Mineral and Rock Physics

MR51A MCC: 123 Friday 0830h

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

Presiding: **D L Kohlstedt,** University of Minnesota**; W B Durham,** Lawrence Livermore National Laboratory

MR51A-01 0835h INVITED

Rheological Constraints on the Plastic Lithosphere

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The early work by Goetze and co-workers at MIT developed a phenomenological framework for application of laboratory measurements of the mechanical properties of rocks to the lithosphere and underlying mantle of Earth. The idea of a strength envelope was conceived as a simplified application of experimental results to understand in broad terms the behavior of rocks at depth. Application with respect to the Earth, notably the continental lithosphere, remains somewhat limited by lateral and vertical heterogeneity in both mineralogy and rock fabric. However, these concepts still retain significant utility in understanding the bulk rheological behavior of the lithosphere and mantle of Earth, as well as that of other planets where the material constituents are likely to be more homogeneous and the observational constraints on mechanical behavior are minimal.

In the strength envelope concept, mechanical behavior below a certain depth (the brittle-plastic transition) will be dominated by the plastic behavior of the rocks that exist in that region. The predominant rock type that likely exists on most non-Earth terrestrial planets is basaltic in composition, with some variability in the plagioclase:pyroxene content and in the chemistry of the individual phases. Mantle rocks are most likely approximated well by an olivine-dominated mineralogy similar to that of Earth. A key issue remains the role of water, which is known to have a significant weakening effect on most silicate rocks. All terrestrial planets, other than Earth, have lost volatiles through volcanic degassing but lack an effective return path for water into their interiors. Thus, the mechanical behavior of the interiors of other terrestrial planets may differ significantly from that of Earth. In this presentation I will focus on the role of water on the mechanical properties of rocks of crustal and mantle mineralogies. In particular, rocks of basaltic composition, gabbros and pyroxenites, under dry deformation conditions are very strong. These rocks are not significantly different in strength from dry upper mantle rocks; thus we expect strong coupling between the crust and underlying mantle. By contrast, under wet conditions, lower crustal rocks are relatively weak compared to olivine-dominated lithologies, potentially providing a weak lower crustal zone that decouples the shallower crust from the mantle lithosphere.

MR51A-02 0855h

Microstructural Constraints on the Rheology of the Lower Crust

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The rheology of the lower crust controls a wide range of geodynamic processes. For example, modeling studies indicate that flow of relatively low viscosity lower crust plays an important role in the rate of post-seismic creep after earthquakes on continental strike-slip faults. Similarly, numerous geodynamic models incorporate a lower crustal rheology that results in decoupling of strain between the crust and upper mantle. I have studied the rheology of lower crustal rocks by analyzing textures in gabbros obtained during ODP drilling of oceanic crust in the Indian Ocean (Hole 735B). These rocks exhibit textures indicative of deformation from magmatic temperatures to greenschist facies. The analysis of oceanic gabbros is ideal for the "calibration" of experimental flow laws for several reasons. (1) The rocks experience a simple (i.e., single stage) down temperature deformation history. (2) Since deformation is more localized as temperature decreases, microstructures representative of the higher temperature history of the rocks are preserved between lower temperature shear zones. (3) The temperature history of oceanic rocks can be well constrained using a combination of geothermometry and metamorphic petrology. (4) The presence of olivine in many of the rocks can be used to calibrate observations (e.g., recrystallized grain size) with the much better constrained properties of olivine. (5) The relatively rapid cooling experienced by oceanic gabbros decreases the likelihood that post-deformational annealing significantly alters deformation fabrics. The recrystallized grain size of plagioclase is slightly smaller than that of adjacent recrystallized olivine, consistent with empirical relationships [e.g., Twiss, 1977]. The presence of recrystallized augite (cpx) grains in the same rocks provides a unique opportunity to determine the temperature of deformation. Recrystallization occurs prior to and after the exsolution of enstatite from the augite grains. The recrystallized grains in the coarser-grained pyroxene show exsolution. Therefore, the temperature of deformation must be greater than the temperature preserved by the exsolution. By contrast, the recrystallized grains in finer-grained rocks are free of exsolution lamellae and are composed of either high-Ca pyroxene (augite) or low-Ca pyroxene (enstatite). In this case, the compositions of the recrystallized grains can be used to determine the temperature during deformation. The deformation conditions determined from these analyses indicate that the rheology of gabbroic rocks is well bracketed by experimental flow laws for gabbroic rocks and suggest that there is not a large difference in the viscosity of lower oceanic crust and mantle.

MR51A-03 0910h

Microstructural Evidence for Grain Size Sensitive Deformation Mechanisms in Naturally Deformed Peridotites

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The rheology of the lithosphere, including the processes responsible for strain localization, are strongly influenced by grain size evolution during deformation. We have used a combination of microstructural observations and geothermometry to constrain conditions at which a transition from dislocation creep to diffusion creep occurs in the oceanic lithosphere. An abyssal peridotite mylonite from the Shaka Fracture Zone was analyzed using electron backscatter diffraction (EBSD) to determine olivine lattice preferred orientation (LPO).

A strong LPO in olivine grains from a coarser grained region (grain size $\sim$100 μm) indicates deformation was accommodated by dislocation creep. In contrast, a finer grained region (grain size $\sim$10 μm) in the same sample shows no LPO, indicating deformation by diffusion creep. These microstructural observations also suggest that a pre-existing LPO was destroyed by the transition to diffusion creep. Previous geothermometry of these peridotite mylonites (Jaroslow et al., 1996) indicates mylonite deformation occurred down to $\sim 600^{\circ}$C.

Olivine deformation mechanism maps imply extremely high strain rates and stresses for the measured grain size and deformation temperature of the mylonite. One problem with the interpretation of these results is determining how grain size reduction resulting from dynamic recrstallization can promote a transition to diffusion creep. For example, at temperatures lower than $\sim 1000^{\circ}$C, the dynamic recrystallized grain size relationship determined by van der Wal et al. (1994) falls almost entirely within the diffusion creep field. However, extrapolation of recently determined flow laws for dislocation accommodated grain boundary sliding indicate that dislocation dominated deformation processes can dominate to lower temperatures, and therefore higher stresses. We conclude that the lack of LPO observed in the finest-grained regions of the mylonite indicates a transition from dislocation-accommodated grain boundary sliding to diffusion creep.

MR51A-04 0925h INVITED

TEM Study of Intergranular Fluid Distributions in Rocks at a Nanometer Scale

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The distribution of intergranular fluids in rocks plays an essential role in fluid migration and rock rheology. Structural and chemical analyses with sub-nanometer resolution is possible with transmission and scanning-transmission electron microscopy; therefore, it is possible to perform the fine-scale structural analyses required to determine the presence or absence of very thin fluid films along grain boundaries. For aqueous fluids in crustal rocks, Hiraga et al. (2001) observed a fluid morphology controlled by the relative values of the solid-solid and solid-fluid interfacial energies, which resulted in well-defined dihedral angles. Their high-resolution transmission electron microscopy (TEM) observations demonstrate that grain boundaries are tight even at a nanometer scale, consistent with the absence of aqueous fluid films. For partially molten ultra-mafic rocks, two conflicting conclusions have been reached: nanometer-thick melt films wet grain boundaries (Drury and Fitz Gerald 1996; De Kloe et al. 2000) versus essentially all grain boundaries are melt-free (Vaughan et al. 1982; Kohlstedt 1990). To resolve this conflict, Hiraga et al. (2002) examined grain boundaries in quenched partially molten peridotites. Their observations demonstrate the following: (i) Although a small fraction of the grains are separated by relatively thick (1 μm) layers of melt, lattice fringe images obtained with a high-resolution TEM reveal that most of the remaining boundaries do not contain a thin amorphous phase. (ii) In addition, the composition of olivine-olivine grain boundaries was analyzed with a nano-beam analytical scanning TEM with a probe size of <2 nm. Although the grain boundaries contained no melt film, the concentration of Ca, Al and Ti were enhanced near the boundaries. The segregation of these elements to the grain boundaries formed enriched regions <7 nm wide. A similar pattern of chemical segregation was detected in subsolidus systems. Creep experiments on the partially molten rocks that were analyzed in this study reveal little weakening even at melt contents approaching 4 vol%, consistent with our observations of melt-free grain boundaries.

MR51A-05 0945h

Flow and kinematics of partially molten continental crust measured by both low- and high-field AMS

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There is considerable debate about the flow of the partially molten mid- to lower continental crust during orogenic deformation. Geologic observations of migmatite terrains suggest that deformation of orogenic crust is controlled by both horizontal flow, leading to layered migmatite, and vertical flow, reflecting the emplacement of gneiss domes cored by migmatite. Lateral flow of the mid- to lower crust has been described by the popular channel-flow model, and vertical flow is driven by gravitational instabilities. Unfortunately, fabrics in migmatites are difficult to unravel due to pervasive, high-temperature recrystallization. Planar fabrics such as migmatitic banding, layering, or foliation, are usually preserved macroscopically, but lineations are commonly unclear. Therefore, the petrofabric analysis of migmatites, including the definition of sense of shear, is problematic.

We have developed a new structural methodology for the study of migmatite based on the anisotropy of magnetic susceptibility (AMS) combined with image analysis. Our results on Archean migmatites of the Minnesota River Valley establish this method as a powerful petrofabric tool. Dimension stone quarries provide ideal sampling sites. The migmatites are coarse grained, granitic to tonalitic in composition and display a centimeter scale compositional layering. The layering and the regional foliation are subhorizontal to shallowly dipping to the NE. Mineral lineations are largely not

observable. Low-field magnetism is carried mainly by primary multidomain magnetite grains ranging 20-200 microns in size. The magnetic susceptibilities are generally high, around 5000 to 10000 10-6 SI. The degree of magnetic anisotropy is large, between 1.2 and 1.3. The principal axes of the low-field AMS ellipsoid coincide with those defined by the foliation, and the magnetic lineation is consistently oriented E-W; the degree of anisotropy is broadly correlated with mineral fabric intensity. In high-field (HF = 1 Tesla), the contribution of magnetite is cancelled and the HF-AMS fabrics result from the mafic silicates only. This is verified by the correspondance of the HF-AMS axes with the mafic minerals shape preferred orientation (SPO) obtained by image analysis. In spite of their pervasive recrystallization under high-grade conditions, these layered migmatites preserve a systematic obliquity between magnetite grain SPO (LF-AMS) and mafic silicates SPO (HF-AMS). We have interpreted this obliquity as resulting from the non-coaxial deformation of markers with different initial aspect ratios and obtain shear senses consistent with mesoscopic kinematic indicators. These preliminary results indicate a vast potential for application to tectonic problems and offer a structural tool to test the role of channel flow and gravity instabilities in the dynamics of the partially molten orogenic crust.

MR51A-06 1000h

A Reappraisal of Recrystallization Mechanisms

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Recrystallization is a key process in controlling creep deformation, physical properties and physical property anisotropies in the crust and mantle. For several decades the consensus view has been that nucleation process for recrystallized grains in deforming monominerallic aggregates has been either: Subgrain rotation recrystallization or Grain boundary bulging and that subsequent growth of the recrystallized grains occurs by strain induced grain boundary migration.

Both the subgrain rotation recrystallization and the grain boundary bulging mechanisms make testable predictions about the crystallographic misorientations between host and recrystallized grains. Electron backscatter diffraction (EBSD) in the scanning electron microscope (SEM) now enables us to test the geometrical predictions of these models with statistical significance.

Where recrystallized grains can be clearly related to parent grains, the misorientations between parent and new grains tend to be of the order of 30 degrees or higher. In these samples, and in more complex polycrystalline samples there is a paucity of boundaries with misorientations between about 5 degrees and about 30 degrees. These relationships are not predicted by either nucleation model.

Dispersion of EBSD data, by rotation around rational crystallographic directions, reflects deformation by dislocation creep and recovery. Discrete boundaries that share the same dispersion axes provide further support for recovery and subgrain rotation, but the misorientations across such boundaries rarely exceed about 5 degrees. Neighbouring recrystallized grains often have the same dimensions as subgrains and the subgrain rotation recrystallization mechanism seems reasonable except that it doesnt explain the sudden increase in misorientations around recrystallized grains, nor the change from misorientation axes parallel to rational crystallographic axes at low misorientation angles to random misorientation axes at high misorientation angles.

Explanation of the misorientations between recrystallized and parent grains requires either: nucleation mechanisms other than subgrain rotation recrystallization or grain boundary bulging mechanisms that modify the boundary misorientations after a nucleus is formed.

We will present examples of the problems described and some potential solutions using naturally and experimentally deformed quartz, calcite, garnet, nickel and steel.

MR51A-07 1015h

Correlations of stress distributions along the fault: from laboratory fracture roughness to fault asperity squeeze

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We analyse the spatial correlations of the absolute stress field along large faults in terms of scaling invariance (self-affine scaling). Despite the small range of resolution, we obtain a signature of correlations consistent with an elastic compression of the fault roughness. Indeed, we compare the wavelet spectrum of the measured stress field to that obtained from a numerical model in which two thick elastic media bounded by rough interfaces are fully squeezed. The interface roughness consists in spatially correlated asperities (i.e. non diluted asperities) described by a self-affine topography, as observed over a very wide range of scales from fractures to faults. If the self-affinity of the rough surfaces is characterized by a Hurst exponent H, we find that the stress field is also self-affine, but with a Hurst exponent $H-1$. Fluctuations of the normal stress are shown to be important, especially at local scales with anti-persistent correlations. A similar property is observed along the Nojima fault before the 1995 Kobe earthquake.

MR51A-08 1050h INVITED

Bounds on the Average Viscosity Coefficient of the Lithosphere from Convective Removal of that Beneath the Sierra Nevada

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Chris Goetze not only made definitive measurements in the laboratory, but he also sought field experiments that could be used to test and extend such experimental results. We describe another that we think he would like. We use geological and geophysical evidence for late Cenozoic convective removal of mantle lithosphere beneath the Sierra Nevada and both theory and numerical experiments for Rayleigh-Taylor instability to place a bound on the average viscosity coefficient for mantle lithosphere. P-wave travel times reveal high-speed zones in the upper mantle west of the Sierra, as well as thinned mantle lithosphere beneath the high region. Differences in xenoliths brought to the surface since 10 Ma imply a transformation of mantle structure; between approximately 15 and 10 Ma, xenoliths contained both garnet peridotite, apparently from depths of 75-135 km, and eclogite from depths of about 35-100 km. Since 3 Ma, however, xenoliths from the upper mantle contain spinel peridotite whose pressure-temperature conditions follow an asthenospheric adiabat. Thus, several authors, beginning with Ducea and Saleeby, have inferred removal of the ecslogitic and cooler peridotitic layers. Elegant theory by Canright and Morris relates the time scale for removal by Rayleigh-Taylor instability of a dense layer with a free top boundary condition. Numerical experiments have corroborated Houseman's analytic approximation for the corresponding time scale for a layer rigidly attached at its top. Further numerical experiment by Conrad confirms Houseman's scaling law for convective instability. These two scaling laws provide bounds on the time scale for removal. The average viscosity coefficient for a layer of mantle lithosphere for power-law creep that we obtain would call for average stresses in mantle lithosphere undergoing strain at 10^{-15} s^{-1} of 20-90 MPa. A comparison with laboratory-based average viscosity coefficients through the mantle lithosphere suggests low temperatures at the Moho, as do those inferred from heat flow and the older xenoliths. Thus, it appears that laboratory measurements can be extrapolated to geological time scales and conditions.

MR51A-09 1110h

The Strengthening Effect of Quartz-Particles on Synthetic Calcite Marbles: A Lost Case for Continuum Mechanics?

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The high temperature laboratory strength, σ, of synthetic two-phase marbles with small fractions of stiff quartz particles ($\leq$0.2) substantially exceeds the strength of the plastic calcite matrix. In fact, the strengthening is at odds with predictions of many continuum mechanics models. Recent efforts in describing the rheology of calcite as observed in laboratory experiments led to a composite flow law that combines a diffusion creep equation with a Peierls-type dislocation creep law. In the latter strength depends on grain size d in a way similar to a Hall-Petch relation ($\sigma \approx \sigma_0 + k \cdot d^{-m}$). Thus, for given strain rate and temperature, strength initially increases with grain size (diffusion creep: $\sigma \propto d^3$) and then decreases again asymptotically approaching a finite strength for infinite size, σ_0, that is related to the intrinsic lattice resistance to dislocation glide as determined from experiments on single crystals. Adding quartz particles of various amounts (ϕ_p) and size (d_p) systematically affects the grain size of the calcite matrix in qualitative agreement with Zener pinning ($d \propto \phi_p/d_p$). In general, adding particles reduces matrix grain size significantly compared to the pure synthetic marbles causing a microstructural strengthening when the matrix deforms in the dislocation creep regime. This source of strengthening was neglected in previous comparisons of experimental observations with calculations of the effect of load transfer between a plastically flowing matrix and rigid particles. If grain-size effects are included, the load-transfer models predict that the presence of the quartz particles changes the relative contributions of the two mechanisms considered in the composite law, increasing the contribution of dislocation creep. Combined with standard models of load transfer the composite law correctly predicts the observed behavior of the two-phase marbles. Thus, the proposed flow law would combine two expressions that depend on grain size in the opposite sense. If correct, the mechanisms would place new constraints on possible mechanisms for shear localization. For example, it is questionable whether recrystallization weakening, a hypothesis frequently assumed in interpreting the formation of shear-zones, could be reconciled with the proposed flow law. Also, our findings show that the suppression of grain growth by the presence of rigid particles does not necessarily promote diffusion creep.

MR51A-10 1125h INVITED

Deformation Experiments at Very High Pressure: What Would Goetze Think?

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New deformation machines such as the deformation-DIA (D-DIA) and rotational Drickamer apparatus (RDA), which operate at confining pressures well in excess of 5 GPa, hold the promise of directly characterizing rock rheology well into the transition zone. Until a few years ago, a sense of rock strength at such depths could be reached only by very large extrapolations based on tenuous measurements of activation volume. The D-DIA and RDA owe their creation directly to the development of bright synchrotron x radiation as an analytical tool for measuring stress and plastic strain inside pressure vessels, replacing traditional load cells and displacement transducers. The D-DIA is a 6-anvil device with the capability of independent movement of certain anvils such that pressure and maximum stress can be controlled independently. It is not unlike cubic deformation devices developed earlier (e.g., Griggs cubic anvil [Carter et al., J. Geol., 72, 687-733, 1964]), except that it is based on the more stable single-actuator hydrostatic DIA design and therefore capable of reaching pressures of 15 GPa, sufficient to cover the full pressure stability range of olivine, for example. The RDA is also an adaptation, of the 25-GPa, 2-anvil hydrostatic Drickamer cell, wherein rotary deformation is imparted by twisting one of the anvils about its axis. Both differ from all other multi-anvil, Bridgman-anvil, and diamond-anvil cells in that they are generically deformation machines: they impart strain without changing confining pressure. The D-DIA geometry is suited for measuring the state of stress in a sample; the RDA will be able to impart very high strains and will thus

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allow us to study the effect of pressure on fabric and texture development in the mantle.

Goetze had an eye for expeditious measurement and high-quality, high-impact data, a sure recipe for advancement of science when it can be achieved. His are probably the best standards for gauging the success of the new machines. Both the D-DIA and RDA have been developed in a relatively short amount of time (sizable groups of motivated investigators are involved in both projects), and mostly without unexpected technological complications. Both have strained samples at conditions approaching design limits, but neither has yet produced what Goetze would consider a meaningful measurement of the state of deviatoric stress. The new machines are solid-medium deformation apparatuses and as such bring the concern that since the medium has significant shear strength, stress measurements may be poorly resolved. There is a difference here, however: the state of stress can be measured directly in the samples themselves, thus mitigating (or even exploiting) the effects of the shear strength of the medium. Even in gas deformation rigs, the opportunity for directly viewing samples is rare; in the solid-medium rig it is unprecedented. X-ray transparent anvils may soon bring stress measurement resolution down to 10 MPa, still a huge error bar in Goetze's world. Time and experience will make the error bars smaller, hopefully to a level where the measurements will have a real impact on our picture of Earth's mantle, and the new high-pressure deformation machines will not end up consigned to the dusty basements of experimental geophysics laboratories.

MR51A-11 1145h

An Experimental Study of the Rheology of Jadeite

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Understanding the rheology of eclogite, probably governed by the behaviour of sodic pyroxenes of the diopside-jadeite solid solution series (omphacite), is essential for predictions on interplate coupling and shear heating in subduction zones and the simulation of subduction processes. We first investigated the mechanical behaviour of the end member jadeite ($NaAlSi_2O_6$). Deformation experiments were carried out on synthetic and natural jadeitite aggregates. The synthetic samples were crystallized in the stability field of jadeite from a synthetic glass precursor. A standard procedure yields uniform microstructures with an average grain size of approximately $12\mu m$. In contrast, the natural jadeitite samples from Myanmar reveal a coarse grain size and a heterogeneous microstructure. Deformation experiments were carried out at a confining pressure of 2.5 GPa in a modified Griggs apparatus using a molten eutectic CsCl/NaCl mixture. For the synthetic samples, the microstructures indicate deformation in the dislocation creep regime, with a grain shape and crystallographic preferred orientation. The mechanical data for synthetic jadeitite were fit by a power law using a global inversion method. An activation energy for dislocation creep of $Q = 326 \pm 27kJ/mol$ and a stress exponent $n = 3.7 \pm 0.4$ and a preexponential factor of $lnA = -3.3 \pm 2.0$ are found for synthetic jadeitite. The microstructure of the deformed coarse-grained natural jadeitite samples reveals inhomogeneous crystal plastic deformation and mechanical twinning. The orientation distribution of twinned and untwinned crystals yields a critical resolved shear stress of 150±25 MPa for the (100)[001] twinning of jadeite. Extrapolation of the flow law for synthetic jadeitite to a geological strain rate of $10^{-14}\ s^{-1}$ reveals that end-member jadeite is significantly weaker than diopside in the dislocation creep regime. The flow strength of pyroxenes of the omphacite solid solution series as a function of composition awaits a systematic study.

MR51A-12 1200h

Plastic Deformation and Strain-Hardening of Forsterite: a Mesoscopic Simulation

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The determination of the rheological properties of deep-Earth's minerals is one of the most challenging issues of Earth Sciences for two reasons. From the experimental point of view, it requires deformation experiments under extreme P, T conditions to be performed. On the theoretical point of view, the experimental data have to be extrapolated over several orders of magnitude in time (strain-rate) and space in order to be applied to the Earth's mantle. The latter aspect can now be addressed through the development of multiscale modelling of plastic deformation.

Significant progress have been achieved in the recent years to simulate plastic deformation of crystals at the mesoscopic scale. One can now compute the collective properties of large numbers of dislocations (e.g. several hundreds of lines) in sufficiently large model crystals, with typical linear dimensions of about 15 m. The most important achievement in this domain is certainly the development of three-dimensional simulations accounting for crystallographic effects and slip geometry initiated by Kubin and Canova.

The mesoscopic approach combines a simplified description of the core properties with the more rigorous elastic theory of dislocations, in order to understand the formation and dynamics of the microstructures of deformed specimens. Dislocation segments (edge, screw and mixed) are displaced on a discrete lattice which has the same symmetry as olivine. The dislocation segments move in response to the local effective stresses applied to them. The mobilities can vary for each slip system or dislocation character. They have been fitted to mechanical data obtained on single crystals.

In this study, we aim to simulate the strain hardening behaviour resulting from the interaction of dislocations from different slip systems. It is thus necessary to describe the interactions between dislocations from intersecting slip planes, including the formation and destruction of dislocation junctions. The stability of dislocation junctions has been investigated from the point of view of elasticity and with the simulation.

MR52A MCC: Hall C Friday 1330h

Applications of Measurements of Physical Properties of Rocks to Large-Scale Tectonic Processes II Posters

Presiding: **R J El-Khozondar,** Al-Aqsa University**; F Heidelbach,** Bayerisches Geoinstitut Universitaet Bayreuth

MR52A-0991 1330h POSTER

Numerical Simulations of Coarsening of Lamellar Structures: Applications to Pervoskite and Magnesiowüstite

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Understanding the microstructural evolution in rocks is essential to theories of the dynamics of the solid interior of the Earth. The eutectoid transformation at 660 km depth produces alternating thin lamellae of pervoskite and magnesiowüstite. We performed numerical simulations of coarsening of lamellar structures using Monte Carlo Potts model.

We find that an isotropic lamellar structure degenerates via edge spheroidization and termination migration into nearly equiaxed grains with a diameter which is 2 to 3 times larger than the original lamellar spacing. The duration of this process is comparable with the time it would take Ostwald ripening to produce grains of the same size. After degeneration of lamellar structure, grain growth quickly reaches the asymptotic regime of coarsening described by a power-law function of time. Lamellae with anisotropic grain boundaries coarsen more slowly and via discontinuous coarsening mechanism. This produces larger grains upon degeneration of lamellae.

MR52A-0992 1330h POSTER

Mechanical Behaviour and Fabric Development in Experimentally Deformed Magnesiowüstite (Mg,Fe)O as a Function of Fe-content

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In a series of tests in a HT-HP deformation apparatus ('Paterson rig') we investigated the deformation behaviour of magnesiowüstite (Mg,Fe)O in torsion at 1400 K, 300 MPa confining pressure and a strain rate of 2 x 10^{-3} s^{-1}. The Fe-content was varied from 10 to 50 at. % in steps of 10 at. %. The samples were deformed to shear strains (γ) up to 15 in order to achieve steady state microstructures and textures. The shear stress - shear strain curves showed little to no weakening after the initial yield and the strength of the samples decreased slightly with increasing Fe.

Analysis with electron backscattering diffraction (EBSD) in the SEM revealed that a crystallographic preferred orientation (texture) developed in all the samples indicating that dislocation creep contributes significantly to the deformation. Deformation is accompanied in all samples by grain size reduction. At low Fe-content (low homologous temperature) the recrystallization mechanism is progressive subgrain rotation; with higher Fe content (and increasing homologous temperatures) grain boundary mobility increases resulting in a larger recrystallized grain size at comparable shear strains.

The development of the crystallographic preferred orientation is characterized by the transition from a deformation texture (γ = 1-6) to a recrystallization texture at $\gamma > 6$. The recrystallization texture remains constant to the highest strains. The deformation texture at lower strains is consistent with dislocation glide predominant on the {111}<110> and {100}<110> slip systems, whereas the recrystallization texture cannot be modelled by dislocation glide alone. This texture evolution was observed in all the samples except those with 50 at. % Fe, where a deformation texture develops only at high shear strains and a recrystallization texture was not found. Preliminary results suggest that the slow formation of a crystallographic preferred orientation in these samples is possibly due to increased grain boundary mobility and grain growth.

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Rheology and Microstructure of (Ca,Sr)TiO_3 Perovskite Deformed in Compression and Torsion

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(Mg,Fe)SiO_3 perovskite is considered to be the most abundant phase in the Earth's lower mantle, along with magnesiowüstite and other minor high pressure phases. Therefore knowledge of the rheological properties of (Mg,Fe)SiO_3 is crucial to the understanding of the rheology of the lower mantle. Presently, deformation experiments, yeilding reliable rheological data, cannot be performed within the stabiltiy field of (Mg,Fe)SiO_3 perovskite. Fortunately, many elements can combine to form the perovskite structure and hence an analog for (Mg,Fe)SiO_3 perovskite that is stable at experimentally tractable conditions can be found. (Ca,Sr)TiO_3 is one such material, which is stable at atmospheric pressure, and undergoes two structural phase transitions between 100 and 1600 K depending on the Ca:Sr ratio. By studying the deformation behavior of (Ca,Sr)TiO_3 some insight can be gained in to the rheological properties of (Mg,Fe)SiO_3 perovskite.

Polycrystalline samples of ($Ca_{0.9}$,$Sr_{0.1}$)TiO_3 have been synthesized from high purity oxides yielding samples with <3% porosity and a grainsize of ca. 100 μm. These samples have been used to study the rheological properties of the tetragonal and cubic phases. Data from compression experiments performed over a temperature range spanning the orthorhombic to cubic phase transition show a power-law rheology with a stress exponent of ~4 and an activation energy of ~600 kJmol^{-1}. A crystallographic preferred orientation develops in the compression experiments that is consistent with [110] slip. ($Ca_{0.9}$,$Sr_{0.1}$)TiO_3 samples deformed in the cubic stability field to high strain in torsion show a comparable strength to compression tests under the same conditions. In these high-strain torsion