S41F-06 1135h

The Role of Flat Subduction in Andean Evolution

David E James[1] (202-478-8838; james@dtm.ciw.edu)

I Selwyn Sacks[1] (sacks@dtm.ciw.edu)

[1]Carnegie Institution of Washington, DTM, 5241 Broad Branch Rd., N.W., Washington, DC 20015, United States

Transient changes in subduction geometry – from normal to flat to normal – and the attendant magmatic and tectonic effects of slab dewatering, continental lithospheric hydration and asthenospheric flow during closing and opening of the subduction zone mantle wedge, have strongly influenced the tectonomagmatic development of the Andes. In the central Andes, the processes of normal-to-flat-to-normal subduction developed in several stages starting with normal subduction. The transition from normal to flat subduction coincides with cessation of main arc magmatism and extensive crustal deformation in the eastern altiplano and eastern cordillera. During flat subduction, water from the slab infiltrates and hydrates the overlying continental lithosphere, resulting in advective cooling manifest by low surface heat flow. Lithospheric hydration is concentrated not only in the usual forearc region but also within the inner arc, particularly in the zone of resubduction where amphibole breaks down and the slab dips steeply into the mantle. The transition from flat to normal subduction brings an influx of asthenospheric material from depth into the growing mantle wedge above the slab. Hot asthenospheric mantle in contact with hydrated lithosphere of the inner arc produces widespread melting of both mantle and crust beneath the eastern ranges coupled with ductile deformation, which in the central Andes was associated with oroclinal formation. The magmatic activity and orogenic uplift accompanying the transition from flat to normal subduction began near the zone of resubduction (the inner arc) and broadened westward as hot asthenospheric material flowed into the mantle wedge above the sinking slab. The cycle is complete when westward broadening of volcanic activity culminates in a resumption of calc-alkaline volcanism along the main volcanic arc. The crust beneath the main arc may be thickened and uplifted by the intrusion or underplating of mantle-derived magmas. Eruptive activity in the inner (eastern) arc, much of it anatectic and correlated with periods of crustal deformation, gradually died out, while the thermally thinned and weakened lithosphere of the eastern cordillera and subandean belt formed a ductilized zone in which compressive stresses were concentrated in Neogene time. The tectonic collapse of the inner arc is correlated with the Neogene formation of the Bolivian orocline. By contrast, the western cordillera and the western altiplano, underlain by the Arequipa-Antofalla cratonic block, underwent relatively minor deformation.

S41F-07 1150h

Regional Tomographic Inversion of P-wave Travel Times in Central Chile and Argentina, between 30° and 36° south.

Lara S Wagner[1] (lwagner@geo.arizona.edu); Susan Beck[1] (beck@geo.arizona.edu); George Zandt[1] (zandt@geo.arizona.edu); Mario Araujo[3] (maraujo@inpres.gov.ar); Jaime Campos[2] (jaime@dgf.uchile.cl); . CHARGE Working Group[1] (charge@geo.arizona.edu)

[1]Department of Geosciences University of Arizona, 1040 E. 4th St, Tucson, AZ 85721, United States

[2]Departamento Geofisica Universidad de Chile, 2085 Avda. Blanco Encalada, Santiago n/a, Chile

[3]INPRES, 47 Norte Roger Balet, San Juan n/a, Argentina

We use regional P-wave travel times to model upper mantle structure beneath Chile and Argentina between 30° and 36° S. This area is of particular interest, because north of 33°S, the subducted Nazca plate descends normally to a depth of 100 km, but then flattens out, continuing along a subhorizontal path for some 400 km before resuming a normal subduction angle and descending into the mantle. South of 33°, the Nazca plate subducts with a constant dip. This difference in subduction style from the north to the south is correlated with changes in volcanism, seismicity, and orogenic structure. Data for this study comes from the CHARGE project, a 22 station broadband portable seismic deployment, and first arrival P-picks from the ISC catalog recorded at an additional 30 stations operated by INPRES and the Seismological Service of the Universidad de Chile. We use the tomographic inversion method of Zhao et al. [1994] to invert over 3100 P-wave picks from over 170 events recorded at 54 stations. This tomography method allows for the introduction of discrete discontinuities, such as the Moho and the top of the subducting slab, which allows for clearer vertical resolution because smearing across these boundaries is reduced. Preliminary results show evidence of low velocity zones possibly associated with the dehydration of the subducting oceanic plate. To the south where the Nazca plate descends at a dip of 30°, the low velocity zone appears to be confined to a narrow area above where the subducted plate reaches 100 - 125 km depth and corresponds to the region beneath the active volcanic arc. To the north, the low velocity zone persists, extending east beneath the Sierras Pampeanas. This correlates well with the flat slab area, indicating that the Nazca plate may dewater continuously as it subducts east until it resumes a normal descent angle into the mantle. However, arc volcanism north of 33° S has been dormant for 8 Ma, suggesting that it is the cold thermal regime of the flat slab, rather than a lack of water, that is primarily responsible for shutting down the arc volcanism. Zhao, D., A. Hasegawa, and H. Kanamori, Deep structure of Japan subduction zone as derived from local, regional, and teleseismic events, *Journal of Geophysical Research, 99*, 22313-22329, 1994.

S41F-08 1205h

Mantle Structure Beneath Central South America

John C VanDecar[1] (+44 20 7843 4545; vandecar@dtm.ciw.edu); Paul G Silver[1] (silver@dtm.ciw.edu); David E James[1] (james@dtm.ciw.edu); Marcelo Assumpcao[2] (marcelo@iag.usp.br); Martin Schimmel[2] (schimmel@ija.csic.es); George Zandt[3] (zandt@geo.arizona.edu)

[1]Carnegie Insitution of Washington, Department of Terrestrial Magnetism 5241 Broad Branch Rd. NW, Washington, DC 20015-1305, United States

[2]University of São Paulo, Department of Geophysics Rua do Matão 1226, São Paulo 05508-900, Brazil

[3]University of Arizona, Department of Geosciences Gould-Simpson Building, Tuscon, AZ 85721-0077, United States

Making use of 60 digital broadband seismic stations that have operated across central South America in recent years, we have undertaken an inversion for the upper- and uppermost lower-mantle P- and S-wave velocity structures beneath the region. We have combined data from four portable PASSCAL-type experiments as well as the 3 GTSN permanent stations (LPAZ, BDFB and CPUP) and 1 Geoscope station (SPB) located in the region. The portable data were deployed at various times between 1992 and 1999 and include: 28 sites from the Brazilian Lithosphere Seismic Project (BLSP: Carnegie Institution of Washington and Universidade de Sao Paulo), 16 sites from the Broadband ANdean JOint experiment (BANJO: Carnegie Institution of Washington and University of Arizona), 8 sites from the Seismic Exploration of the Deep Altiplano project (SEDA: Lawrence Livermore National Laboratory) and 4 sites from the University of Brasilia. The P- and S-wave relative delay times are independently obtained via a multi-channel cross correlation of band-passed waveforms for each teleseismic event. These data are then inverted using an iterative, robust, non-linear scheme which parameterizes the 3-D velocity variations as splines under tension constrained at over 120,000 nodes across South America between latitudes of 15 and 30 degrees South. Amongst other features, we robustly image the high-velocity subducting Nazca plate penetrating into the lower mantle and the high-velocity root of the 3.2 Gyr old Sao Francisco Craton extending to depths of 200-300 km. We will discuss the consistency between our tomographic models and predictions of dynamic mantle models based on plate tectonic reconstructions of subduction.

S41G MCC: 3009 Thursday 1020h

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

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

S41G-01 1025h INVITED

Earthquake Fracture Energies and Weakening of Faults by Thermal Pressurization of Pore Fluid

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

Dept. of Earth and Planet. Sci. and Div. of Engin. and Appl. Sci., Harvard Univ., 224 Pierce Hall, Cambridge, MA 02138

Seismic inferences of fracture energy G constrain how fault strength degrades during slip and allow testing of candidate physical mechanisms. Recently G has been estimated by interpreting parameters from seismic slip inversions within a self-healing rupture model (Rice, Sammis and Parsons, 2003), and by studying the scaling of radiated energy and stress drop with earthquake size (Abercrombie and Rice, 2003). Those and earlier studies suggest that for larger events (slip > 0.1 m), G ranges from 0.1 to 10 MJ/m^2 with average of 2-4 MJ/m^2. There is a clear trend for G to increase with slip over the broad range from mm to m slip. Sibson-Lachenbruch thermal pressurization of pore water is examined as a possible general fault weakening mechanism for large crustal events. For adiabatic and undrained conditions, with strength given by the effective stress law with a constant friction coefficient f, the thermal properties of water in this context (Lachenbruch, 1980; Mase and Smith, 1988) lead to $G = 1.7(\sigma_n - p_o)(1 + r)h$. Here h is shearing zone thickness, σ_n is normal stress, assumed constant during slip, p_o is ambient pore pressure, and r is the ratio fractional volume change of pore space per unit pore pressure increase divided by the compressibility of the pore fluid. Dilatancy is neglected; if confined to only the early phases of slip, it decreases p_o from ambient and so increases G, but the effect may be modest. The model predicts exponential decay of strength with slip, with e-folding slip distance $1.7(1 + r)h/f$. The total temperature rise in K is $\approx 0.6(1+r)(\sigma_n - p_o)$ where the latter factor is in MPa. Estimating r = 1-2 and evaluating $\sigma_n - p_o$ as overburden minus hydrostatic pore pressure at 7 km as a representative centroidal depth for large crustal events, we obtain $G \approx$ 1-6 MJ/m^2 for h = 2 to 10 mm. Shear zone thicknesses towards the lower end of such a range are suggested by recent field studies (Chester and Chester, 1998), which identify a narrow principal failure zone within a 10s of mm thick ultracataclastic core. Temperature rises are 150-230 K and preclude melting, although rises at 14 km may be twice larger and temperature there could reach the onset of melting. That predicted G compares favorably with the above seismically inferred range. For $f = 0.6$, the slip needed to fully experience the weakening (as twice the e-foldng slip) is of order 0.02-0.17 m, so many smaller slip events will not experience full weakening. G values estimated seismically for them should be smaller, as seems to be the case (Abercrombie and Rice, 2003). Those smaller G values may be influenced by more modest weakening mechanisms like studied in rate and state friction, which are likely to dominate at sub-mm slip. Corrections to the thermal pressurization estimate of G for large events arise because the shearing zone may not retain its water during failure, so that strength is not fully reduced, and from the feature that fast-moving ruptures fronts generate enough stress off the main fault plane to cause secondary failure within the bordering damage zone (Poliakov et al., 2002; Rice et al., 2003). The latter effect becomes particularly strong as rupture speed approaches its subsonic limit (Rayleigh speed for mode II); it consumes energy and increases G, but also leaves freshly failed material immediately adjacent to the shearing zone. That will promote drainage, for which an elementary model will be described. Complete strength loss then cannot be achieved by the pore fluid mechanism and temperature continues to rise so that ultimately melting occurs if slip becomes large enough.

S41G-02 1045h INVITED

Slip localization on narrow surfaces within exhumed fault zones: implications for earthquake rupture processes and seismic energy budgets

Zoe K Shipton[1] (353 1 608 1121; shiptonz@tcd.ie)

James P Evans[2] (435 750 1267; jpevans@cc.usu.edu)

[1]Department of Geology Trinity College, College Green, Dublin 2, Ireland

[2]Department of Geology Utah State University, 4505 Old Main, Logan, UT 84322, United States

Observations of exhumed faults, with net offset ranging from cm to km, indicate that fault slip is often accommodated on slip surfaces only mm's to cm's thick embedded in a damage zone 10's to 100's m thick. The same deformation textures observed in the smallest faults are seen along faults of greater length and offset. We use rock mechanics and earthquake energy and moment relationships to show that slip zone thickness t is a function of seismological parameters (seismic efficiency η, defined as the proportion of the total driving stress that contributes to seismic radiation, τ_a), fault gouge properties (grain surface area per unit mass of fault gouge S, density ρ), co-seismic slip, D and the fracture energy (crushing energy per unit area of rupture G), according to the relationship t = τ_a D /η S ρ G. By using reasonable values of these parameters this relationship predicts that the thickness should be of the order of millimeters, close to our field observations. Given that G scales with rupture size and that the other parameters vary over a narrow range, this equation shows that co-seismic slip should remain restricted to narrow zones across a large range of slip magnitudes (rupture areas). During a rupture, stored strain energy is partitioned into radiated seismic energy, E$_a$, work done against frictional resistance to slip,

E_f, (resulting in heating of the fault zone) and the energy required to create a new rupture surface and/or rerupture a healed surface, E_g. Given the relatively low seismic efficiency of earthquakes, much of the energy from an earthquake goes into propagating slip along the narrow slip zone. There are a number of complex 3-D processes that could potentially consume energy on faults, which are not typically represented in most fault zone energy balance models. Energy must be consumed by deformation of the damage zone, movement of fluid flow, heating of the focal region of the fault, and chemical alteration in the fault zone. Preliminary calculations indicate that alteration consumes a small proportion of the energy, leaving mechanical, thermal, and fluid motion processes as possible energy sinks.

S41G-03 1105h

Earthquake Apparent Stress Scaling for the 1999 Hector Mine Sequence

William R. Walter[1] (925-423-8777; bwalter@llnl.gov)

Kevin Mayeda[1] (kmayeda@llnl.gov)

[1]Earth Sciences Division, Lawrence Livermore National Lab. L-205, P.O. Box 808, Livermore, CA 94551

There is currently a disagreement within the geophysical community on the way earthquake energy scales with magnitude. One set of studies finds evidence that energy release per seismic moment (apparent stress) is constant (e.g. Choy and Boatwright, 1995; McGarr, 1999; Ide and Beroza, 2001). Other studies find the apparent stress increases with magnitude (e.g. Kanamori et al., 1993; Abercrombie, 1995; Mayeda and Walter, 1996; Izutani and Kanamori, 2001). The resolution of this issue is complicated by the difficulty of accurately accounting for attenuation, radiation inhomogeneities, bandwidth and determining the seismic energy radiated by earthquakes over a wide range of event sizes in a consistent manner. We try to improve upon earlier results by using consistent techniques over common paths for a wide range of sizes and seismic phases. We have examined about 130 earthquakes from the Hector Mine earthquake sequence in Southern California. These earthquakes range in size from the October 16,1999 Mw=7.1 mainshock down to ML=3.0 aftershocks into 2000. The mainshock has unclipped Pg and Lg phases at a number of high quality regional stations (e.g. CMB, ELK, TUC) where we can use the common path to examine apparent stress scaling relations directly. We are careful to avoid any event selection bias that would be related to apparent stress values. We fix each stations path correction using the independent moment and energy estimates for the mainshock. We then use those corrections to determine the seismic energy for each event based on regional Lg spectra. We use a modeling technique (MDAC) based on a modified Brune (1970) spectral shape but without any assumptions of corner-frequency scaling (Walter and Taylor, 2002). We perform similar analysis using the Pg spectra. We find the energy estimates for the same events are consistent for Lg estimates, Pg estimates and the estimates using the independent regional coda envelope technique (Mayeda and Walter, 1996; Mayeda et al, 2003). So far the results show the seismic energy to moment values or apparent stress increases with moment similar to our 1996 study. We plan to perform similar studies for other Southern California earthquake sequences. This work was performed under the auspices of the U.S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.

URL: http://earthscience.llnl.gov/scaling-workshop/

S41G-04 1120h

Earthquake source scaling and self-similarity estimation by stacking P and S spectra

German Andres Prieto[1] (gprieto@epicenter.ucsd.edu)

Peter Shearer[1] (shearer@igpp.ucsd.edu)

Debi Kilb[1] (dkilb@epicenter.ucsd.edu)

Frank L. Vernon[1] (vernon@epicenter.ucsd.edu)

[1]IGPP - SIO - UC San Diego, 9500 Gilman Drive, La Jolla, CA 92093-0225, United States

We investigate source parameter scaling by stacking P and S spectra from a set of small events (M = 0.5 - 3.0) recorded between 1993 and 2003 by the ANZA Seismic Network (http://eqinfo.ucsd.edu). Around 2700 events were located in a tightly clustered volume (100 km3), which included the October 31 2001, M = 5.1 event and its aftershock sequence. Between 9 and 12 ANZA network stations recorded the 400 events with M > 0.5, which have high signal to noise ratios. The observed spectra are the product of source spectra, receiver and propagation response functions as well as source and receiver site effects. We apply a signal to noise ratio cutoff and corrections for gain and instrument response. For all events in the tight cluster, assuming they have similar focal mechanisms, we attempt to isolate differences in the source spectra. Since each station records multiple events and each event is recorded at multiple stations, we can solve for source and station terms by an iterative method. For all events in the tight cluster the ray path from source to a single seismic station is similar, making the along-path-attenuation similar as well. We use these results to test whether apparent stress (the ratio between radiated seismic energy and moment) increases with increasing moment or remains constant for a wide range of event sizes. We also examine the self-similarity of earthquakes. If earthquakes are self-similar, the spectra of all events, once corrected for attenuation, should simply be rescaled versions of the spectra of different sized events. This will be true regardless of the specific source model or the assumed spectral falloff at high frequencies.

S41G-05 1135h

Heat Generation and Strength of Seismogenic Faults Constrained by Fission-Track Data

David L. Kirschner[1] (314-977-3128; dkirschn@eas.slu.edu)

David N. Cuevas-Miranda[1,2] (camandulo@hotmail.com)

Mohamed El-Shafei[1,3] (elshafeim@hotmail.com)

John I. Garver[4] (garverj@union.edu)

[1]Dept. of Earth and Atmospheric Sciences, Saint Louis University, St. Louis, MO 63103, United States

[2]Dept. of Marine Science, University of Puerto Rico, Mayaguez, PR 00681, Puerto Rico

[3]Dept. of Geology, Suez Canal University, Ismailia 41522, Egypt

[4]Geology Dept., Union College, Schenectady, NY 12308, United States

There has been a longstanding debate regarding the strength of the San Andreas fault and other large faults in the San Andreas system. Some field- and laboratory-derived data are consistent with these faults being anomalously weak, while other data are consistent with these faults having normal strength. One of the most widely accepted and oft-quoted data in support of weak faults is the absence of anomalously high heat flow in the vicinity of these faults. Friction in a normal-strength fault should produce significant amounts of heat, resulting in elevated heat flow in and adjacent to the fault. There is no uniformly high heat-flow along the San Andreas fault, resulting in the well-known "stress / heat-flow" paradox. To provide new data directly related to resolving the stress / heat-flow paradox, we have obtained fission-track data for 41 apatite samples and 8 zircon samples from two inactive strike-slip faults in the San Andreas system (the San Gabriel and Punchbowl faults) that have been exhumed 2 to 5 kilometers. San Gabriel fault samples were collected in traverses near Whitaker Peak, the "Earthquake locality", and along Bear Creek. Samples were also collected from one traverse in the Devil's Punchbowl County Park. Apatite FT dates are between 51 to 25 Ma from Whitaker Peak, 54 to 24 Ma from the Earthquake locality, and 44 to 6 Ma from Bear Creek. Zircon FT dates from Bear Creek range between 61 and 40 Ma. Apatite FT dates from the Punchbowl fault range between 15 and 7 Ma. FT dates vary systematically with distance from the fault cores along individual traverses. The dates do not, however, young monotonically towards the faults, which would be expected if there had been sustained elevated temperature along the faults. More thermochronologic data (U-Th/He) from the same samples will help resolve factor(s) responsible for the variations in FT dates, and ultimately the strength of these faults when they were active.

S41G-06 1150h

Slip Surfaces in Fault Breccia From the Sierra Madre Fault Zone: Geometry and Mechanical Implications

Philippos Mordohai[2] (213-821-1822; mordohai@aludra.usc.edu)

Ory Dor[1] (213-740-6754; dor@usc.edu)

Jeremy Zechar[1] (zechar@aludra.usc.edu)

Charles G Sammis[1] (213-740-5836; sammis@usc.edu)

Yehuda Ben-Zion[1] (213-740-6734; ybz@usc.edu)

[1]University of Southern California, Department of Earth Sciences, Science Hall 117, Los Angeles, CA 90089-0740, United States

[2]University of Southern California, Department of Electrical Engineering, PHE 204 MC-0273, Los Angeles, CA 90089-0273, United States

Fault breccia from the Sierra Madre Fault Zone is imaged using a new technique, resolving a highly detailed structure of internal slip surfaces with characteristic distribution of orientations and senses of slip. We excavated a 25x28x35 cm3 sample of brecciated granite from the hanging wall of the Sierra Madre fault near JPL, La Canada, California. The base of the sample was attached to the principal slip surface, dipping 40° to the NW, showing up-dip slip striations. The sample was carefully removed with known orientation while maintaining its integrity. We used a two camera digital imaging system developed in the Department of Electrical Engineering at USC. With the positions of the cameras and sample fixed, we progressively removed the outer layers of the specimen exposing the internal slip surfaces. Each slip plane was marked with a spot; a line was marked if slicknsides were observed, and a stereo photo taken. These 3D images were analyzed to give the normal to each slip plane and the tangent to each slip line. The slip surfaces are few millimeters to several centimeters wide. They branch and coalesce to create a dense micro- and meso-scale network. The polygons bounded by these surfaces are composed of powdered granite that maintains its original fabric. The surfaces are shiny, present clear slicknsides and have silky touch. Larger slip surfaces show macroscopic curvature producing roughness at various wavelengths. This curvature is comprised of the smaller slip planes that were marked for the imaging. We hypothesize that initial fracturing process created the small-scale planes which then coalescenced by rotation and abrasive wear to create the large surfaces. These large slip surfaces are generally sub-parallel to the fault strike and sub-perpendicular to its slip vector. Analysis of 196 planes indicates that the dip direction of 123 planes (63%) is between the east and the south, nearly opposite to the fault. Another 59 planes are dipping in the NE and SW quadrants, 43 of them trend to the ENE and to the SSW. Only 14 planes (7%) trend NW, subparallel to the fault. The distribution of inclinations covers the entire range, except for the planes that trend with the fault. Of these, 9 are sub-vertical and 3 are sub-horizontal. The slicknsides were imaged as lines in space but the senses of motion have not yet been determined. They are low-angle 3D lines with no consistent trend indicating mostly horizontal motion. The mechanical origin of this set of surfaces needs a further verification. While they are not consistent with Riedel shear geometry, the characteristics of the surfaces show that they accommodate a small amount of rotation that may reflect simple shear. This requires a relatively homogeneous stress field. As this is not necessarily the case, they might be of dynamic origin, reflecting the heterogeneity of a process-zone stress field ahead of the earthquake rupture. Finally, the dynamic reduction of normal stress during the passage of a rupture can control the formation of this geometry, but requires that the slicknsides (to be verified) will demonstrate a tensile regime.

S41G-07 1205h

Laboratory Earthquake Experiments: The SubRayleigh to the Intersonic Transition

Kaiwen Xia[1,2] ((626) 395-6931; xia@gps.caltech.edu)

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

Hiroo Kanamori[1] ((626) 395-6914; hiroo@gps.caltech.edu)

[1]California Institute of Technology, Seismological Laboratory Mail Code 252-21 1200 E. California Blvd, Pasadena, CA 91125

[2]California Institute of Technology, Graduate Aeronautical Laboratories 1200 E. California Boulevard Mail Stop 105-50, Pasadena, CA 91125

We designed a laboratory earthquake model to investigate spontaneous rupture propagation. An important question is how fast a rupture can propagate. Rosakis et al [1999] demonstrated that a shear rupture can propagate at a supershear speed under impact loading; Here, we investigate an earthquake-like shear rupture which is spontaneous in nature. In our experiments, a fault is simulated with two photoelastic plates (Homalite) held together by friction and the far field tectonic loading is simulated by pre-compression. The fault forms a certain angle with the compression axis. A unique design is used for triggering dynamic rupture using an exploding wire technique. With this method, we can control the timing of triggering and initiate spontaneous rupture driven by the applied stress. We observed both subRayleigh and supershear ruptures depending on the magnitude of loading and the orientation of the fault plane with respect to the loading axis. Under proper loading conditions, a shear rupture which initially propagates at the Rayleigh wave speed initiates a secondary rupture at the shear wave front and this secondary rupture propagates at a supershear speed (close to the longitudinal wave speed). Eventually, the two ruptures combine as one supershear rupture. In general, this observation is consistent with the Burridge-Andrews mechanism [Burridge, 1973; Andrews, 1976]. We modified Andrews' theory

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which relates the supershear initiation distance L to loading conditions by introducing a dependence of the critical slip distance d_0 on normal pressure. This modified theory yields a better agreement with the experimental data. This transition provides a mechanism for nucleation of supershear ruptures in a 2-D problem. Although such transition has been reported for some earthquakes (e.g., 2001 Kunlunshan earthquake), confirmation of it must await further studies.

S42A MCC: Level 1 Thursday 1330h

New Views of Seismic Hazard in Cascadia III Posters *(joint with G, T, V)*

Presiding: **T M Brocher,** U.S. Geological Survey**; A J Calvert,** Simon Fraser University

S42A-0139 1330h POSTER

Spatial and Temporal Correlation Between Nonvolcanic Low-frequency Tremors and Slow Slip Events Detected in the Southwest Japan Subduction Zone

Kazushige Obara[1] (81-29-860-2211; obara@bosai.go.jp)

Hitoshi Hirose[1] (hirose@bosai.go.jp)

[1]NIED(National Research Institute for Earth Science and Disaster Prevention), 3-1, Tennodai, Tsukuba 305-0006, Japan

Megathrust earthquakes of magnitude greater than 8 have repeatedly occurred in southwest Japan due to the subduction of the Philippine Sea plate. Recently, non-volcanic seismic tremors have been discovered in the fore-arc side of the subducting plate (Obara, 2002) by analyzing the continuous records of the high-density high-sensitivity seismograph network, NIED Hi-net. The tremors are not distributed homogeneously in the narrow belt along the strike of the slab but spatially clustered. The major activity of the tremor is also clustered periodically, with a period of 2 or 3 months in the east and middle part of Shikoku area, and about 6 months in the west of Shikoku. Every Hi-net observatory is equipped with a high-sensitivity accelerometer, which has wide range in frequency response. Output from horizontal components of the accelerometer can be analyzed as tilt movement. In the west of Shikoku, we found that step-like tilt changes occurred four times in two years of 2001 and 2002 associated with periodic major tremor activities. Each tilt change continues for a few days at the stations near the source area of the tremor. The duration of the tilt change is simultaneously associated with the major activity of the tremor. The tilt step is about 0.1 micro radian in maximum. Based on the observed tilt step the slow slip event is estimated to occur on a reverse fault at around the interface of the subducting Philippine Sea plate. The simultaneous activity of the tremors and the slow slip events is very similar to ETS (Episodic tremor and slip) detected in Cascadia subduction zone (Rogers and Dragert, 2003). Both observations in young subduction zones might be important for understanding the condition of the transition zone on the plate boundary and monitoring the stress accumulation at the locked section of the slab.

S42A-0140 1330h POSTER

Why is the Cascadia subduction zone backarc hot? Numerical tests of mantle wedge flow

Claire A Currie[1,2] (250-363-6404; currie@uvic.ca)

Kelin Wang[1,2] (kwang@nrcan.gc.ca)

Roy D. Hyndman[1,2] (rhyndman@nrcan.gc.ca)

Jiangheng He[2] (jhe@nrcan.gc.ca)

[1]School of Earth and Ocean Sciences, University of Victoria, PO Box 3055, Victoria, BC V8W 3P6, Canada

[2]Pacific Geoscience Centre, Geological Survey of Canada, PO Box 6000, Sidney, BC V8L 4B2, Canada

Understanding mantle wedge processes is critical for constraining thermal and petrological controls on in-slab earthquakes and the behaviour of the deep subduction thrust fault. Observational constraints indicate that the mantle wedge at the northern Cascadia subduction zone is extremely hot. Below the volcanic arc, temperatures greater than 1300°C are required for magma generation. In the backarc, surface heat flow, seismic velocities, thermal isostasy and xenolith studies suggest temperatures of 1200°C at 60 km depth for a distance of 500 km. The landward limit of the backarc is the abrupt contact with the thick, cold North America craton, making high backarc temperatures even more surprising. An initial compilation of thermal data shows that most other backarcs are similarly hot. Finite element thermal models are used to investigate the backarc mantle flow structure that maintains these high temperatures. Two principle driving forces for flow are: traction along the top of the subducting slab and buoyancy forces due to lateral thermal heterogeneities, such as cooling by the slab and Rayleigh instabilities. In this study, we primarily deal with traction-driven flow, using Cascadia subduction parameters. A thick (>200 km) lithosphere was introduced at the landward backarc boundary, consistent with the presence of the North America craton root. For an isoviscous mantle, the craton deflects hot material from depth into the wedge, resulting in a warmer wedge than models without a craton, although the temperatures are 150-300°C lower than inferred from observations. Decoupling of the wedge from the over-riding plate increases the backarc Moho temperature by over 100°C; temperatures below the arc are relatively unaffected. With a more realistic stress- and temperature-dependent viscosity, high velocity flow originates from great depths along the landward boundary, even without a craton. Flow is strongly focussed into the wedge corner, leading to much higher sub-arc temperatures (>1250°C). However, the flow pattern produces low backarc mantle temperatures and heat flow, inconsistent with observations. For all models, full coupling between the subducting plate and wedge was assumed. If partial decoupling occurs, due to the presence of hydrated mantle or serpentine/talc, wedge flow velocities will be slower, and the wedge will be cooler than predicted by the models. None of the traction-driven flow models simultaneously produced high temperatures below the volcanic arc and a uniformly hot backarc. Numerous studies indicate that the mantle wedge viscosity is less than 10^{19} Pa s. Initial tests suggest that at such low viscosities, wedge flow driven by thermal buoyancy may be more important than traction-driven flow.

S42A-0141 1330h POSTER

Spherical Viscoelastic Finite Element Model for Cascadia Interseismic Deformation

J. He[1] (1-250-3636441; jhe@nrcan.gc.ca)

K. Wang[1,2] (1-250-3636429; kwang@nrcan.gc.ca)

H. Dragert[1,2] (1-250-3636447; hdragert@nrcan.gc.ca)

M. M. Miller[3] (1-509-9632825; meghan@geology.cwu.edu)

[1]Pacific Geoscience Centre, Geological Survey of Canada, 9860 West Saanich Road, Sidney, BC V8L 4B2, Canada

[2]School of Earth and Ocean Sciences, University of Victoria, 3800 Finnerty Road, Victoria, BC V8P 5C2, Canada

[3]Dept.of Geological Sciences, Central Washington University, 400 East 8th Avenue, Ellensburg, WA 98926, United States

We have developed a 3-D spherical viscoelastic finite element model for the Cascadia subduction zone to study temporal and spatial variations of interseismic deformation. Previous 3-D viscoelastic finite element models of subduction zone earthquake cycles all use the Cartesian system, with the surface of the earth map-projected on to a horizontal plane. For earthquakes that rupture very long plate-boundary segments, such as the 1700 Cascadia, 1960 Chile, and 1964 Alaska great earthquakes, the Cartesian approach is inconvenient and less accurate. 3-D analytical solutions take into account the spherical geometry of the earth but have difficulty dealing with realistic plate boundary structure. For the new spherical finite element model, we use 27-node tri-quadratic isoparametric element. The resultant large sparse matrix system is solved by the stabilized bi-conjugate gradient method with ILUT preconditioning of fill-in level 6. Our experience suggests that lower order elements in the spherical system would result in unacceptable numerical errors unless one set of mesh lines is strictly radial. For the great Cascadia earthquake, we employ a smooth coseismic rupture model inferred from thermal data and results of tsunami models of the 1700 event, but we test different slip distances. For interseismic deformation, we use the conventional backslip approach. The contemporary deformation of the Cascadia margin consists of interseismic strain accumulation and a geological secular motion that can be described by a rotation of the forearc relative to North America. To isolate the interseismic deformation, we remove the secular motion from both the model formulation and geodetic data. The model predicts decreasing margin-normal shortening rates throughout the interseismic period as a result of stress relaxation in the viscoelastic mantle. The rate of decrease depends on the assumed mantle viscosity. With a viscosity of 10^{19} Pa s, model surface deformation at 300 years after the great earthquake agrees with geodetically observed contemporary deformation very well. The model also confirms the previous finding based on a Cartesian model that an inland region continues to move seaward several decades after the great earthquake.

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Source Parameter Studies of Historical and Recent Earthquakes of the Cascadia Subduction Zone and Mendocino Triple Junction Region

Katy R Wiest[1] (915-747-5983; wiest@geo.utep.edu)

Todd R Theiner[1] (915-747-5983; theiner@geo.utep.edu)

Aaron A Velasco[1] (915-747-5101; velasco@geo.utep.edu)

Diane I Doser[1] (915-747-5851; doser@geo.utep.edu)

[1]University of Texas at El Paso, Geological Sciences, El Paso, TX 79968-0555, United States

We are comparing the seismograms of recent (post-1989) earthquakes to those of historic earthquakes (pre-1966) recorded at the same (or similar) station locations to determine how comparable the historic earthquakes are to recent events with well determined hypocenters and rupture parameters. The seismograms of recent events will be used as empirical Greens functions in a deconvolution process to more accurately determine the directivity and rupture process of the older events. Our initial work in the Cascadia Subduction zone has focused on earthquakes within the subducting Pacific plate occurring in 1939, 1946, 1949 and 1965, in locations similar to the 1999 Satsop and 2001 Nisqually earthquakes. Preliminary analysis of waveform information suggests that the 1949 Olympia earthquake has a different rupture history to the east and south of the epicenter, as compared to the Nisqually earthquake. In the Mendocino Triple Junction region, we have focused on modeling smaller magnitude earthquakes using an earth simplification transform. We will calibrate the technique using several intermediate magnitude events that have occurred on the Mendocino fault and within the Gorda plate.

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Northern Cascadia Earthquake Catalogue, 1980-Present

Taimi L Mulder[1] (1-250-363-6436; mulder@pgc.nrcan.gc.ca)

Garry C Rogers[1] (1-250-363-6450; rogers@pgc.nrcan.gc.ca)

[1]Geological Survey of Canada, Pacific Geoscience Centre, PO Box 6000, Sidney, BC V8L 4B2, Canada

The Cascadia subduction zone trancends the international boundary between Canada and the United States. This is where the Juan de Fuca plate subducts beneath the North America plate from Vancouver Island, British Columbia in the north and extending south through Washington, and Oregon. Seismicity catalogues exist for each side of the border: the Western Canadian Earthquake Catalogue (Geological Survey of Canada at the Pacific Geoscience Centre (PGC), Sidney, BC) and the Pacific Northwest Earthquake Catalogue (University of Washington (UW), Seattle, Washington). It is desirable for many kinds of studies and displays to have one catalogue. To this end we have merged the two catalogues together into one, which is consistent in location and magnitude. Earthquakes have been tagged as to whether they occurred in the North America plate or the Juan de Fuca plate. The northern Cascadia Earthquake Catalogue has proven extremely useful for research, plotting, and display of the seismicity patterns in this region. Cross-sections of seismicity perpendicular to the subduction front and running through Port Alberni, BC, Victoria, BC, and Seattle, Washington clearly show variations in the angle of dip of the subducting plate. Magnitude comparison between the two networks required a magnitude correction for the smallest events. For UW magnitudes less than 2.6, M_L(PGC) = M_C(UW) - 0.1; for UW magnitudes greater than or equal to 2.6, M_L(PGC) = M_C(UW).

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Physical Property Correlations and Radiocarbon Ages Illuminate Cascadia Earthquake Recurrence Patterns

Chris Goldfinger[1] (541 737-5214; gold@coas.oregonstate.edu)