple estimates for the size of the nucleation zone are $C\mu L/(F\sigma)$, where C is a geometric parameter of order 1, μ is the shear modulus, and F is b in Dieterich, *Tectonophysics*, 1992 and $(b-a)$ in Rice, *JGR*, 1993. Our study was motivated by the fact that these estimates do not match the sizes of nucleation zones observed in our simulations of earthquake sequences when the parameters of the friction law are varied.

The case $a = 0$ (no direct effect) of the rate and state friction is closely related to linear slip-weakening law and reduces to it in the limit $V\theta/L \gg 1$. In the case of linear slip weakening and quasi-static formulation, Uenishi and Rice (submitted to *JGR*, 2001) proved that the nucleation size h^* depends on the rate of weakening W and an elastic parameter μ^* ($= \mu$ for antiplane elasticity) only, i.e. $h^* = 1.158\mu^*/W$. If the limit $V\theta/L \gg 1$ is valid at least at the latest stages of the nucleation process (which is plausible due to rapid increase in slip velocity and is supported by our simulations), then we can show that the nucleation size for the case $a = 0$ and quasi-static slip is the same as for the linear slip-weakening formulation with $W = b\sigma/L$, that is, $h^*_{a=0} = 1.158\mu^* L/(b\sigma)$, regardless of the initial conditions or shape of the peaked loading on the fault. Some other aspects of the nucleation, such as time to instability, do depend on initial conditions and shape of the loading stress. Note that if the fault is locked before the nucleation, then $V\theta/L \ll 1$ would apply initially.

However, ample experimental evidence suggests that the direct effect is present ($a > 0$) for the range of velocities relevant to nucleation. Our simulations show that while $a = 10^{-8}$ to 10^{-6} result in the nucleation sizes h^* very close to that of $a = 0$, the value as small as $a = 10^{-4}$ already increases h^* more than twice in a particular problem studied. Clearly, this cannot be captured by either the Dieterich, 1992 or Rice, 1993 estimates. With the experimentally derived value $a = 0.01$, h^* becomes about $4.5h^*_{a=0}$. Equally importantly, the whole nucleation process is altered. While in the linear slip-weakening case the nucleation zone expends until the dynamic event starts, the case $a = 0.01$ results in a larger slowly slipping region which shrinks to a zone about $3h^*_{a=0}$ and then expands to about $4.5h^*_{a=0}$ before breaking out in an instability. We will also report on the results of nondimensional analysis and our current studies to elucidate the dependence of the nucleation process on initial conditions and rate and shape of the loading.

S61E-06 0945h

Slip Development and Instability on a Heterogeneously Loaded Fault with Power-Law Slip-Weakening

James R Rice[1] (617-495-3445; rice@esag.harvard.edu)

Koji Uenishi[1,2] (617-496-1467; uenishi@esag.harvard.edu)

[1]Department of Earth and Planetary Sciences and Division of Engineering and Applied Sciences, Harvard University, 224 Pierce Hall, 29 Oxford Street, Cambridge, MA 02138, United States

[2]Research Center for Urban Safety and Security, Kobe University, 1-1 Rokko-dai, Nada, Kobe 657-8501, Japan

We consider slip initiation and rupture instability on planar faults that follow a non-linear slip-weakening relation and are subjected to a locally peaked loading stress, the level of which changes quasi-statically in time. For the case in which strength weakens linearly with slip, Uenishi and Rice [2002] (http://esag.harvard.edu/uenishi/research/nl/nl.html) have shown there exists a universal length of the slipping region at instability, independent of any length scales entering into the description of the shape of the loading stress distribution. Here we study slip development and its (in)stability for a power-law slip-weakening relation, giving fault strength as $\tau = \tau_p - A\delta^n$ where τ_p is the peak strength at which slip initiates, δ is the slip, and A is a constant. Such a form with $n \approx$ 0.2-0.4 has been inferred, for slips from 1 to 500 mm, as an interpretation of seismological observations on the scaling of radiated energy with slip [Abercrombie and Rice, *EOS*, 2001; *SCEC*, 2002]. It is also consistent with laboratory experiments involving large rotary shear [Chambon et al., *GRL*, 2002]. We first employed an energy approach to give a Rayleigh-Ritz approximation for the dependence of slipping length and maximum slip on the level and shape of the loading stress distribution. That was done for a loading stress distribution $\tau_p + Rt - \kappa x^2/2$ where x is distance along the fault, κ is a constant, and Rt is the stress change from that for which the peak in the loading stress distribution equals the strength τ_p. Results show there is no longer a universal nucleation length, independent of κ, when $n \neq 1$, and that qualitative features of the slip development are significantly controlled by n. We also obtained full

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numerical solutions for the slip development. Remarkably, predictions of the simple energy approach are in reasonable quantitative agreement with them and give all qualitative features correctly. Principal results are as follows: If $n > 2/3$, the behavior is qualitatively similar to that for $n = 1$ (linear case). A slipping region develops gradually with increasing loading until it reaches the critical length above which the system becomes unstable. Beyond that critical length, an unstable equilibrium branch commences for which the load must decrease to continue to grow the slip and size of the slipping region. If $n > 1$, there exists a maximum allowable length of the slipping region, terminating the branch of unstable equilibrium states beginning at the critical length. If $n < 2/3$, like suggested by the observations, the analysis indicates that upon initiation of slip the loading must be decreased in order to expand the slipping region. That is, an unstable equilibrium branch initiates at slip $\delta = 0^+$, and hence the results suggest that instability will occur as soon as the peaked value of the loading stress reaches the strength τ_p. This, however, is a prediction based on using the power law starting at $\delta = 0^+$, whereas the observational results underlying it correspond to an amount of slip that is already greater than the sub-mm range of slip at instability inferred in laboratory studies. In this $n < 2/3$ range, the unstable equilibrium branch ultimately stabilizes with increasing length of the slipping zone, in that the loading must start to increase again to grow the slipping region further.

S61E-07 1000h

Frictional Heating of Pore Fluid Produces Complete Stress Drop in Large Earthquakes

Dudley Joe Andrews (650 329 5606; jandrews@usgs.gov)

U.S. Geological Survey, Mail Stop 977 345 Middlefield Road, Menlo Park, CA 94025, United States

Heat generated in a slip zone during an earthquake can raise fluid pressure and thereby reduce frictional resistance to slip. The amount of fluid pressure rise depends on the associated fluid flow. Heat generated at a given time produces fluid pressure which decreases inversely with the square root of hydraulic diffusivity times elapsed time. If the slip velocity function is crack-like, there is a prompt fluid pressure rise at the onset of slip, followed by a slower increase. The stress drop associated with the prompt fluid pressure rise increases with rupture propagation distance. The threshold propagation distance at which thermally-induced stress drop starts to dominate over frictionally-induced stress drop is proportional to hydraulic diffusivity. If hydraulic diffusivity is 0.02 m2/s, estimated from borehole samples of fault-zone material, the threshold propagation distance is 300 m. The stress wave in an earthquake will induce an unknown amount of dilatancy and will increase hydraulic diffusivity, both of which will lessen the fluid pressure effect. Nevertheless, if hydraulic diffusivity is no more than two orders of magnitude larger than the laboratory value, then stress drop is complete in large earthquakes.

S61E-08 1035h

Insights on Fault Behaviour From the Seismic Nucleation Phase

Jean-Paul Ampuero[1] ((33) 1 44 27 24 21)

Jean-Pierre Vilotte[1] ((33) 1 44 27 38 88; vilotte@ipgp.jussieu.fr)

[1]Departement de Sismologie et Departement de Modelisation Physique et Numerique, Institut de Physique du Globe de Paris, 4 Place Jussieu, Paris 75252, France

Recent attempts have been done to retrieve such constitutive properties as slip weakening critical slip D_c from seismological data. In the framework of a model first proposed by Ionescu and Campillo (1997), we analyze seismograms featuring a nucleation phase and we show how these observations can help to constrain the constitutive parameters of the fault.

The model predicts an exponential growth of the seismic moment during the unstable dynamic nucleation phase: $M_0(t) \propto \exp(s_m t)$. The growth rate s_m is related to the weakening rate of an assumed linear slip weakening friction law or, in a more general context, to the effective weakening rate of the fault and also the effective properties of the surrounding fault zone. This exponential behaviour implies an exponential rise of seismograms allowing to a direct measure of s_m by seismological, remote, means. We first illustrate the measure of s_m from recordings of the Kobe earthquake, finding $s_m \approx 1/150$ Hz. Consistency is checked by using stations at different epicentral distances. Combining this measure with independent estimates of fracture energy and borehole observations of the structure of the Nojima fault zone, we estimate $D_c = 11$ cm for the nucleation of this earthquake and we assess the role of the structure of the fault zone during nucleation.

S61E-09 1050h

A Common Origin for Aftershocks, Foreshocks, and Mutliplets

Karen R Felzer[1] (617-495-1172; felzer@seismology.harvard.edu)

Rachel E Abercrombie[2] (617-353-2532; rea@bu.edu)

Göran Ekström[1] (617-495-1172; ekstrom@seismology.harvard.edu)

[1]Department of Earth and Planetary Sciences, Harvard University, 20 Oxford St., Cambridge, MA 02138

[2]Department of Earth Sciences, Boston University, 658 Commonwealth Ave., Boston, MA 02215

It is well known that many earthquakes trigger aftershocks, subsequent (and traditionally smaller) earthquakes which are nearby in time and space. It has been debated whether other phenomena that involve earthquake clustering, such as foreshock-mainshock pairs and earthquake doublets and multiplets simply result from the same process that causes aftershocks, or are a separate type of special phenomena. Using the CNSS, CMT, and MLI catalogs we demonstrate that for earthquakes in California and the Solomon Islands, the rate at which foreshocks trigger mainshocks, and the rate at which multiplets occur, are in agreement with the rate at which mainshocks trigger aftershocks. We also find that this agreement in rate is highly unlikely to result from random chance, and is similarly unlikely to result from any triggering of incidental seismicity by the growing nucleation zone of a large earthquake. Thus our statistical analysis indicates that only a single model of earthquake triggering is required to explain aftershocks, foreshocks, and multiplets.

URL: http://www.seismology.harvard.edu/˜felzer

S61E-10 1105h

Influence of Fault Bends on the Growth of Dynamic Shear Ruptures

Carl-Ernst Rousseau[1] (401-874-2542; roussea@egr.uri.edu)

Ares J. Rosakis[2] (626-395-4523; rosakis@atlantis.caltech.edu)

[1]University of Rhode Island, 222B Wales Hall, Kingston, RI 02881, United States

[2]California Institute of Technology, Mail Code 105-50, Pasadena, CA 91125, United States

Earthquake ruptures are modeled as dynamically propagating shear cracks with the aim of gaining insight into the physical mechanisms governing their arrest or, otherwise, the often observed variations in rupture speeds. Fault bends have been proposed as being a major cause for these variations. Following this line of reasoning, the existence of deviations from fault planarity is embraced as the main focus of this study. Asymmetric impact is used to generate shear loading and to propagate dynamic mode-II cracks along the bonded interfaces of two otherwise identical homogeneous constituents. Secondary planes inclined at various angles are also introduced to represent fault bends or kinks. The experiments show that certain fault bend inclinations are favored as alternate paths for rupture continuation, whereas others suppress further motion of the incoming rupture. The asymptotic elastodynamic stress fields at the tip of the growing rupture are used to develop two criteria for rupture propagation or arrest at the kinked interfaces. These criteria correlate very well with the experimental results. Since most field evidence suggests that the average rupture speeds during crustal earthquakes are sub-Rayleigh, this work first focuses on incoming rupture speeds that are just below the Rayleigh wave speed. Reports of intersonic rupture speeds having surfaced recently, experiments and analyses are also performed within that speed regime.

S61E-11 1120h

Nonrandom Clustering of M4+ Seismicity in Northern and Central California

John E. Ebel[1] (617-552-8300; ebel@bc.edu)

Alan L, Kafka[1] (617-552-3650; kafka@bc.edu)

[1]Weston Observatory, Boston College, Department of Geology and Geophysics, 381 Concord Rd., Weston, MA 02493, United States

A catalog of M4+ earthquakes in northern California and northwestern Nevada was declustered of aftershocks, foreshocks and triggered events and then searched for non-Poissonian elements. This catalog covers the region from 37.0 deg N to 44.5 deg N and the years 1910 to 2001. For this time period the Poisson probability of one or more M4+ events in any 10-day period in this region is 35%. A similar pattern is seen in the seismicity before 1967. Since 1968, 40.3% of the M4+ events in northeastern California and northwestern Nevada were followed by another M4+ event within 10 days somewhere in the study region. Similarly, since 1968, 39.3% of the M4+ events in the San Andreas region of northwestern California were followed by another M4+ event within 10 days somewhere in the study region. Thus, for these areas M4+ earthquakes occur more frequently within short time periods than would be expected from temporally random seismicity. A second catalog of M4+ earthquakes in central California was also declustered of aftershocks, foreshocks and triggered events and then analyzed for unusual spatio-temporal patterns. This catalog covers the region from 34.0 deg N to 40.0 deg N and the years 1932 to 2000. Of 39 M4+ independent mainshocks at Long Valley, California since 1932, 23 occurred within 10 days of an M4+ somewhere in the region of the central San Andreas Fault. This suggests that there is a link between the seismicity of the central San Andreas and Long Valley. Curiously, only five M4+ events at Long Valley since 1932 occurred within 10 days of an M4+ event at or near the Coso geothermermal area..

S61E-12 1135h

Clustering of Major Earthquakes on Individual Faults: Characterization Via a Single Non-Dimensional Parameter

Shelley J Kenner[1] (859-257-5506; skenner@uky.edu)

Mark Simons[2] (626-395-6984; simons@caltech.edu)

[1]Dept. of Geological Sciences, Univ. of Kentucky, 101 Slone Building, Lexington, KY 40506-0053, United States

[2]Seismological Laboratory, Calif. Institute of Technology, MC: 252-21, Pasadena, CA 91125, United States

On a single fault segment, geologic and paleoseismic evidence from locations such as the Basin and Range [*Friedrich et al.* JGR, in review] and Dead Sea Transform [*Marco et al.*, JGR, 1996] indicate that occurrence of major earthquakes in time is often extremely heterogeneous and may exhibit temporal clustering. We consider major earthquake clustering as the occurrence of multiple event sequences with intra-cluster inter-event times much shorter than the average time between clusters. Here we investigate the role of time-dependent postseismic stress transfer, in combination with environmental noise in the parameters that govern fault behavior, in controlling major earthquake clustering.

The role of long-term postseismic transients can be investigated using a pseudo-1D spring-dashpot-slider model of time-dependent stress transfer in a 3-layer lithosphere. To simulate a 2D lithosphere, stress is conserved coseismically and is transferred from the elastic crust to underlying Maxwell viscoelastic elements representing the lower crust/upper mantle. Interseismically, lithospheric layers are coupled so that postseismic stress concentrations in the lower crust/upper mantle may be dissipated via stress transfer between layers. Normally distributed random noise is added to the fault failure criteria to simulate environmental noise.

The equations that govern the system behavior can be non-dimensionalized in terms of various rheological parameters, average earthquake stress drop, $\Delta\tau_{eq}$, effective viscosity, η_{eff}, and the characteristic long-term strain rate across the fault, $\dot{\epsilon}_{flt}$. This non-dimensionalization results in a single controlling parameter W, where W is defined as $\Delta\tau_{eq}/\eta_{eff}\dot{\epsilon}_{flt}$. As W increases, earthquake clustering increases. For a reasonable choice of rheologies and input noise with a coefficient of variation (C_v = standard deviation/mean) of 0.20, W = 1, 10, and 100 yields earthquake recurrence intervals with $C_v = 0.217$, 0.31, and 1.29, respectively. Qualitatively, clustering phenomena dominates the system behavior when recurrence intervals are distributed with $C_v > \sim 0.5$.

S62A MCC: Hall C Saturday 1330h

Challenges of Regional Monitoring Posters *(joint with PA)*

Presiding: **M P Flanagan,** Lawrence Livermore National Laboratory; **M Tolstoy,** Lamont-Doherty Earth Observatory of Columbia University

S62A-1165 1330h POSTER

Theoretical Analysis of Seismic Wave Imaging Using SAR

Dennis R. Fatland (303-444-0094; fatland@vexcel.com)