form of the porosity perturbation term implicitly embedded in the Biot framework is deduced, which turns out to be solely dependent on the pressure difference of the two phases.

A modification of the elastic parameter in the Biot fluid pressure equation, as being sought in the BISQ model, implies that the form of underpinning porosity perturbation term is being altered. It turns out that for such a modification the porosity perturbation term must assume the dependence on the pressure difference as well as the total pressure of the two phases. Since the same porosity perturbation term underlies the Biot solid pressure equation also, this equation must also be modified accordingly.

We find that once the correction for squirt flow is properly incorporated in the Biot theory by modifying its both, fluid and solid, pressure equations on account of porosity perturbation term being dependent on the pressure difference as well as the total pressure of the two phases, the resulting framework is the volume-averaged theory of poroelasticity (de la Cruz and Spanos, Geophys. 1985; Sahay et al., GJI 2001).

MR61A-1040 0830h POSTER

Applying Statistical Rock Physics to Quantify the Effects of Geologic Heterogeneities on Seismic AVO Signatures in Offshore Venezuela

Tapan Mukerji[1]

Ezequiel Gonzalez[1]

Carlos Cobos[2]

Enrique Hung[2]

Gary Mavko[1]

[1]Stanford Rock Physics Lab, Geophysics Dept. Stanford University, Stanford, CA 94305, United States

[2]PDVSA-EPM, edif Chuao, Caracas, DF 1064-1, Venezuela

The objective of this study was to better understand observed amplitude anomalies, and quantify the geologic uncertainty associated with the feasibility of using seismic AVO signatures to detect hydrocarbons in offshore Venezuela region. Data from four wells were analyzed. Prediction of shear velocity was carried out in selected wells as none of the wells have shear logs. Sand and shale properties were estimated from selected zones based on the gamma-ray logs and geologic information about the formations. Fluid substitution was carried out within the sand zones taking into account the properties of the reservoir fluids. Monte-Carlo (MC) simulations, incorporating statistical variability and correlations of rock properties, were used to compute normal-incidence reflectivity and AVO gradient for different pore fluid conditions: brine sands, oil sands and gas sands. The computed seismic signatures were used to evaluate the feasibility of using seismic AVO for pore fluid and lithology discrimination. Forward modeling of CDP gathers was carried out and AVO signatures from synthetic CDP gathers were compared to MC simulations.

The main conclusions are: statistical rock physics and AVO modeling analyses of data from wells indicate that Pliocene gas/oil sands are expected to have observable seismic amplitude and AVO signatures, with negative R(0) and small gradient G at top sand. However, the signature changes from Pliocene to Miocene sands. Depth-dependent geologic trends in AVO patterns were identified using data from Pliocene and Miocene sands. Directly using Pliocene AVO patterns to interpret amplitudes from Miocene sands without correcting for the trend could lead to potential pitfalls. Miocene sands are expected to have much weaker fluid signatures, as they are high velocity, stiff sands. Volcanoclastics and carbonates are other possible sources of strong amplitude and AVO signatures, and hence may cause false alarms if not properly interpreted. A combination of reflection polarity and strong AVO gradient can help to distinguish volcanics and limestones from the sands.

MR61A-1041 0830h POSTER

Standing Torsional Waves in Fluid-Saturated Porous Circular Cylinder

Selene Solorza[1] (+(52-646) 1745050 x 26542; solorza@cicese.mx)

Pratap N. Sahay[1] (+(52-646) 1745050 x 26518; pratap@cicese.mx)

[1]CICESE, Department of Seismology, Km 107, Carretera Tijuana-Ensenada, Ensenada, BC 22860, Mexico

For dynamic measurement of elastic constants of a porous material saturated with viscous fluid when resonance-bar technique is applied, one also observes attenuation of the wave field. The current practice is to interpret it in terms of solid-viscosity by assuming a viscoelastic rheology for porous material.

The likely mechanisms of attenuation in a fluid saturated porous material are: 1) motion of the fluid with respect to the solid frame and 2) viscous loss within the pore fluid. Therefore, it is appropriate to assume a poroelastic rheology and link the observed attenuation value to fluid properties and permeability. In the framework of poroelastic theory, the explicit formula linking attenuation to the properties of solid and fluid constituents and permeability are not worked out yet. In order to established such a link one has to workout solutions of appropriate boundary value problems in such a framework.

Here, we have carried out the solution of boundary value problem associated with torsional oscillation of a finite poroelastic circular cylinder, casted in the framework of volume-averaged theory of poroelasticity. Analysing this solution by a perturbative approach we are able to develop explicit expressions for resonance frequency and attenuation for this mode of vibration. It shows how the attenuation is controlled by the permeability and the fluid properties, and how the resonance frequency drops over its value for the dry porous frame due to the effect of the fluid-mass.

MR61A-1042 0830h POSTER

Standard-free Pressure Measurement by Ultrasonic Interferometry in a Multi-Anvil Device

Hans J. Mueller[1] (+49-331-288-1443; hjmuel@gfz-potsdam.de)

Christian Lathe[1] (+49-40-8998-2691; christian.lathe@desy.de)

Frank R. Schilling[1] (+49-331-288-1875; fsch@gfz-potsdam.de)

Joern Lauterjung[1] (+49-331-288-1020; lau@gfz-potsdam.de)

[1]GeoForschungsZentrum Potsdam, Telegraphenberg, Potsdam D-14473, Germany

A key question to all high pressure research arises from the reliability of pressure standards. There is some indication and discussion of an uncertainty of 10-20% for higher pressures in all standards. Simultaneous and independent investigation of the dynamical (ultrasonic interferometry of elastic wave velocities) and static (XRD-measurement of the pressure-induced volume decline) compressibility on a sample reveal the possibility of a standard-free pressure calibration (see Getting, 1998) and, consequently an absolute pressure measurement.

Ultrasonic interferometry is used to measure velocities of elastic compressional and shear waves in the multi-anvil high pressure device MAX80 at HASYLAB Hamburg enabling simultaneous XRD and ultrasonic experiments. Two of the six anvils were equipped with overtone polished lithium niobate transducers of 33.3 MHz natural frequency, for generation and detection of ultrasonic waves with a frequency sweep between 5 and 55 MHz. Different buffer - reflector combinations were tested to optimize the critical interference between both sample echoes. NaCl powder of 99.5 % purity (analytical grade by Merck) was used as starting material for manufacturing the samples used as pressure calibrant after Decker (1971). The medium grain size was 50 μm. The powder was pressed to a crude sample cylinder of 10 mm diameter and a length of 20 mm using a load of 6 tons resulting in an effective pressure of 0.25 to 0.3 GPa. The millimeter sized samples (diameter 2.4 mm and 1.6 mm length for 6 mm anvil truncation and diameter 3.1 mm and 1.1 mm length for 3.5 mm anvil truncation) for the high pressure experiments were shaped with a high-precision ($\pm$ 0.5 μm) cylindrical grinding machine and polished at the front faces. From the ultrasonic wave velocity data we calculated the compressibility of NaCl. This requires in situ density data. Therefore the sample deformation during the high pressure experiments was analyzed in detail and the results were compared with models published by different authors. The experimental results measured with different set-ups under different pressure conditions were compared with EoS-data derived from static compression experiments up to 5 GPa (Bridgman, 1940) and up to 30 GPa (Holland & Ahrens, 1998; Birch, 1986) using experimental data from Boehler & Kennedy (1980) and Fritz et al. (1971). At 1.2 GPa and 5.3 GPa the results of static compression data exactly correspond to our velocity-based data, polynomial-fitted up to the power of 7. In the range between 2 and 4 GPa our dynamical data have 1.5 - 3 % higher values. Furthermore the pressure revealed according to Decker (1971) is in accordance to our standard-free pressure calibration within the uncertainty of the experiment.

Birch, F., J., Geophys. Res., 91, 4,949-4,954, (1986).
Boehler, R., Kennedy, G.C., J. Phys. Chem. Solids, 41, 517-523, (1980).
Bridgman, P.W., Physical Review, 57, 237-239, (1940).
Decker, D.L., J. Appl. Physics, 42, 3,239-3,244, (1971).
Fritz, J.N., Marsh, S.P., Carter, W.J., McQueen, R.G., NBS Spec. Publ., E.C. Lloyd ed., 326, 201-208, (1971).
Getting, I.C., Eos, 79, F830, (1998).
Holland, K.G., Ahrens, T.H., Geophys. Mon. 101, Manghnani, M.H. & Yagi, T. eds., 335-355, (1998).

MR61A-1043 0830h POSTER

A New Method of Determining the Specific Storage and the Hydraulic Conductivity of a Rock Sample

Insun Song[1] (44 131 650 5827; i.song@glg.ed.ac.uk)

Stephen C Elphic[1] (44 131 650 8545; selphick@ed.ac.uk)

Ian G Main[1] (44 131 650 4911; ian.main@ed.ac.uk)

Bryne T Ngwenya[1] (44 131 650 8524; bryne.ngwenya@ed.ac.uk)

[1]Dept of Geology and Geophysics, University of Edinburgh, West Mains Road, Edinburgh EH9 3JW, United Kingdom

We describe a new and relatively straightforward technique of determining the specific storage and the hydraulic conductivity of a tight core sample from a record of the upstream or/and the downstream hydraulic heads generated by constant-rate flow pumping. First, an analytic solution of the general diffusion equation is derived, subject to proper boundary conditions in which a flow pump injects fluid into a cylindrical specimen placed between two reservoirs. The solution for the hydraulic head consists of two parts: an asymptotic limit at long time scales, and a transient part that decays with time and eventually converges to zero. Based on our solution, the hydraulic heads of the upstream and downstream reservoirs will increase linearly with time after the transient. The slope of the linear function depends on the specific storage of rock sample for a given test condition. The intercept of the linear function and the difference in hydraulic head between the two reservoirs are related to both rock hydraulic properties and the other test system parameters. This result suggests that we can obtain the specific storage from the increasing rate of hydraulic head, and the hydraulic conductivity from the intercept or the difference in hydraulic head if the other test system parameters such as the compressive storage of the reservoirs and the dimension of rock specimen are known. The most important merit of our new method is that both the specific storage and the hydraulic conductivity can be simply determined from a single test record. No tedious history matching with a transient curve is required. We applied the new technique to a tight micritic limestone from the Gulf of Corinth, Greece, using a core sample 38mm in diameter and 15mm in length. For the simplicity of our test system, we removed the downstream reservoir. The measurement of the hydraulic head versus the flow generated by the pump yields 5.9×10^{-10} m^2 of the upstream compressive storage. We recorded the upstream hydraulic head generated by the flow pumping into one end of rock specimen with a constant flow rate of $10^{-10}m^3$/sec. After a transient stage, the curve stabilised at a constant increasing rate, as predicted. The linear increasing rate of the head and the intercept of the linear function yielded the specific storage as $2.8\times10^{-6}\pm5.9\times10^{-7}$ (m^{-1}) and the hydraulic conductivity as $4.1\times10^{-14}\pm5.3\times10^{-15}$ (m/sec), equivalent to 4.1×10^{-21} m^2 in permeability units.

M R

MR62A MCC: Hall C Saturday 1330h

Applications of Measurements of Physical Properties of Rocks to Large-Scale Tectonic Processes III Posters *(joint with P, S, T, DI)*

Presiding: **B Evans,** Massachusetts Institute of Technology**; H De Bresser,** Utrecht University

MR62A-1044 1330h POSTER

Effects of Melt and Pyroxene Content on the Rheology of Naturally Deformed Peridotites

Michael G Braun[1] (mbraun@whoi.edu)

Greg Hirth[1] (ghirth@whoi.edu)

Peter Kelemen[1] (peterk@whoi.edu)

[1]WHOI, MS 8, Woods Hole, MA 02536, United States

Although the rheology of the shallow mantle beneath oceanic spreading centers is generally approximated by the behavior of polycrystalline olivine aggregates, laboratory experiments demonstrate that

the rheology of olivine aggregates can be affected by the presence of melt or additional solid phases. In this study we examine microstructural variation in naturally deformed peridotites from the Oman ophiolite to constrain the effects of melt and pyroxene on the rheology of the shallow mantle. Using electron backscatter diffraction and digital petrographic analysis, we have measured grain size, grain shape, and lattice-preferred orientation (LPO) of olivine and pyroxene in detailed sections of dunites and adjacent harzburgites. Due to the large grain size (up to 45 mm) in some rocks, we use composite sections of multiple samples from each locality.

We observe systematic variations in grain size, texture, and magnitude of olivine LPO in dunites in proportion to the width of the dunite. Wider dunites exhibit much coarser grain size and a stronger, more orthorhombic LPO (similar to Dijkstra et al, 2002) than narrower, more recrystallized, dunites, which exhibit a strong [100] pole but girdles in [010] and [001]. Harzburgites adjacent to the dunites show olivine LPOs similar in orientation and magnitude to those of the smaller dunites, although some field observations indicate the strength of dunites may be significantly different from that of the surrounding harzburgite. Initial orthopyroxene data exhibit an LPO indicative of slip on (100)[001], the easy slip system in enstatite.

Geochemical data suggest that dunites represent high porosity conduits for melt transport. Melt flux calculations based on field measurements of the distribution of dunite widths in Oman suggest that melt fraction is proportional to the width of the dunite conduit [Braun and Kelemen, 2002]. The larger grain size and stronger LPO preserved in wider dunites may reflect enhanced grain growth due to a higher melt fraction while the dunite was an active melt conduit. The coarse grain size may subsequently strengthen the wider dunite relative to the harzburgite, such that the smaller dunites and surrounding peridotite recrystallized more during continued deformation. These microstructural observations can be used to place constraints on the relative viscosities of dunite and harzburgite in the shallow mantle.

MR62A-1045 1330h POSTER

Experimental Constraints on the Mechanics of Dyke Emplacement in Partially Molten Olivines

Sergio Vinciguerra[1,2] (++39-347-9129548; sergio.vinciguerra@ct.infn.it)

Xiaohui Xiao[1] (++1-617-253-5810; xhxiao@mit.edu)

Brian Evans[1] (++1-617-253-4353; brievans@mit.edu)

Giulio Di Toro[3] (++39-049-8273941; giulio.ditoro@unipd.it)

[1]EAPS, Massachusetts Institute of Technology, 54-724, 77 Mass. Avenue, Cambridge, MA 02139, United States

[2]Dipartimento di Fisica e Astronomia, Universita' di Catania, Via S. Sofia, 68, Catania 95123, Italy

[3]Dipartimento di Geologia,Paleontologia e Geofisica, Universita' di Padova, Via Giotto 1, Padova 35137, Italy

Dykes emplacement is a key mechanism of magma transport in the lithosphere. However, a complete dynamic model is not yet available, because the details of coupling between the viscous stresses, the country rock deformation, and the role of fractures are not fully understood. We performed experiments to determine melt concentration and strain distributions around basalt dykes in a San Carlos olivine matrix with 10% wt% MORB matrix, by using a high-pressure, high-temperature Paterson apparatus. Undrained triaxial compression experiments have been conducted after hot-pressing San Carlos olivine with 10% MORB, fully encapsulated by nickel shells. Creep and constant displacement rate experiments were performed at 1473 K and confining pressure of 300MPa, at constant stresses (80-160MPa) and constant strain rates ranging from 3x10-4 to 5x10-5s-1. Microstructural observation and chemical analyses of the melt distribution show an increase of MORB matrix from 10% in proximity of the dyke (1-2mm) to 4-5% at 3-4mm away. Melt migration appears to be controlled by the loading conditions and by the dyke geometry. As expected, the highest melt concentrations, and presumably, the highest stress concentrations, are found at the tip of the dyke. The deformation of matrix appears to be controlled by granular flow, but dilatancy occurs near the tip of the dyke, indicating coupled MORB transport and granular flow.

MR62A-1046 1330h POSTER

Development of Pressure Shadows in Partially Molten Rocks

Marshall Sundberg[1] (612-626-0572; sundberm@carleton.edu)

Mark E Zimmerman[1] (612-626-0572; zimme030@umn.edu)

David L Kohlstedt[1] (612-626-0572; dlkohl@umn.edu)

[1]Dept of Geology & Geophysics, Univ of Minnesota, 310 Pillsbury Dr SE, Minneapolis, MN 55455, United States

To investigate the factors involved in the formation of pressure sha-dows, we have deformed a series of synthetic rock samples in triaxial compression and simple shear. Our fine-grained ($\sim$15 μm) samples are composed of either 95% San Carlos olivine + 5% MORB, 93% San Carlos olivine + 2% FeS+ 5% MORB, or 95% Beaver Bay anorthite + 5% MORB. Additionally, we placed 5-30 small ($\sim$1 mm diameter), approximately spherical zirconia inclusions in each sample. Compression samples were deformed to strains of 10-20%, and shear samples were deformed to a shear strain of 250%. These experiments were performed at P = 300 MPa and T = 1523K for the olivine-rich samples and T = 1473 K for the anorthite-rich samples in a gas-medium pressure apparatus with differential stresses between 10 and 100 MPa.

Our results indicate that significant migration of melt can occur under these conditions. In the olivine + MORB compression samples deformed to a strain of 20%, melt depleted lobes with $\sim$0.5 the original melt concentration develop in the region of maximum compressive stresses, and melt-rich regions containing about 1.5 to 2.0 times the original melt concentration occur in the region of minimum compressive stress. In all olivine + MORB compression samples a halo of higher melt density surrounds the inclusion. The melt redistribution is the most pronounced in the sheared samples, forming regions of high melt concentration ($\sim$2.0 to 2.5 times the original concentration) in the low-pressure regions around the inclusion.

To investigate the effect of compaction length ($\delta_c = (k\eta/\mu)^{1/2}$, where k is the permeability, η the shear viscosity, and μ the melt viscosity) on the development of pressure shadows, the results on the olivine + MORB samples were compared to those on olivine + MORB + FeS and anorthite + MORB. The addition of FeS reduces the permeability and hence compaction length relative to the olivine + MORB samples ($\sim$1 mm versus $\sim$10 mm). The resulting melt distribution was more homogenous with little or no pressure shadow formation. The replacement of olivine with anorthite reduces the shear viscosity of the sample and thus also reduces the compaction length to $\sim$1 mm. The final melt distribution around the inclusions is nearly homogeneous with no partitioning of melt into a pressure shadows. These observations suggest that the development of pressure shadows is hindered if the compaction length is relatively small, that is, on the order of the size of the inclusions.

MR62A-1047 1330h POSTER

Experimental Observations of Deformation-driven Melt Segregation in Mantle Rocks: Connecting Melt Distribution and Rheology

Benjamin K. Holtzman[1] (612-626-0572; holtz007@umn.edu)

David L. Kohlstedt[1] (612-626-1544; dlkohl@umn.edu)

Jason Phipps Morgan[2] (jmorgan@geomar.de)

[1]Dept. of Geology and Geophysics, Univ. of Minnesota, 310 Pillsbury Dr. SE, Minneapolis, MN 55455, United States

[2]GEOMAR, Wischhofstrasse 1-3, Kiel D-24148, Germany

In partially molten mantle rocks experimentally deformed in simple shear, we have previously demonstrated that the melt will segregate if the compaction length of the material is on the order of the sample thickness. This observation implies that melt-rich bands will form during deformation on lengthscales smaller than the compaction length. In this study, we attempt to relate statistical observations of melt distributions with the measured rheological properties via calculations of the viscous dissipation produced during each experiment. As a system deforms, melt segregates into melt-rich, and thus weaker, bands, which in turn modify the solid flow field. This strain partitioning affects the rheology, and thus the viscous dissipation. In order to quantitatively relate dissipation to melt distribution, we first characterize the melt distribution (or melt band configuration) by several average properties (average area fraction of bands and average melt fraction in bands) and statistical properties (band spacing, angle, and thickness). Then, expressions for dissipation rate are derived for a strain-partitioned system in terms of these parameters. From these calculations, we can characterize the evolution of melt segregation during the experiment and the effects of segregation on the rheological properties of the rock. Initial analyses suggest that melt segregation and strain partitioning lower the total dissipation of the system relative to a non-segregated system. The extent to which the deforming system evolves to a dynamic steady state (i.e. constant average configuration and constant dissipation), is an open question.

This study is leading toward an understanding of how to scale the occurrence and structure of deformation-driven melt segregation in experiments upward to the meso-scale processes of the mantle and lower crust. Deformation may be an important driving force for the initial segregation of melt into channels deep in a melting region and in the modification of those channels and the solid flow field further up in any melting region as interactions with lithosphere intensify. Furthermore, segregated melt can dramatically influence the mechanical and transport properties of partially molten rock in a wide range of geodynamic environments.

URL: http://olivine.geo.umn.edu

MR62A-1048 1330h POSTER

Non-hydrostatic Wetting of Grain Boundaries in Mantle Rocks

Saswata Majumder[1] (612-626-0572; maju0003@umn.edu)

Perry H Leo[2] (612-625-0535; phleo@aem.umn.edu)

David L Kohlstedt[1] (612-626-1544; dlkohl@umn.edu)

[1]Department of Geology and Geophysics, University of Minnesota, 310 Pillsbury Drive SE, Minneapolis, MN 55455, United States

[2]Department of Aerospace Engineering and Mechanics, University of Minnesota, 110 Union Street. S.E., Minneapolis, MN 55455, United States

Deformation of fluid bearing rocks affects the distribution of pore fluids. In a large number of geologically important solid-fluid systems the fluid forms an isotropic network of tubules along grain edges at low fluid fractions. When such rocks are deformed in the laboratory at high pressures and temperatures, the fluid becomes distributed along grain boundaries in narrow bands in a sense antithetic to the sense of shear. Thus, during deformation, the fluid distribution changes from a network of interconnected tubules along grain edges to a planar network along the grain boundaries. We propose a model for the stress assisted transition from tubular network to the planar network of pore fluid. In this model, grain boundaries do not support any shear stress and thus can relax some of the applied stress by sliding. However, when polycrystalline aggregates are stressed, sliding grain boundaries are pinned at triple grain junctions. As a result, stress is concentrated along grain boundaries near triple grain junctions. The sign of normal stress along the grain boundaries depends on the orientation of the grain boundary with respect to applied shear stress. Stress concentrations are quickly relaxed by diffusive material transport along grain boundaries to a uniform stress distribution independent of position. However, during progressive deformation, normal stress builds up along the grain boundaries. The pressure of the liquid in a triple grain junction changes in response to the change in grain boundary stress. Thus, the average normal stress along the grain boundary can increase to a critical value when the total energy of the system is minimized by wetting of the grain boundary by the fluid in triple grain junction. The time required to reach the critical average stress along the grain boundaries depends strongly on grain size for small grain sizes. Once the critical average stress is reached, fluid flows from the triple grain junction to wet the grain boundary. A planar network of grain boundary fluid is established. The time taken to establish the complete network depends on the viscosity of the pore fluid.

MR62A-1049 1330h POSTER

Pressure- and temperature-dependent thermal expansivity and the effect on mantle convection and surface observables

Harro Schmeling[1] (+49-(0)69-798-23335; Schmeling@geophysik.uni-frankfurt.de)

Gabriele Marquart[2] ((030) 253 50 50; marquart@geo.uu.nl)

Thomas Ruedas[1] (+49-(0)69-798-24949; ruedas@geophysik.uni-frankfurt.de)

[1]Institute of Meteorology and Geophysics University of Frankfurt, Feldbergstrasse 47, Frankfurt D-60323, Germany

[2]Faculty of Earth Sciences, Budapestlaan 4, Utrecht 3584 CD, Netherlands

In most mantle convection studies with variable thermal expansivity only the pressure dependence is considered. Here we investigate the effect of temperature and/or pressure dependent thermal expansivity α on the distribution of buoyancy forces in mantle convection. Thermal expansivity is calculated for realistic earth parameters and a map on its dependence on T and p is given. By studying simple 2D constant viscosity convection and comparing cases with constant

α, $\alpha(p)$, $\alpha(T)$, and $\alpha(p,T)$ we find that for the mantle temperature the pressure dependence of α is important. For the lithosphere the dependence of α on temperature is dominating, since the temperature dependence of α is much stronger in the low-pressure regime. Also dynamic topography changes considerably if α is T and p dependent compared to a constant or only p dependent case.

MR62A-1050 1330h POSTER

Anisotropic Permeability and Melt Redistribution in Dynamic Systems

Justin W Hustoft[1] (612-626-0572; hust0059@umn.edu)

David L Kohlstedt[1] (612-626-1544; dlkohl@umn.edu)

[1]Dept of Geology and Geophysics, University of Minnesota, 310 Pillsbury Dr SE, Minneapolis, MN 55455, United States

Previous research into the mechanism of planetary core formation has lead to the conclusion that the cores of the terrestrial planets can only develop by the settling of metallic melt through a magma ocean. This conclusion was reached by examining the equilibrium distribution of core-forming melts in a silicate matrix under hydrostatic pressure conditions. These studies verified that, under hydrostatic conditions, metallic melts are distributed in isolated pockets, that is, their dihedral angle in olivine is $> 60^{\circ}$. However, the influence of deformation (non-hydrostatic stress) on the system was not taken into account. Deformation experiments performed in our lab have demonstrated that initially isolated iron sulfide melt pockets become aligned during deformation, altering the permeability of the system. In our studies, samples composed of olivine + iron sulfide with and without MORB were deformed at 1523 K and 300 MPa at shear stresses ranging from 10 to 100 MPa. Samples were deformed either under constant load or at a constant displacement rates of $10^{-6} - 10^{-4} s^{-1}$. Shear strains ranged from 0.8 to 2.5. The microstructures of the samples were examined in reflected light and scanning electron microscopy. In the case of olivine + 5 vol% iron sulfide + 10 vol% MORB, a sample sheared to $\gamma = 2.5$ in a series of constant load steps revealed bands of high basalt concentration. These silicate melt-rich bands are aligned at $\sim 20^{\circ}$ to the shear plane and antithetic to the shear direction. The silicate melt fraction in the bands is ~ 0.2 while the melt fraction in the regions between the melt-rich bands is ~ 0.02. The silicate melt bands are $\leq 50\mu$m wide and are space $\sim 100\mu$m apart. The average size of the iron sulfide blebs in the silicate melt-rich band is larger than the average size of blebs outside the band. Two other samples of the same composition were sheared to strains of 0.8 and 1.5 at constant displacement rates but lacked melt-rich bands. In the case of olivine + 5 vol% iron sulfide without MORB, iron sulfide melt-rich bands developed in a smaple sheared to $\gamma = 1.5$ in constant load steps. The sulfide blebs in this sample coarsened as isolated blebs interconnected during deformation, leading to the development of metallic melt-rich bands. Therefore, we conclude that deformation may make it possible for core-forming melt to accumulate in and segregate from a solid silicate matrix.

MR62A-1051 1330h POSTER

Experimental Constraints on Thermal Cracking of Peridotite at Mid-Ocean Ridges

Brian deMartin[1] (bjd@mit.edu)

Greg Hirth[2] (ghirth@whoi.edu)

Brian Evans[3] (brievans@mit.edu)

[1]MIT/WHOI Joint Program, Dept. Geology and Geophysics, Woods Hole, MA 02543, United States

[2]WHOI, Dept. Geology and Geophysics, Woods Hole, MA 02543, United States

[3]MIT, EAPS, 54-718, Cambridge, MA 02139, United States

Fluid flow at oceanic spreading centers controls the cooling and rheology of oceanic lithosphere, the biological and chemical evolution of hydrothermal systems, and serpentinization of mantle peridotite. Faults provide conduits for focused flow at the ridges and likely provide the channels necessary to sustain high-temperature hydrothermal vents. However, dispersed fluid flow can be accommodated though a zone of thermally fractured rock and promote distributed serpentinization of the lithosphere at slow spreading ridges. Thermal fractures form in upwelling mantle peridotite due to both thermal expansion anisotropy and thermal expansion mismatch between mineral grains. To test the applicability of micromechanical models for thermal cracking in peridotite and determine the critical stress intensity factor necessary to initiate thermal cracking in the oceanic lithosphere, we have run controlled cooling rate experiments on hot-pressed olivine aggregates. During the experiments, we use a pore fluid monitoring technique to determine when cracking proceeds to an extent where an interconnected microcrack network develops. By varying grain size, cooling rate, and confining pressure during the experiments, we can either enhance or suppress thermal cracking within the olivine samples. Larger grain sizes (38 - 60 microns) or faster cooling rates (1^{o}C/s) enhance microcrack formation. Based on our experiments, we estimate a critical stress intensity factor of $\sim 0.65 - 0.75$ MPa m$^{1/2}$. The laboratory experiments can be scaled to the Earth using micromechanical models for the influence of grain size and cooling rate on the freezing temperature for viscous dissipation of thermal stresses (Evans and Clarke, 1980). The depth extent of thermal cracking can be estimated by coupling micromechanical models of stress intensity resulting from anisotropic thermal contraction with thermal models for upwelling mantle at oceanic spreading centers. Our analysis indicates that thermal cracking of peridotite is likely at depths less than ~ 4 km beneath the seafloor and at temperatures less than $\sim 350^{o}$C. These predictions agree well with the depth of a transition from serpentinized to unaltered peridotite in the oceanic lithosphere determined from seismic observations.

MR62A-1052 1330h POSTER

Relating Permeability to Diagenesis via Numerical Experimentation

Ayako Kameda[1] (650 224 6716; kamedaa@pangea.stanford.edu)

William Bosl[2] (925-424-5015; bosl@llnl.gov)

Jack Dvorkin[1] (650 725 9296; jack@pangea.stanford.edu)

[1]Dept. of Geophysics, Stanford University, Stanford, CA 94305, United States

[2]Lawrence Livermore National Laboratory, 7000 East Avenue, Livermore, CA 94550-9234, United States

We quantitatively link permeability to diagenesis in sandstone by conducting numerical pore-scale fluid-flow experiments on a CT-scanned sample. The 3D micro-topology of the sample is represented by zeros for the pores and ones for the mineral phase. Absolute permeability is obtained from lattice-Boltzmann viscous flow simulation in the digital pore space. The numerical results closely match measured permeability in the sample. We numerically alter the original digital sample by (a) depositing cement on the grain surface and (b) inserting small "silt" particles into the pore space. By calculating the permeability of the altered sandstone, we obtain permeability-porosity trends that differ depending on the diagenetic alteration process. Thin-section 2D images of rock are much cheaper to obtain and more readily available than 3D images. Thus we explore the possibility of obtaining accurate permeability estimates from 2D images. In this approach, the 3D digital pore space realizations are generated from digitized 2D images via statistical indicator simulation. We produce digital 2D images from the original 3D digital sample by slicing it in the computer. The 2D porosity of the slices, on average, is the same as the measured 3D porosity. However, the statistical spread around the average value is noticeable. It is remarkable that the calculated permeability of the statistically reconstructed 3D realizations matches, on average, the calculated permeability of the original digital sample and also the measured permeability. Finally, we apply diagenetic alterations to 2D slices, statistically reconstruct the corresponding 3D samples, and calculate their permeability. The results indicate that in clastic sediments, absolute permeability can be accurately estimated from 2D sections. Also, the effect of diagenesis on porosity and permeability can be quantified using 2D section alteration and realistic permeability-porosity trends can be established.

MR62A-1053 1330h POSTER

Shear Enhanced Compaction During Nonlinear Viscous Flow of Porous Rock

Xiaohui Xiao[1] (xhxiao@mit.edu)

Brian Evans[1] (brievans@mit.edu)

[1]EAPS, Massachusetts Institute of Technology, 77 Massachusetts ave, Cambridge, MA 02139, United States

For geological materials, there are few experiments investigating the effect of second phase on semi-brittle flow. Under circumstances where the matrix deforms via plasticity or viscous creep, microvoids near second particles may nucleate either by decohesion of the particle-matrix interface or by particle fracture. The mechanical behavior may be greatly influenced by the presence of such microvoid which can, for example, lead to pressure sensitivity of plastic flow and ductile fracture. In this paper, we extend the previous studies of semi-brittle flow of synthetic calcite-quartz aggregates to a range of temperature and effective pressures where viscous creep occurs. Triaxial deformation experiments were performed on Solnhofen limestone and hot-pressed calcite-quartz aggregates containing 10, 20 and 30 wt% quartz at confining pressure of 300 MPa, pore pressure 50 to 290 MPa, temperature from 673K to 1073K and at strain rates of 3.0×10^{-5}, 8.3×10^{-5} and 3.0×10^{-4}. Starting porosity varies from 5 to 9%. We made axial and volumetric strain measurements during the mechanical tests, measured pore volume change by monitoring the volume of pore fluid that flows out or into the specimen at constant pore pressure. Yield stress increases with decreasing porosity and shows a dependence on both effective pressure and strain rate. Thus, the yield stress versus effective pressure can be described as a yield surface with negative slope that expands with decreasing porosity and increasing strain hardening, gradually approaching the envelope of strength at 10% strain, which has positive slope. The local slope of yield surface (μ) varies from -0.1 to -1.2, and dilation coefficient (β) from -0.1 to -0.66. At high effective pressure, the value of (μ+β) may be favorable for formation of compaction band [Issen and Rudnicki, 2001]. Creep of porous rock can be modeled to first-order as an isolated equivalent void in an incompressible nonlinear viscous matrix [Budiansky et al.1982]. Based on their constitutive equations, we used an incremental method to calculate the strain-stress curve of the porous material under a constant external strain rate. The numerical simulations reproduce general trends of the deformation behavior of the porous rock as observed in our experiments, including the decrease of yield stress with increasing effective pressure and significant strain hardening at high effective pressure. The drop of yield stress with increasing porosity is modeled well, and so is the volumetric strain rate, which increases with increasing porosity.

MR62A-1054 1330h POSTER

Numerical Simulation of Compaction Bands in High-Porosity Sedimentary Rock

Regina Katsman[1] (972-8-934-4923; Regina.Katsman@weizmann.ac.il)

Einat Aharonov[1] (972-8-934-4228; Einat.Aharonov@weizmann.ac.il)

Harvey Scher[1] (972-8-934-2545; Harvey.Scher@weizmann.ac.il)

[1]Weizmann Institute of Science, Department of Environmental Sciences and Energy Research, Rehovot 76100, Israel

Geologists have recently discerned naturally occurring discrete localized planar zones of deformation, associated with compaction of initially high-porosity rock. Compaction bands are characterized by significant porosity reduction and grain crushing, which may influence fluid transport, and stress and strain distribution in sedimentary formations. Thus, it is important to understand the conditions whereby compaction bands form and develop. A theoretical continuum approach of Issen and Rudnicki, associates an instability in the elastic constitutive relation with the emergence of planar compaction bands, perpendicular to the compressive principal stress. In order to gain insight into the formation mechanisms of the compaction bands under a variety of boundary conditions, we developed a discrete model, where the material is represented as a hexagonal lattice of springs that can transfer only normal forces (Central Force Spring model). In contrast to a continuum formulation the discrete lattice model allows for a statistical distribution of material properties (e.g., Young modulus, stress threshold etc). The occurrence of grain crushing and porosity reduction is represented by a change in the elastic properties of each element that exceeds a certain stress threshold. The emergence of compaction bands is simulated by the response to the redistribution of forces of the subsequent modified spring-network (with now altered elements) under the same tri-axial loading regime. Parametric analysis is conducted to explore the conditions under which compaction bands form and develop.

MR62A-1055 1330h POSTER

Effect of Particle Size Distribution on the Formation of Compaction Band in Granular Material

Baoshan Wang[1] (86-10-8801-5333; wangbs@ustc.edu)

Yong Chen[2] (86-10-8801-5335; yongchen@public.bta.net.cn)

Juan Li[2] (86-10-8801-5333; lijuangirl@hotmail.com)

[1]University of Science and Technology of China, 96 Jinzhai Road, Hefei, Anh 230026, China

[2]China Seismological Bureau, 63 Fuxing Ave.,, Beijing 100036, China

Compaction band is commonly observed in sandstone and even in the honeycombed material (Papka and Kyriakides, 1999). In sandstone, the compaction

M
R

bands come into being only under a narrow interval of confining pressure (Olsson and Holcomb, 2000), and these confining pressures are around the critical value for cataclastic flow (Zhang, Wong and Davis, 1990). Critical pressure of cataclastic flow is related to the particle size distribution, porosity, Poisson ratio, fracture toughness, initial crack size, and Young's modulus. For quartz rich sandstone, except the particle size distribution and porosity, the other factors are almost identical. So the particle size and porosity are thought to have key effects on the formation of compaction bands. Numerical experiments are conducted on samples with uniformly distributed balls using discrete element method. In the sample with wide rang of particle size, the force chains are developed along the dominant large balls, which form the frame of the sample. In more homogeneous material, the force distribution is more uniform. And under moderate hydrostatic compression, some of the balls reach their critical force gradually, and often in tabular or sub-tabular style. If biaxial load are performed right after this, compaction bands are supposed to arises. While when the hydrostatic compression increase, most of the balls reache their critical force, and the cataclastic flow occur. Further experiments will be done on different size distribution such as fractal distribution.

MR62A-1056 1330h POSTER

Compaction, Dilatancy and Failure in Porous Carbonate Rocks

Patrick Baud[1] (33-3-90240083; pbaud@eost.u-strasbg.fr)

Veronika Vajdova[2] (631-632-8302; vvajdova@ic.sunysb.edu)

Teng-fong Wong[2] (631-632-8212; Teng-fong.Wong@stonybrook.edu)

[1]Institut de Physique du Globe de Strasbourg, Laboratoire de Physique des Roches, EOST 5 rue Rene Descartes, Strasbourg Cedex 67084, France

[2]SUNY Stony Brook, Geosciences, SUNY SB, Stony Brook, NY 11794-2100

To investigate the influence of porosity change on the brittle-ductile transition, we conducted a systematic investigation of the phenomenology and micromechanics of shear-enhanced compaction, dilatancy and failure in the Solnhofen, Tavel and Indiana limestones with porosities ranging from 3% to 16%. Hydrostatic and triaxial compression experiments were conducted on nominally dry samples at confining pressures up to 435 MPa. Under sufficiently high confinement, shear-enhanced compaction was observed in all three limestones. The compactive yield behavior of Solnhofen limestone samples (with initial porosities as low as 3%) is phenomenologically similar to that of carbonate rocks, sandstone and granular materials with porosities ranging up to 40%. The compactive flow is commonly observed to be a transient phenomenon, in that the failure mode evolves with increasing strain to dilatant cataclastic flow and ultimately shear localization. It is therefore inappropriate to view stress-induced compaction and dilatancy as mutually exclusive processes, especially when large strains are involved as in many geological settings. Synthesis of our new data and published data on more porous carbonate rocks show that the compactive yield stress decreases with increasing porosity. At the same porosity, the compactive yield stress of a carbonate rock is lower than that of a siliciclastic rock. Microstructural observations show that the inelastic compaction arises from pore collapse accompanied by crystal plasticity and cataclastic processes in the solid matrix. Several versions of the plastic pore collapse model were employed to interpret the micromechanics of compaction and failure in these carbonate rocks.

MR62A-1057 1330h POSTER

Determination of the complete elastic stiffnesses from ultrasonic phase velocity measurements

Marko K Mah[1] ((780) 492 1055; mah@phys.ualberta.ca)

Douglas R Schmitt[1] ((780) 492 3985; doug@phys.ualberta.ca)

[1]Institue for Geophysical Research, Department of Physics University of Alberta, Edmonton, AB T6G 2J1, Canada

The complete set of 21 elastic stiffnesses of a composite material is found from ultrasonic measurements of the phase velocity anisotropy. Co-planar arrays of specially constructed near-point ultrasonic transducers of differing polarizations are used to generate and recorded ultrasonic waveforms travelling at a variety of differing angles within a number of differing planes through a composite material. Using a well-tested tau-p plane wave decomposition technique, quasi-P and quasi-S wave phase-speeds are obtained from these ultrasonic waveforms. The resulting 779 individual phase velocities are inverted, under no a priori presumptions about the symmetry or orientation of the material, to provide all the stiffnesses of the material. These show the composite material has a nearly orthorhombic symmetry as is expected from its visually observable texture. This orthorhombic character is further apparent in a number of bootstrap tests of the inversion that assumes differing levels of symmetry from triclinic to orthorhombic and using various subsets of the measured phase velocities. However, the present analysis of the anisotropic material does not account for the effects of wave-speed dispersion evident in the observed waveforms. This dispersion is particularly severe for the in-plane quasi-S wave polarization and is possibly a consequence of the fine layered structure of the material. Some effects of dispersion on the tau-p plane wave decomposition technique are examined in data acquired on a block of isotropic plexiglass. This technique will be applied to a layered sedimentary rock and some of the preliminary results will be presented.

MR62A-1058 1330h POSTER

Composite Grain Size Sensitive and Grain Size Insensitive Flow of Naturally Deformed Calcite Mylonites : Evidence From Quantitative Microstructural Analysis

Marco Herwegh[1] (marco.herwegh@geo.unibe.ch)

Hans De Bresser[2] (j.h.p.debresser@geo.uu.nl)

Jan Ter Heege[3] (Jan.terHeege@ruhr-uni-bochum.de)

[1]Institute of Geological Sciences, University of Bern Baltzerstrasse 1, Bern 3012, Switzerland

[2]Faculty of Earth Sciences, Utrecht University Budapestlaan 4, Utrecht 3584 CD, Netherlands

[3]Institut fur Geologie, Mineralogie und Geophysik, Ruhr-Universitat Bochum Universitatstrasse 150, Bochum 44780, Germany

Microstructures in naturally deformed rocks form the crucial link between experimental and theoretical rock deformation studies and the interpretation of large-scale tectonic processes. In this respect, calcite is one of the best-studied crustal materials, and a large body of data exists on both natural and experimental deformation at a wide range of conditions. At relatively high temperature, deformation conditions predicted on the basis of experimental work show reasonably good agreement with estimates from natural rocks. At low temperature, however, there is far less consistency, which appears to be largely due to uncertainties associated with the interpretation of microstructures in terms of specific mechanisms.

In this study, we investigated calcite mylonites from the Helvetic Nappe stack (Swiss Alps) with the aim of establishing criteria to interpret low-temperature deformation and recrystallization microstructures in rocks that potentially deformed by multiple mechanisms. The samples were taken from three major thrust planes and showed a systematic increase in deformation temperature in the range 250-400°C. Geological constraints imply a constant strain rate along individual thrusts in the order of 10^{-10}-10^{-11} s^{-1}. Microstructures were analyzed applying quantitative image analysis techniques.

The calcite mylonites show grain size distributions that are close to lognormal. Average values (ranging 2-40 μm), distribution ranges and aspect ratios of the grains all increase with temperature. The microstructures show evidence for subgrain rotation recrystallization at the lowest temperature, giving way to migration recrystallization at higher temperature. Application of recrystallized grain size piezometers resulted in unrealistically high values of paleo-stress, occasionally even above lithostatic pressure. As an alternative then to these piezometric relations, the measured grain size distributions have been incorporated in composite rheological laws of grain size sensitive (GSS) and grain size insensitive (GSI) creep, applying up-to-date experimentally calibrated flow laws for calcite. Using the above strain rates as constraints, more realistic stress values of 60-90 MPa resulted. More importantly, the observed change in aspect ratio of the deformed grains appears to correlate with a change in contribution of GSS mechanisms to the overall strain rate. It follows that grain size distribution and aspect ratio form potential microstructural parameters that allow meaningful interpretation of rocks deformed by multiple (GSS+GSI) mechanisms.

MR62A-1059 1330h POSTER

Chemico-Mechanical Coupling during Reactive Flow in Oolitic Limestone

Nicholas W.A. Odling[1] (nodling@glg.ed.ac.uk)

Stephen C Elphick[1] (selphick@glg.ed.ac.uk)

Bryne T Ngwenya[1] (bryne.ngwenya@glg.ed.ac.uk)

Ian Main[1] (ian.main@glg.ed.ac.uk)

[1]Edinburgh University, Grant Institute of Geology West Mains Road, Edinburgh EH9 3JW, United Kingdom

Hydrous fluids migrating on fault planes undergo decompression and thus local disequilibrium, reacting with their wallrocks and depositing or dissolving species. This physico-chemical interaction will affect local fluid flow, permeability and effective stress in the region of the fault, and may lead to fault valving. For a geologically meaningful system we have studied the reaction between dilute sulphuric acid and oolitic limestone under constant volume flow. The carbonate-gypsum reaction doubles the solid molar volume, and is capable of blocking the pore space, leading to large increases in the pore fluid pressure under constant volume flow conditions. 0.1M acid was circulated through 38mm diameter core plugs of Indiana limestone in a heated Hassler cell at 90°C, at which conditions gypsum precipitates as blockyprisms. Confining and end loads were 20Mpa and 10Mpa respectively, pore fluid pressure was measured at the in-flow and out-flow pistons. The out-flow pore fluid pressure was controlled at 3.5 MPa by a back pressure regulator and the flow rate through the plug was 15cm3.day-1. After some 24 hours the in-flow pore fluid pressure began to oscillate, showing repeated cycles of gradual rise to a differential pressure of 1.2MPa, followed by a sudden drop, giving a saw-tooth appearance in the fluid P/time relationship. At the experiments end the up-stream face of the core had been entirely converted to solid gypsum except where penetrated by a small number of holes 1.5mm in diameter. X-ray tomography showed that these holes are the terminations of narrow dissolution channels (wormholes) that penetrate approximately parallel to the core axis. The pressure oscilations are interpreted as resulting from chemico-mechanical coupling at the wormhole tip as it sequentially reacts to blocks the pore space, then breaks through as the pore fluid pressure rises. The maximum 1.2MPa thus gives the tensile strength of the gypsum reaction lining to the wormhole tip, equating to a hydraulic head of about 100m. This implies that fault valving would be impossible for this system for fluid reservoirs separated by more than this height difference. It seems, therefore, that the efficacy of valve faulting process in porous rocks is limited primarily by the local tensile strength of the mineral sealing deposited on fault walls.

URL: http://www.glg.ed.ac.uk/science/rockphysics

MR62A-1060 1330h POSTER

The Effect of Dynamic Recrystallization on Rheology, Microstructure and Grain Size Distribution: Inferences From Experiments on Polycrystalline Halite

Hans De Bresser[1] (+31-30-2534973; J.H.P.deBresser@geo.uu.nl)

Jan Ter Heege[2] (+49-234-3225909; Jan.terHeege@ruhr-uni-bochum.de)

Chris Spiers[1] (+31-30-2534972; cspiers@geo.uu.nl)

[1]HPT laboratory, Faculty of Earth Sciences, Utrecht University, P.O. box 80021, Utrecht 3508 TA, Netherlands

[2]Institute for Geology, Mineralogy and Geophysics, Ruhr-University Bochum, Universitaetstrasse 150, Bochum D-44780, Germany

It is commonly observed that dynamic recrystallization can affect the rheology of rock materials by altering the microstructure during deformation. The rheology of dynamically recrystallizing materials can be affected by changes in the dislocation substructure or by changes in grain size distribution, leading to a different relative contribution of grain size sensitive and grain size insensitive creep. The grain size distribution can be altered by different processes associated with dynamic recrystallization, such as the consumption or coalescence of grains by migrating boundaries, leading to grain growth, or the formation of new high angle grain boundaries, leading to grain size reduction. This study focuses on two major issues related to the rheology of dynamically recrystallizing materials: (1) the development of a recrystallized grain size distribution and its dependence on the deformation conditions, and (2) assessment of rheological weakening due to dynamic recrystallization and its importance for strain localization in nature. To investigate this, the effect of strain, temperature, stress and strain rate on rheology, microstructure and recrystallized grain size distribution was systematically explored using experiments on wet and dry polycrystalline halite. Samples of both wet and dry materials were deformed at 50 MPa confining pressure and strain rates of $5x10^{-7}$-$1x10^{-4}$ s^{-1}, temperatures of 75-240°C and stresses of 7-22 MPa. The experiments stress the importance of water for deformation of rock materials as wet and dry polycrystalline halite show distinctly different flow behavior and strength at similar deformation conditions. Deformation of dry polycrystalline halite results in continuous work hardening and development of a clear subgrain structure under the investigated conditions. Deformation of wet polycrystalline halite results in oscil-

lating flow stress accompanied by progressive subgrain rotation and massive fluid-assisted grain boundary migration, leading to a much lower flow stress than in the dry material. The observed flow behavior and strength can only be explained when composite dislocation and solution-precipitation creep in combination with grain boundary migration recrystallization are taken into account. Most of the resulting recrystallized grain size distributions of wet polycrystalline halite were found to be close to lognormal with a median grain size and standard deviation that decrease with increasing stress and temperature. The data allowed testing of available models for the development of steady state dynamic recrystallized grain size distributions. From the observed flow behavior, we infer that dynamic recrystallization does not lead to major rheological weakening in materials exhibiting relatively fast grain boundary migration. Therefore, it is unlikely that rheological weakening by grain boundary migration is sufficient to lead to strain localization in geological materials that in general exhibit lower migration rates than wet polycrystalline halite.

MR62A-1061 1330h POSTER

Crystallographic Preferred Orientations and Seismic Properties of Gabbroic Rocks

benoit ildefonse[1] (benoit@dstu.univ-montp2.fr)

david mainprice[1] (david@dstu.univ-montp2.fr)

cristina maria gusmao de burgos[1] (Cristina.Burgos)

[1]Lab de Tectonophysique, ISTEEM Universite Montpellier 2, Montpellier 34095 cx 5, France

The crystallographic preferred orientations (CPO) of mineral phases in gabbroic rocks are a key component for our understanding of the physical properties (rheology, seismic velocities and anisotropy, ...) of the lower continental crust and oceanic crust. In the past, the CPO of gabbros were rarely analyzed, because of the difficulty of measuring low-symmetry crystal (plagioclase, clinopyroxene) orientation using the universal stage. The recent use of the EBSD (Electron Back-Scattered Diffraction) technique in geosciences makes the measurement of these minerals much easier, using a scanning electron microscope.

We present a series of EBSD measurements of CPO in gabbroic rocks from the Oman ophiolite, from the lower crust at the South-West Indian ridge (ODP Hole 735B), and from igneous intrusions in the Itabuna belt (Sao Francisco craton, Bahia, Brazil). The measured samples cover a wide range of flow conditions, from magmatic flow to plastic flow at the ductile/brittle transition, with an emphasis on the high-temperature structures.

Plagioclase is the dominant mineral phase and forms the solid framework. Its fabrics generally display a girdle of [100] in the foliation plane, with a maximum parallel to the mineral lineation, a point maximum of [010] normal to the foliation, and a weaker concentration of [001] in magmatically deformed samples. Moving from magmatic flow to dislocation creep, the fabrics tend to retain their strong [010] point maximum and to have weaker [100] and stronger [001] maxima.

The fast direction of elastic wave propagation in plagioclase is [010]. Consequently, the effect of plagioclase in a foliated gabbro (i.e. fast direction normal to foliation) tends to be opposite to the one of olivine and clinopyroxene (i.e. fast direction parallel to lineation), resulting in a weak anisotropy, with a fast-propagation direction strongly dependent on the modal composition of the gabbro. Results are compared to the more classical fabrics and seismic properties of mantle peridotites.

MR62A-1062 1330h POSTER

Application of Impression Creep and Microindentation Hardness Tests in Experimental Rock Deformation

Dorothée Dorner[1] (dorothee.dorner@ruhr-uni-bochum.de)

Klaus Röller[1] (klaus.roeller@ruhr-uni-bochum.de)

Martin Schellewald[2] (ms@wtech.ruhr-uni-bochum.de)

Bernhard Stöckhert[1] (bernhard.stoeckhert@ruhr-uni-bochum.de)

[1]Institute of Geology, Mineralogy and Geophysics, SFB 526, Ruhr-University Bochum, Bochum 44780, Germany

[2]Institute of Materials, SFB 526, Ruhr-University Bochum, Bochum 44780, Germany

The perspectives of indentation techniques for the investigation of the rheology of minerals and rocks are explored. Microindentation hardness tests using a Vickers pyramid geometry on various minerals show that this method is suitable to investigate the strength of minerals in the low-temperature plasticity regime. Experiments on the pyroxene solid solution series jadeite-diopside revealed a good correlation between hardness and shear modulus indicating that jadeite and diopside belong to the same isomechanical group. Hardness tests on olivine provided insight into its strength anisotropy. Orientation analysis of SEM scale slip lines allowed the determination of the activated slip systems, with the crystal orientation determined by EBSD. Impression creep tests using a cylindrical indenter were performed to study the high-temperature deformation behaviour of materials at low strain rates. This method was originally established in engineering materials science, but has not previously been applied to minerals. Creep parameters obtained by impression creep tests compare well to those obtained in conventional uniaxial creep tests. The microstructure around the indents and its evolution along strain and strain rate gradients can be studied. Both methods require a minimum of sample preparation. While microindentation hardness tests can be performed on small grains within natural aggregates, impression creep tests are suitable for both single crystals and polycrystalline aggregates.

MR62A-1063 1330h POSTER

Influence of Interlayer Bonding on the Frictional Behavior of Sheet-Structure Minerals

Diane E Moore[1] (650-329-4825; dmoore@usgs.gov)

David A Lockner[1] (650-329-4826; dlockner@usgs.gov)

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

We compare the frictional strengths of 16 sheet-structure minerals, measured under oven-dried and water-saturated conditions, to identify the factors that cause them to be relatively weak compared to most other rock-forming minerals. We ran room-temperature frictional sliding experiments on sawcut rock samples containing a 1-mm layer of gouge of a given mineral separate. The samples were vacuum-dried at 120 degrees C overnight and then immediately tested in a triaxial apparatus at 100 MPa normal stress and 0.5 micrometers/sec sliding velocity. The samples were sheared dry to 4 mm displacement, then water was introduced to a pressure of 10 MPa and sliding was resumed at 100 MPa effective normal stress. Preliminary work (Morrow et al., 2000, Geophys. Res. Lett., v. 27, pp. 815-818) indicated a possible correlation between the coefficient of friction of a dry gouge and the strength of its interlayer bonds, and the new results verify this correlation. The dry values of coefficient of friction range upwards from about 0.2 for graphite, levelling off at about 0.8 for margarite, clintonite, gibbsite, kaolinite, and lizardite. SEM examinations support the hypothesis that for those gouges with a dry coefficient of friction less than 0.8, shear occurs by breaking through the interlayer bonds to form new cleavage surfaces. For samples whose dry coefficient of friction is approximately 0.8, consistent with Byerlee's law, the interlayer bonds are sufficiently strong that other frictional processes dominate. This correlation suggests that the energy input associated with a given value of the coefficient of friction may be calibrated against laboratory cleavage measurements (e.g., about 5000 mJ/sq. m surface energy of muscovite cleaved in a vacuum; dry coefficient of friction of 0.6). The addition of water causes strength to decrease for every mineral except graphite. The range of values for water-saturated coefficient of friction is 0.2 for talc and graphite to 0.7 for the brittle micas margarite and clintonite. If these minerals are separated into groups with similar crystal structures, the water-saturated coefficient of friction increases with increasing interlayer bond strength in each group. We propose that the water in the saturated gouges exists as thin, structured films that are bonded to the plate surfaces proportional in part to the mineral's surface energy; the water-saturated coefficient of friction would then reflect the stresses required to shear through the water films. Increasing temperature and pressure would tend to reduce the width of the water films and cause the strength to increase towards the limiting dry value.

MR62A-1064 1330h POSTER

Primary Grain Shapes and Grain Preferred Orientations: Why NO Analysis of Finite Strain is Complete Without Their Incorporation

Paul H. Wetmore[1] (213-740-8261; wetmore@earth.usc.edu)

Scott R. Paterson (213-740-6103; paterson@earth.usc.edu)

[1]Dept. of Earth Sciences, University of Southern California, 3651 University Ave., Los Anglese, CA 90089, United States

The final shapes and orientations of fabric elements (e.g. quartz grains in a sandstone) used to quantify the intensity of finite strain experienced by a rock is the product of distortions, volume changes, and rotations on a pretectonic primary fabric. Unfortunately, most studies reporting quantitative assessments of finite strain assume initially spherical shapes, non-spherical but randomly or uniformly oriented fabric elements, or that the effect of primary fabrics are identifiable even after straining.

In this study we have compiled the results of >150 fabric ellipsoid determinations from a variety of undeformed sedimentary and volcanic rock types including multiple fabric elements (e.g. crystals, pumice) from within the volcanics. While depending greatly upon the rock type and the particular fabric element in question, the primary fabric ellipsoids determined here range from those that only slightly departed from a sphere (e.g. sandstones: 1.3: 1.1: 1; pebbly mudstone1.25: 1.15: 1: HBL in volcanics: 1.2: 1.1: 1) to those which are extremely oblate (e.g. pumice: 3.2:2.4:1; shale: 1.5: 1.4:1). These results highlight the need for caution when selecting the type of fabric element used in strain analyses. This arises from the observation that some populations of fabric elements, such as pumice, not only yield relatively high initial mean axial ratios but also exhibit a broad range of initial axial ratios. Additionally, since the final fabric ellipsoid is the multiplicative product of the primary ellipsoid and the superimposed strain ellipsoid, the data generated in this study indicate that even for the fabric elements that yield relatively small primary fabric intensities the effect on the final ellipsoid may be dramatic. For example, the 2D combination of a primary fabric ellipse with a ratio of 1.3:1 with a strain ellipse of 2:1 would result in a final ellipse of 2.6:1, an apparent 30% more extension if the preexisting fabric is not accounted for.

Because the orientations of the primary fabric ellipsoids reported here rarely exhibit consistent relationships to bedding directed removal of the primary fabric contribution is not generally possible. We suggest, however, that the most appropriate means of correcting for the affect of a primary fabric is to multiply the finite fabric ellipsoid by the reciprocal of the mean primary fabric ellipsoid axis by axis for every axis combination. This process, therefore, brackets the range of possible final strain intensities.

MR62B MCC: Hall C Saturday 1330h

Elasticity and Constitution of the Earth's Interior I Posters *(joint with S, T, V, DI)*

Presiding: **S V Sinogeikin,** University of Illinois; **R M Wentzcovitch,** University of Minnesota

MR

MR62B-1065 1330h POSTER

Equation of state of K+Fe at high pressure: K in the Earth's core?

Kanani K. M. Lee[1] ((510) 643-8325; leeka@uclink.berkeley.edu)

Raymond Jeanloz[1] (jeanloz@uclink.berkeley.edu)

[1]Department of Earth Planetary Science University of California, Berkeley, 307 McCone Hall, Berkeley, CA 94720-4767, United States

X-ray diffraction to 60 GPa of potassium heated with iron reveals a 2-3% inflation of the hexagonal close-packed unit-cell volume of Fe, suggesting that K dissolves into the ϵ-Fe phase at pressures above $\sim$25 GPa. The equation of state of this K-Fe phase is well described by the Birch-Murnaghan formalism [Birch, 1978], with a zero-pressure isothermal bulk modulus slightly higher than that of ϵ-Fe: $K_{0T} = 240$ ($\pm$10) GPa, assuming a pressure derivative $K_{0T}' = 4$. Our results are compatible with both theoretical [e.g., Bukowinski, 1979] and experimental work [Parker et al., 1996] indicating that K transforms from alkali- to transition-metal character under pressure. The implication is that potassium can indeed be incorporated into the core early during Earth history, and thus provide an additional source of heat for the geodynamo and mantle dynamics.

MR62B-1066 1330h POSTER

Stability of *bcc*-Iron in the Earth Core: The End of Controversy

Anatoly B Belonoshko[1] (46 (0) 8 7908868; Anatoly.Belonoshko@fysik.uu.se)

Rajeev Ahuja[2] (46 (0)18 4713626; rajeev@fysik.uu.se)

Borje Johansson[1,2] (46 (0)8 7906758; borje@fysik.uu.se)