zones in mantle wedges may be attributable to "superplastic" flow under low stresses within the ultra-fine-grained dehydration products in dehydration-induced fault zones. Abers, G. A. Earth Planet. Sci. Lett., 176, 323-330 (2000). Fujie, G. et al., Geophys. Res. Lett., 29, 7 (2002). Brocher, T. M. et al., Geology, 31, 267-270 (2003).

T42D-06 1455h

HIGH TEMPERATURE DEFORMATION OF OMPHACITE IN ECLOGITE: IMPLICATIONS FOR SUBDUCTED LITHOSPHERE

Junfeng Zhang[1,2] (1-909-787-5516; jezhang@citrus.ucr.edu)

Harry W. Green[1,2] (1-909-787-4505; hgreen@mail.ucr.edu)

Haemyeong Jung[1] (1-909-827-7035; hjung@citrus.ucr.edu)

[1]Inst. Geophys. Planet. Phys., University of California, Riverside, CA 92521, United States

[2]Dept. of Earth Sciences, University of California, Riverside, CA 92521, United States

Omphacite is a major component mineral in subducted oceanic crust at depth. It often develops strong lattice preferred orientation and dominates the flow properties and seismic anisotropy in eclogite. Investigation on the rheology of omphacite is important for a better understanding of geodynamic problems associated with eclogite in subduction zones. The high temperature deformation behavior of polycrystalline omphacite ($Di_{58}Jd_{42}$) is being studied at temperatures of 1300-1500 K, a confining pressure of 3 GPa, and strain rates of 10^{-4}/s to 10^{-5}/s. We obtained a power-law creep for the high temperature deformation of omphacite with n=3.1, Q=289 KJ/mol, and a preexponential factor of $10^{-1.2}$MPa^{-n}s^{-1}. These results show that the creep strength of omphacite falls between its two end members of solid solution (diopside and jadeite), which supports the previous arguments that sodic pyroxene could be significantly weaker than other pyroxenes (enstatite and diopside). A steady increase of flow strength is also observed after adding garnet. Eclogite reconstituted from powders of 50% garnet ($Pry_{21}Alm_{18}Gro_{61}$), 40% omphacite ($Di_{58}Jd_{42}$), 10% quartz shows strength about 3 times that of polycrystalline omphacite. These data are consistent with observations of extensive deformation of omphacite in eclogite at low peak metamorphism temperatures during deep subduction and exhumation. These preliminary results also suggest that strain will concentrate into omphacite-rich domains within the subducting zones.

T42D-07 1510h

Nanoindentation Creep of Quartz, Olivine, and Calcite, with Implications for Rate and State Friction Laws

David L. Goldsby[1] (401 863-1922; David_Goldsby@brown.edu)

Andrei Rar[2] (865 974-8202; 2ut@email.cind.ornl.gov)

George M. Pharr[2] (865 974-8202; pharr@utk.edu)

Terry E. Tullis[1] (401 863-3829; Terry_Tullis@brown.edu)

[1]Department of Geological Sciences, Brown University, 324 Brook Street, Providence, RI 02912, United States

[2]Department of Materials Science, University of Tennessee, and Metals and Ceramics Division, Oak Ridge National Laboratory, 434 Dougherty Engineering Building, Knoxville, TN 37996-2200, United States

A hallmark observation from friction experiments on rocks is that the coefficient of friction increases linearly with the log of time of quasi-stationary contact. This increase in friction, or *state* in the rate- and state-variable friction laws, is usually attributed to an increase in real area of contact between rough surfaces caused by deformation of highly stressed contacts. This behavior is typically explored in slide-hold-slide (SHS) friction experiments at ambient temperature. Despite the importance of the evolution of the state variable for determining conditions for which earthquakes may nucleate, contact-scale deformation mechanisms in rocks remain unknown. In an effort to identify these deformation mechanisms, nanoindentation creep experiments were conducted on single crystals of quartz, olivine and calcite at room temperature and constant loads of 50 to 250 mN. The amount of creep in a typical nanoindentation creep test is indicated by the increase in indentation area with time, determined from the measured displacement of indenter into the specimen and the well-characterized geometry of the indenter tip. A major limitation of such tests, that displacements are difficult to discern from thermal noise, was eliminated by employing *continuous stiffness* techniques. A 45-Hz oscillation in displacement of 2 nm amplitude was imposed on a diamond Berkovich indenter held at otherwise constant load for times comparable to those in SHS tests, up to $5{\times}10^4$ s. By analyzing the resulting specimen response with a frequency-specific analyzer, a nearly continuous measure of the contact stiffness, proportional to contact area, was obtained. Thus, contact area is determined over times too short for significant thermal drift. Changes in area with time from indentation tests were compared with those inferred from complementary SHS tests on quartz, olivine and calcite rocks conducted in a high pressure rotary-shear apparatus. The contact area between indenter and specimen increased linearly with log time for each mineral, in qualitative agreement with the linear increase in area with log time inferred from SHS tests. However, the rate of fractional area increase from nanoindentation tests is much larger than inferred from SHS tests, by factors of 2, 5, and 10 for quartz, olivine, and calcite, respectively. This discrepancy may indicate that contact stresses in the two tests are the same, but that area formed during the hold in SHS tests is partially destroyed during reloading after the holds, as demonstrated for acrylic plastic and glass (*Dieterich and Kilgore*, 1994). Alternatively, the difference may indicate that contact stresses in rock friction experiments are significantly less than determined from indentation tests.

T42D-08 1525h

Nature and Origin of Cataclastic Bands in Well Cemented Quartz Arenite

John R Farver[1] (419-372-7203; jfarver@bgnet.bgsu.edu)

Charles M Onasch[1]

[1]Bowling Green State University, Department of Geology, Bowling Green, OH 43403-0218, United States

Cataclastic bands are a common structure in well-cemented quartz arenites deformed at low temperatures (<250°C). These structures have been interpreted to originate by cataclasis with or without recrystallization. However, recent studies of samples from the Tuscarora and Oriskany sandstones from the Appalachian Valley and Ridge province suggest dilation was more important than shear in the formation of these bands. The cataclastic bands consist of sharply to diffusely-bounded tabular bodies ranging in thickness from 50 μm to a few cm filled with quartz having a uniform 5 μm grain size. In some cases, wall-parallel displacement can be demonstrated, but in others, the displacement is purely dilational. Two-phase, aqueous fluid inclusions in vuggy cores found in some bands yield homogenization temperatures of 140-170°C. FTIR data from traverses across cataclastic bands show a marked decrease in water content within the bands compared to nearby wall rock grains, and also suggest the presence of submicroscopic sheet silicates (mica or clays). In cathodoluminescence the bands are uniformly dark in contrast to brighter luminescing wall rock grains indicating either complete reconstitution of original wall rock or introduction of new phases. Rather than cataclasis, the fine grained texture in the bands is believed to result from rapid crystal growth in a dilating fracture with variable, but small amounts of shear. Despite the fine grained texture, the presence of sheet silicates suggests that these bands may have acted as a fluid conduit, not a permeability barrier.

T42E MCC: 2002-2004 Thursday 1700h

Birch Lecture

Presiding: **P Segall,** Stanford University

T42E-01 1710h INVITED

Splitting, Stretching and Spreading of Lithosphere

W. Roger Buck (845-365-8592; buck@ldeo.columbia.edu)

Lamont-Doherty Earth Obs, Columbia University, Palisades, NY 10964, United States

That lithospheric plates diverge across relatively narrow zones has been accepted since the late nineteen sixties. Thus, in surprise many that several basic features of continental rifts and oceanic spreading centers were first observed in the last few years. Several of these new findings concern the distribution of molten or frozen magma along segments of present or past divergence. One view that the observations reinforce is that tectonic processes often cannot be understood without accounting for magmatism. This talk highlights the impact of new observations on how we think about the processes of faulting and magmatism from the plate tectonic scale to the scale of individual faults and magma chambers.

T51A MCC: 3007 Friday 0800h

Analysis of Plate Boundary Deformation Using Stress and Strain Rate Data in Tandem I *(joint with G, S)*

Presiding: **S Miyazaki,** Stanford University**; K Wang,** Geological Survey of Canada

T51A-01 0800h INVITED

A Thermo-Mechanical Model of the San Andreas Fault System in Central and Northern California

Stephan V. Sobolev[1] (stephan@gfz-potsdam.de)

Mark D. Zoback[2] (zoback@pangea.stanford.edu)

Andrey Yu. Babeyko[1] (babeyko@gfz-potsdam.de)

[1]GeoForschungsZentrum-Potsdam, Telegrafenberg, Potsdam 14473, Germany

[2]Stanford University, Mitchell Building, room 359, Stanford, CA 94305-2215, United States

The San Andreas Fault System (SAFS) in central and northern California is a family of sub-parallel strike-slip faults that accommodate the transform motion between the Pacific and the North America plates. We present here a fully coupled numerical thermo-mechanical model of the SAFS as it evolved over the past 20 Myr following the northward migration of the Mendocino triple junction. The strike-slip displacements and fault perpendicular compression (over the last 5 Myr) are implemented as side boundary conditions in the upper 20 km of the 100 km deep model box, other parts of the side boundaries and bottom boundary being free for material flow. The model employs realistic visco-elasto-plastic rheology and allows for spontaneous generation of faults. The modeling replicates the evolution of multiple strike-slip faults, the overall eastern migration of the San Andreas fault itself from the western edge of the Coast Ranges near Cape Mendocino to the eastern edge in central California, the variation of heat flow in the Coast ranges along and across the SAFS as well as high angle (60-80°) between the direction of the maximum horizontal stress and the local fault orientation in the upper crust. The modeling shows that the key conditions for such behavior are the cooling (and strengthening) of the lithosphere following passage of the triple junction which causes ductile deformation at depth to migrate eastward with time and the drop of frictional strength at high strain in the upper crust which results in a small number of major transform faults to develop, rather than a broad distribution of such faults. Our modeling suggests that the major faults in the SAFS in Central and Northern California must have been weak during most of the 20 Myr period over which it evolved.

T51A-02 0820h

Seismic Versus Aseismic Deformation in Iran Inferred from GPS and Seismicity Data

Frederic Masson[1] (33 4 67 14 48 92; fmasson@dstu.univ-montp2.fr); Jean Chery[1]; Joseph Martinod[2]; Denis Hatzfeld[3]; Philippe Vernant[1]; Farokh Tavakoli[4]; Moshen Ashtiany[5]

[1]LDL -UMR CNRS 5573, Universite Montpellier, Pl. E. Bataillon, Montpellier 34095, France

[2]LMTG - UMR CNRS 5563, Universite Paul Sabatier, 38, rue des 36-Ponts, Toulouse 31400, France

[3]LGIT - UMR CNRS 5559, Universite Joseph Fourier, BP 53, Grenoble 38041, France

[4]Geodynamic Department, National Cartographic Center, Po. BOX 13185-1684, Meraj Ave, Tehran 19531, Iran (Islamic Republic of)

[5]International Institute of Earthquake Engineering and Seismology, Farmanieh, Dibaji, Arghavan St., N 27, Tehran 19531, Iran (Islamic Republic of)

The present tectonic of Iran results from the north-south convergence between the undeformed shield areas of Arabia to the south-west and Eurasia to the north-east. A GPS network of 28 benchmarks has been surveyed in September 1999 and October 2001. Our GPS velocity field defines a quantitative strain pattern of the Arabia-Eurasia collision. It allows to answer three major questions which can be addressed quantifying the present-day Iranian tectonics. a) How is quantitatively distributed the deformation within this juvenile continental collision between different active structures (Zagros, Alborz, Caucasus) ? b) How is accommodated the transition from a continental collision in Zagros to an oceanic subduction in Makran ? c) Is the deformation accommodated seismically or aseismically ? This presentation will focus on this third question. The combined analysis of the geodetic strain rate field and the strain rate field deduced from the seismicity allows to characterise the style of deformation and specially to precise the part of the seismic deformation relatively to the aseismic one. Geodetic measurements record complete deformation (seismic and aseismic) while earthquakes provide information about the seismic deformation. Iran is one of the best place to study the seismic/aseismic deformation ratio because it is a very large deformed area (1500 x 1500 km2), covered by a geodetic network and characterised by a dense and well known historical seismicity. Comparison of seismic and geodetic strain rates indicates that highly strained zones experience mainly aseismic deformation in southern Iran and seismic deformation in northern Iran. This correlate with large earthquakes distribution. Indeed, a dense, low intensity seismicity is observed in the Zagros whereas the largest earthquakes occur in northern Iran. Jointly used, earthquake data and geodetic strain may be of valuable help in order to define the earthquake potential in highly populated areas of northern Iran.

T51A-03 0835h

Paleoseismic Data Used to Evaluate Long Term Earthquake Behavior

Kate M. Scharer[1] (541-346-4647; kscharer@darkwing.uoregon.edu)

Ray J. Weldon[1] (541-346-4584; ray@newberry.uoregon.edu)

Thomas E. Fumal[2] (tfumal@usgs.gov)

Glenn P. Biasi[3] (775-784-4576; glenn@seismo.unr.edu)

[1]University of Oregon, Dept. of Geological Sciences 1272, Eugene, OR 97403, United States

[2]U. S. Geological Survey, 345 Middlefield Road MS977, Menlo Park, CA 94025, United States

[3]University of Nevada Reno, Seismological Laboratory MS174, Reno, NV 89557-0141, United States

The Wrightwood, California paleoseismic record can be used to evaluate important behavior parameters for the southern San Andreas fault. A total of 27 paleoearthquakes have been resolved for two time intervals. The "upper section" includes 14 dated earthquakes from 500 AD to the present; each earthquake is paired with a displacement estimate. Intervals between earthquakes average 105 years but vary from 10 to 224 years. Displacement estimates also vary, from 1 to 7 m of measured slip with an average of 3.2 m. Variation in the displacement estimates may be exaggerated by how deformation is manifest at the site or by preservation of the evidence. The "deep section" of 13 dated earthquakes spans 3000 to 1200 BC, but contains little displacement data. Based on structural similarities we believe that the deep section is similar in overall behavior. Displacements, earthquake ages, and slip rate at Wrightwood suggest that the San Andreas fault exhibits neither time predictable nor slip predictable behavior. While the average slip rate is 3.1 cm/yr, both the deep and upper sections show variation in slip released through time. Both sections have short periods (5 events) of high slip rates (9 cm/yr) and longer intervals (7 to 9 events) of low slip rates (2 cm/yr). We used the average slip rate and displacement data of the upper section to estimate the strain level of the fault through time. Earthquakes are represented by strain drops equivalent to their displacement and strain is accumulated at the average slip rate between earthquakes. The resulting strain history shows periods of net strain accumulation and loss with a range equivalent to 5 earthquake displacements. Periods of net strain release have both more frequent and larger earthquakes whereas periods of net strain accumulation have both longer intervals and smaller events. The current strain level is approaching a high which as been reached only three times in the past 1500 years. The highest strains are followed by either a very large earthquake or a flurry of average to large sized earthquakes. Strain level does not reliably predict displacement of the subsequent event, but does correlate weakly with the length of the ensuing interval. Periods of higher strain release are associated with shorter intervals. We also evaluated strain accumulation through time assuming a characteristic slip (3.2 m). The resulting strain history still shows periods of net strain release and gain, but the range is reduced to the displacement of 3 earthquakes. These results indicate that the periods of net strain loss result from both the frequency and size of the earthquakes. When displacement is modeled as uniform, the correlation between strain level and ensuing interval length is weakened. From these relationships, we conclude that: (1) shorter recurrence intervals appear to be more common at high strain levels. (2) displacement data does not correlate with other parameters, or the correlation is obscured by measurement imprecision. (3) approximately one-third of the strain released by the San Andreas fault occurs during short periods of time (15% of the record), characterized by shorter recurrence intervals and possibly larger events. (4) currently, strain exceeds the level of all but 3-5% of the past 1500 years, and strain has never remained at this level for more than 25 years.

T51A-04 0850h

Developing a methodology for imaging stress transients at seismogenic depth

Nathalie Valette-Silver[1] (1-202-478-8834; nvsilver@dtm.ciw.edu)

Paul G. Silver[1] (1-202-478-8834; silver@dtm.ciw.edu)

Fenglin Niu[2] (1-713-348-4122; niu@rice.edu)

Tom Daley[3] (1-510-486-7316; tmdaley@lbl.gov)

Ernest L. Majer[3] (1-510-486-6709; elmajer@lbl.gov)

[1](1) DTM, Carnegie Institution of Washington, 5241 Broad Branch Road, NW, Washington, DC 20015, United States

[2](2) Department of Earth Science, Rice University, 6100 Main Street, Houston, TX 77005, United States

[3](3) Earth Science Division, Lawrence Berkeley National Laboratory, 1 Cyclotron Road, Berkeley, CA 94720, United States

It is well known that the crust contains cracks down to a depth of several kilometers. The dependence of crustal seismic velocities on crack properties, and in turn, the dependence of crack properties on stress, means that seismic velocity exhibits stress dependence. This dependence constitutes a powerful instrument for studying subsurface transient changes in stress. While these relationships have been known for several decades, time-dependent seismic imaging has not, as of yet, become a reliable means of measuring subsurface seismogenic stress changes. There are two primary reasons for this: 1) lack of sufficient delay-time precision necessary to detect small changes in stress, and 2) the difficulty in establishing a reliable calibration between stress and seismic velocity. The best sources of calibration are the solid-earth tides and barometric pressure, both of which produce weak stress perturbations of order 10^2-10^3 Pa. Detecting these sources of stress requires precision in the measurement of fractional velocity changes δv/v of order 10^{-5}-10^{-6}, based on laboratory experiments. Preliminary field experiments and the analysis of uncertainty from known sources of error suggest that the above precision is now in fact achievable with an active source. Since the most common way of measuring δv/v is by measuring the fractional change in travel time along the path, δT/T = -δv/v, one of the dominant issues in measuring temporal changes in velocity between source and receiver is how precisely we can measure travel time. Analysis based on the Cramer-Rao Lower Bound in signal processing provides a means of identifying optimal choices of parameters in designing the experimental setup, the geometry, and source characteristics so as to maximize precision. For example, the optimal frequency for measuring δT/T is found to be proportional to the Q of the medium. As an illustration, given a Q of 60 and source-receiver distances of 3 m, 30 m, 100 m and 2000 m the optimal frequencies are 15 KHz, 1.5 KHz, 450 Hz, and 22.5 Hz respectively. We have conducted a series of preliminary experiments to assess the level of precision achievable, and its dependence on a variety of other parameters. The experiments were performed in two 15-meter-deep holes, which are separated by 3 meters inside the Lawrence Berkeley National Laboratory facility, with a piezoelectric source and a 12 string of 24 hydrophone at 0.5 m spacing. The parameters tested include: voltage of the applied pulse, duration of pulse and sampling rate. The pulse was repeated 10 times per second and record length was 10 milliseconds. In each case, we recorded 100 single-source pulses in addition to 2 traces consisting of a real-time stack of 100 source pulses. We have measured the delay time between the seismograms of different pulses with a variety of cross-correlation-based algorithms. All methods yielded very consistent measurements of delay time, with precision ranging from 10^{-7}-10^{-8} s for the 100-record stacks. Since the travel time between the source and receivers is $\sim$2 ms, this corresponds to precision in δT/T of order 10^{-4}-10^{-5} after 10 s of recording. With hourly sampling, we should be able to achieve a precision (10^{-5}-10^{-6}), which is sufficient for measuring stress changes associated with tides and barometric pressure.

T51A-05 0905h INVITED

What can we Learn From Small Non-Recoverable Strains at Plate Boundaries?

Jonathan C. Lewis[1] (413-577-3816; lewis@geo.umass.edu)

Christopher J. Pluhar[2] (813-459-4089; cpluhar@emerald.ucsc.edu)

[1]Department of Geosciences University of Massachusetts, 611 North Pleasant Street, Amherst, MA 01003, United States

[2]Department of Earth Sciences, University of California, Santa Cruz, CA 95064, United States

Background seismicity carries often overlooked information about how the crust responds to plate motions. Integrating focal mechanisms for background seismicity with (1) geologic observations, and (2) geodetic constraints, is critical to establishing a better understanding of both the rock record and contemporary deformation. Treating the crust as a micropolar continuum it is possible to constrain not only the orientations and relative magnitudes of the principal strains but also the vorticity of crustal blocks with respect to the large-scale continuum. We show the utility of this approach with examples from the Cascadia margin and the Coso Range (within the Eastern California shear zone). In the upper crust of the Cascadia margin, seismogenic strain appears to be dominated by accommodation of motion of the Oregon forearc block. This suggests that the shallow crust is responding to long-term motion of the Oregon forearc rather than the interseismic locking of the subduction megathrust. In the area west of Mt. Rainier, this response is marked by nonzero relative vorticity in a regime of N-S shortening and crustal thickening. To date, geologic studies necessary to evaluate the significance of this vorticity have not been completed. In contrast within the Coso Range of California, seismogenic strain at Wild Horse Mesa indicates a component of relative vorticity that is broadly consistent with paleomagnetically constrained finite rotations of the ca. 3 Ma lava flows that compose the mesa. This area is centered at a right-releasing step in the Eastern California shear zone and thus is experiencing active transtension. Stratigraphic constraints have been used to suggest that significant dextral shearing in this region initiated ca. 3.5-2 Ma. The seismogenic response to transtension is depth-dependent plane strain with crustal thinning above 5 km and horizontal dextral shearing from 5-8 km. Both structural levels indicate subhorizontal E-W maximum stretching. Relative vorticity at deeper levels is consistent with down-viewed clockwise rotation, in accord with paleomagnetic results. Relative vorticity at shallower levels is consistent with E tilting of crustal blocks, which has not been resolved paleomagnetically. In addition, micropolar modeling of outcrop-scale brittle faults exposed in the eastern part of Wild Horse Mesa shows subhorizontal maximum stretching directions that are in general agreement with those determined for contemporary deformation. At 90% confidence, bootstrap models suggest a sense of block rotation that is in accord with that evident from the paleomagnetic data, as well as prolate strain, consistent with transtension. The latter finding suggests that the time-integrated record of shearing captures the contemporary, depth dependent plane strains as a 3-dimensional deformation. These rocks, in fact, record evidence for partitioning of strain at fine spatial scales with faults that record crustal thinning and crustal thickening intimately mixed with the more dominant strike-slip faults. In total, the neotectonic record of non-recoverable strain at Wild Horse Mesa is in accord with (1) expectations based on the current boundary conditions, and (2) models for the formation of the youthful Eastern California shear zone. The faults that provide this record are invariably limited to the outcrop scale, and are interpreted to be akin to the structures that accommodate contemporary background seismicity. These small structures therefore appear to provide an important link between understanding the rock record and contemporary non-recoverable deformation.

T51A-06 0925h INVITED

Water-weakened lower crust and its role in the concentrated deformation in the Japanese islands

Yoshihisa Iio[1] (iio@rcep.dpri.kyoto-u.ac.jp)

Takeshi Sagiya[2] (sagiya@seis.nagoya-u.ac.jp)

Yoji Kobayashi[3] (iio@rcep.dpri.kyoto-u.ac.jp)

Ichiro Shiozaki[4] (shiozaki@cv.tottori-u.ac.jp)

[1]Disater Prevention Research Institute, Kyoto University, Gokasho, Uji 611-0011, Japan

[2]Nagoya University, Furou-cho,Tikusa-ku,, Nagoya 464-8602, Japan

[3]Institute for Geoscience, University of Tsukuba, Tennoudai 1-1, Tsukuba 305-0006, Japan

T

[4]Institute for Geoscience, Tottori University, 4-101 Minami, Koyama-cho, Tottori 680-8552, Japan

The nature and origin of the concentrated deformation zone along the Japan Sea coast (NKTZ: Niigata-Kobe Tectonic Zone) was investigated by carefully analyzing the GPS data and qualitatively modeling the lower crust in NKTZ. It was concluded that this deformation zone is not a plate boundary between the Amurian plate (AMU) and the North America plate but is rather an internal deformation zone near the eastern margin of AMU. The data previously obtained on the conductivity anomalies in the lower crust and the 3He/4He ratios suggest that the concentrated deformation in NKTZ results from the lower crust in NKTZ being weakened by a high water content. The high water content is thought to result from the dehydration of subducting slabs.

T51A-07 0945h

Pacific-North America plate boundary deformation in the greater Salton Trough area, southern California, USA

Noah P Fay[1] (5413464653; nfay@newberry.uoregon.edu)

Eugene D Humphreys[1] (5413465575; gene@newberry.uoregon.edu)

[1]University of Oregon, Department of Geological Sciences, Eugene, OR 97403, United States

The general kinematic nature of the Pacific-North American plate boundary in southern California is well described by long-term geologic fault slip-rate estimates and short-term geodetic measurements of surface displacement rates. In general, these data sets agree, often through simple kinematic models. There are, however, interesting differences in the greater Salton Trough/Imperial valley (a sedimentary basin). Geologic estimates of slip-rate on the block-bounding faults (e.g., the southern San Andreas, San Jacinto, Imperial, etc.) favor the San Andreas as the major plate-boundary fault. Recent geodetic strain estimates suggest the San Jacinto fault accommodates as much, or more, strain than the San Andreas fault. These discrepancies could reflect the disparate time scales over which geology and geodesy measure crustal deformation. Also, significant lateral and vertical variations in crustal rheology (elastic properties such as shear strength), which thus far have not been included in kinematic models of geodetic data in this area, may have important effects on interpretation of geodetic displacement rates. We present preliminary results of a finite element model driven by well-known far-field plate motions to test the influence of variations in crustal rheology on observed geodetic displacements. Crustal elastic properties are calculated from seismic velocity estimates from the SCEC 3D velocity model. Model surface displacement rates are compared to the SCEC crustal motion map.

T51B MCC: 3005 Friday 0800h

Structure and Dynamics of the Oceanic Upper Mantle II *(joint with OS, S, V)*

Presiding: **J Gaherty,** Georgia Institute of Technology**; J Korenaga,** Yale University

T51B-01 0800h INVITED

Cooling history of the Pacific lithosphere

M. H. Ritzwoller[1] (ritzwoller@ciei.colordo.edu)

N. M. Shapiro[1] (nshapiro@ciei.colorado.edu)

S. Zhong[1] (szhong@ciei.colorado.edu)

J. van Hunen[1] (hunen@ciei.colorado.edu)

[1]Center for Imaging the Earth's Interior, Department of Physics, University of Colorado at Boulder, Boulder, CO 80309-0390, United States

Plate tectonics is expressed most simply in oceanic plates where a thermal boundary layer or lithosphere forms as the plate cools during its journey away from mid-ocean ridges. Based on a seismic model of the Pacific upper mantle inferred from a new compilation of seismic surface wave dispersion measurements, we show that, on average, the Pacific lithosphere has experienced a punctuated cooling history, cooling diffusively for its first 70 Ma and then reheating in the Central Pacific between ages of 70 and 100 Ma predominantly at depths between 70 and 150 km. From 100 Ma to about 135 Ma, the processes of reheating are substantially weaker than in the Central Pacific, on average, and the lithosphere undergoes a second phase of diffusive cooling. The cause of the reheating in the Central Pacific remains unclear, although thermal plumes at a number of length scales are probably important, particularly to modulate thermal boundary layer instabilities (TBI). We argue, however, that TBI forms naturally as the plate cools. We present the results of simulations that show that, with the right rheology, TBI can explain the average characteristics of the observed cooling history of the Pacific plate. To explain the variability within age ranges observed across the Pacific, however, may require additional physical processes not included in our simulations, such as variations in the conditions of formation of the lithosphere or the effects of deeper seated thermal plumes.

T51B-02 0820h

Seismic Structure of the Mantle Beneath Western Pacific Using 3D Fréchet Kernels

Liangjun Chen[1] (liangjun@usc.edu)

Li Zhao[1] (zhaol@usc.edu)

Thomas Jordan[1] (tjordan@usc.edu)

[1]Univ. of Southern California, Dept. of Earth Sciences, Los Angeles, CA 90007

Two decades of seismic tomography studies have yielded earth models with three-dimensional (3D) velocity heterogeneities in the mantle on both global and regional scales. We have developed a tomography technique which uses 3D Fréchet kernels in setting up the linearized inverse problem. We present a 3D model of the shear-speed structure for the mantle beneath the Western Pacific Ocean. Over 1600 three-component recordings of earthquakes (Mw $>$ 5.5) from the seismic zones around the western Pacific rim were processed to obtain $\sim$30,000 frequency-dependent phase delays for various of seismic waves, including S, SS, upper-mantle guided and surface waves, and ScS reverberations. The 3D Fréchet kernels for these delay times are computed by the coupled normal mode theory described by Zhao, Jordan, and Chapman (2000), and the measurements were inverted for a 3D radially anisotropic shear-speed model. The model parameters include shear-speed variations throughout the mantle and perturbations to radial shear-wave anisotropy in the uppermost mantle. The resolving power has been investigated through a series of inversion tests, which indicate that the horizontal and vertical resolving lengths are about 750 km and 250 km, respectively, in the upper mantle. Our results for the large-scale variations in the isotropic shear speeds are generally consistent with published global tomographic models. Comparison of inversion results using 2D and 3D Fréchet kernels shows a good correlation between 2D and 3D inversion, and somewhat lower amplitude in 3D inversion. Our model reveals greater lateral heterogeneity than the global models, especially in the 200-400 km depth range, suggesting a complex 3D mantle flow in the western Pacific upper mantle.

T51B-03 0835h

The Origin of the Low Velocity Zone: Laboratory Constraints

Ulrich Faul[1] (uli.faul@anu.edu.au)

Ian Jackson[1] (ian.jackson@anu.edu.au)

[1]Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia

One of the most prominent features of oceanic upper mantle is a minimum in shear wave velocity usually observed at a depth between 100 and 200 km. Partial melting is most commonly invoked as an explanation, but a change in deformation mechanism and the presence of water have also been suggested. An important observation is that the depth of the low velocity zone varies with age of the oceanic lithosphere, implying a relationship with the thermal structure rather than a process occurring at a fixed depth. We have measured shear modulus and attenuation of polycrystalline olivine as a function of temperature at seismic periods. The data from five samples ranging in mean grain size by more than an order of magnitude have been fitted to an extended Burgers model that allows extrapolation of our measurements to the larger grain sizes expected in the upper mantle. An important experimental observation is that polycrystalline olivine behaves nearly elastically at temperatures below $\sim 900^{\circ}$C and seismic periods. Above this temperature anelastic processes cause attenuation and shear modulus reduction, resulting in much larger and period-dependent modulus variation relative to lower temperatures. We have calculated shear wave velocities for oceanic upper mantle from the fit to our experimental data and a conductively cooling half-space model commonly invoked to explain the age dependent structure of oceanic lithosphere. In addition to the temperature sensitivity, pressure dependence also is taken into account by an activation volume and anharmonic pressure derivative of the shear modulus. When the shear wave velocity is calculated as a function of depth, a pronounced velocity reduction occurs where the temperature first exceeds $\sim 900^{\circ}$C, corresponding to the onset of anelastic behavior. As long as the temperature increases rapidly along the conductive part of the geotherm, the velocity continues to decrease. Once the geotherm joins the adiabat, the increase in temperature with depth is much more modest and the pressure dependence becomes dominant, causing an increase in velocity. This combination of temperature and pressure dependence therefore results in a velocity minimum that is age dependent for oceanic lithosphere less then 100 Myr old. When comparing our calculated velocity profiles with those observed seismologically we find that our calculations match the observations fairly well-both with respect to the magnitude of the calculated velocities and the age dependent depth of the velocity minimum. The calculated attenuation is also consistent with seismic observations, with the least well constrained parameter being the activation volume. Comparison of calculated zero-age velocities with velocities determined by the MELT Seismic Team suggests the presence of melt beneath the East Pacific Rise.

T51B-04 0850h INVITED

Modeling seismic anisotropy in 3D mantle flow beneath Hawaii

Jules T. Browaeys[1] (33-1 44 27 47 96; browaeys@ipgp.jussieu.fr)

Neil M. Ribe[1] (33 -1 44 27 24 79; ribe@ipgp.jussieu.fr)

Edouard Kaminski[1] (33 -1 44 27 24 85; kaminski@ipgp.jussieu.fr)

[1]IPG Paris, 4, place jussieu, Paris 75252, France

Large-scale measurements of azimuthal anisotropy in the Pacific ocean show a global alignment of fast directions with the motion of the plate. However, significant disturbances occur around the Hawaii hotspot. Direct geodynamical modeling of seismic anisotropy can be used to extract information about mantle flow from these observations. The steady flow field around a thermal plume interacting with a moving lithosphere is determined using a 3-D variable-viscosity convection code. Next, the lattice preferred orientation of olivine and enstatite at each grid point is determined by along-streamline integration of the evolution equations of Kaminski and Ribe (Earth Planet. Sci. Lett., 2001) which account for plastic deformation of the crystals and for dynamic recrystallization by nucleation and grain boundary migration. Finally, the full elastic tensor at each grid point is calculated using a Voigt average. The anisotropy is strongest around the plume conduit and in the depth range 80-150 km where the hot plume material spreads laterally, and its orientation varies substantially as a function of both lateral position and depth. To apply our results to the Hawaiian region, we calculate synthetic anisotropic phase velocity maps at different depths and compare them with maps inferred from seismic observations. We will also present preliminary calculations of synthetic seismic observables, using the spectral element code of Komatitsch and Tromp (Geophys. J. Int., 2002) and a simplified version of our model in which the full elastic tensor at each point is replaced by the best-fitting hexagonal approximation.

URL: http://www.ipgp.jussieu.fr/~kaminski

T51B-05 0910h

Evidence for Upper Mantle Flow Associated with the African Superplume

Mark D Behn[1] (202-478-8837; behn@dtm.ciw.edu)

Clinton P Conrad[2] (cpconrad@umich.edu)

Paul G Silver[1] (silver@dtm.ciw.edu)

[1]Department of Terrestrial Magnetism, Carnegie Institution of Washington, 5241 Broad Branch Road, NW, Washington, DC 20015, United States

[2]Department of Geosciences, University of Michigan, Ann Arbor, MI 48109, United States

The presence of a large-scale, low seismic velocity anomaly in the mid to lower mantle beneath Africa is a robust feature of global tomographic models. Assuming the low velocities are associated with warm, less dense material, the African seismic anomaly has been ascribed to a long-lived thermal upwelling from the lower mantle. Such large-scale upwelling should exert significant driving forces on the surrounding plates and affect the regional horizontal mantle flow field. To test this model we compare seismic anisotropy inferred from shear wave splitting measurements with instantaneous flow calculations that incorporate mantle density structure derived from seismic tomography. We calculate splitting parameters at 12 ocean island stations surrounding Africa. Splitting measurements from island stations are ideal for interpreting anisotropy induced