that separate an eclogite-bearing footwall from low-grade Devonian sedimentary basins. Previous mapping divided the allochthons into two tectonostratigraphic units: Dalsfjord Suite orthogneisses overlain by Høyvik Group paragneisses. We used zircon geochronology to unravel the complex deformation of these two units: detrital zircons from Høyvik Group quartzites yielded two distinct age populations of 1100 and 1600 Ma while Dalsfjord Suite crystalline gneisses and schists gave single zircon age populations between 1600 and 1700 Ma. These zircon age populations support new field observations that indicate that the Høyvik Group and Dalsfjord Suite represent a basement-cover unconformity that was isoclinally folded into E-vergent map-scale nappes during early contraction. Thermobarometry on coarse garnet-muscovite schists across the region indicates tectonic burial to peak pressures of 12-17 kb and 550-625 C. During late stage orogenic collapse, these nappe structures were rotated and transposed parallel to the stretching direction as the region experienced widespread extension and the Devonian Basins opened. The Devonian sedimentary basins are much less deformed than the underlying allochthons. Distal sandstones from the western Hornelen Basin yielded three distinct zircon age populations of 420, 1200 and 1700 Ma, while proximal conglomerate matrix from the eastern Hornelen Basin yielded two distinct zircon age populations of 1700 and 1000 Ma. The presence of 420 Ma zircons within the basins indicates that Caledonian metamorphic rocks must have been exhumed prior to the opening of the extensional basins.

T32F-07 1730h

Two-stage exhumation history of Miocene high-pressure, low-temperature rocks from the footwall of the Cretan detachment fault, Crete, Greece

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The island of Crete represents an emergent fore-arc high in the modern Hellenic subduction zone. The island exposes high-pressure, low-temperature metamorphic rocks (maximum P-T conditions estimated at 1 GPa, >250 C) juxtaposed against unmetamorphosed rocks by the Cretan detachment fault, a major structure that excises at least 20 km of structural section. We present new zircon (U-Th)/He data to constrain the cooling and exhumation history of the high-pressure metamorphic rocks. Additionally, we combine new stratigraphic and microstructural observations with a review of previously published thermochronologic data to create a revised interpretation of the P-T-t evolution of the lower plate. Stratigraphic constraints require that the metasediments of the lower plate were deeply subducted sometime after 36 to 32 Ma. White mica Ar-Ar ages, interpreted here as sub-closure crystallization ages, suggest peak metamorphic conditions were reached between 24 and 20 Ma. Previously published zircon He ages reveal cooling through 240 C at about 18 Ma. Our new zircon He ages show that the lower plate rocks cooled below 210 C around 10 Ma. Finally, conglomeratic deposits indicate exposure of the HP rocks at the surface at about 8.5 Ma. Exhumation rates are estimated using a one-dimensional thermal model to account for advection of isotherms and the Dodson relationship to account for the effect of cooling rate on effective closure temperature. This analysis indicates an exhumation rate of 0.7 km/m.y. during 18 to 10 Ma, followed by faster exhumation, at about 2 km/m.y., between 10 and 8.5 Ma. These rates are much smaller than previous estimates by Thomson et al. (1998) of sustained rates of 4 km/m.y. We use these results to constrain the rate of slip on the Cretan detachment, which is widely considered to have formed as a low-angle normal fault. Previous workers have argued that, given its low dip, slip on the Cretan detachment must have been 20 to 30 km/m.y., which is approaching the modern convergence rates estimated for the Hellenic subduction zone that underlies Crete (40 km/m.y.). This conclusion is in contrast to fault slip rates determined from studies of the metamorphic core complexes of the Basin and Range province, which typically are 3 to 8 km/m.y. and generally no more than 10 km/m.y. Our results indicate much slower slip rates for the Cretan detachment. Assuming that exhumation is entirely due to slip on a low angle detachment, we estimate that the slip rate was about 1.5 km/m.y. from 18 to 10 Ma, and about 4 km/m.y. after 10 Ma.

T32F-08 1745h

On-Going Regional Metamorphism Under the Japanese Islands

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Combining the phase diagrams of MORB + water, pelitic-psammitic rocks, and of peridotite + water, with thermal structure of the descending slabs of the Pacific in NE Japan and Philippine Sea (PHS) in SW Japan, and with velocity structure of sub-arc mantle, we can draw the metamorphic facies distribution of regional metamorphism, water circulation under the Japanese islands and small-scale mantle convection in the wedge mantle. The most uncertain parameter is a thermal structure calculated by numerical simulation, because of difficulty of evaluation of frictional heating, heat transportation by dehydration and mantle convection in the hanging wall. To overcome this problem, the direct seismic determination of the depth of blueschist-eclogite transformation (50-60km depth in the Pacific slab), seismogenic zone (150°C to 350°C), depth limit of tremor seismicity (Obara, 2002, dehydration limit at 40km depth, ca.500°C) slab melting in SW Japan (750-800°C at 80km depth) were used as fixed temperatures. Moreover, the thickness of Pacific MORB crust (6km) and overlying sedimentary mass (3km), Moho depth and shape of wedge mantle in both SW and NE Japan were used through the recent seismic investigations. Under the NE Japan arc, the MORB crust on the descending Pacific slab is regionally metamorphosed at 50-60km depth ca. 550°C from blueschist to amphibole eclogite to release 1.5 wt% water by the discontinuous reaction. The complex dehydration reaction of dense-hydrous silicates including antigorite occur at depths ca.200-180km from which water-rich fluids penetrate upwards into dry eclogite where it may be partially melted to form felsic magma. It may react to generate pyroxenite in the mantle wedge and become a rising wet column to cause arc magmatism as documented by the high-resolution P-wave tomographic images (Zhao et al., 1992). On the other hand, the low-T (ca.550°C) wet rising column at 50-60 km depth right above the Pacific slab hydrates the hanging wall. The two rising wet columns merge at Moho below the arc-trench gap to form a dowelling flow. The small-scale convection cell in the wedge mantle at shallow depth <200km may preserve the 3 km thick felsic regional metamorphic belt at depth range from 70-80km to 50km on the downgoing Pacific slab. On the other hand, the active volcanoes are rare in SW Japan and dip of subducting PHS plate is small, a thin wedge mantle is hydrated extensively in the oceanward half, but not in the continental side. The possible presence of thin (ca.2km) felsic materials on the PHS slab may exhume as a plastic flow against the subducting PHS slab (4cm/y) due to the small-scale corner flow in the wedge mantle.

T41A MCC: 2002-2004 Thursday 0800h

At the Seismogenic Front: Dynamic Processes at Convergent Margins I

(joint with G, S)

Presiding: **H Tobin,** New Mexico Institute of Technology**; K Ujiie,** IFREE/Japan Marine Science and Technology Center

T41A-01 0800h

What can old Rocks Tell us About the Upper Aseismic to Seismic Transition in Subduction Zones?

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At subduction zones the upper aseismic transition occurs at 5 - 15 km and at modeled temperatures of 100 to 150 deg. C. Combined studies of the structural and thermal history of subduction complexes thus allow placing rocks above or below this transition. Rocks deformed at temperatures less than 125 deg. C show an array of mesoscopically ductile and compactive deformational features that are associated with loss of intergranular fluid. Deformation zones dewater, expand into adjacent less consolidated sediment, producing intervals of stratal disruption. Stratal disruption is commonly accommodated by cataclastic shear zones or "deformation bands". Clays dominate shear zones. Such distributed deformational features and clay-dominated shear zones probably are velocity strengthening and not seismogenic. Rocks deformed at temperatures greater than 125 deg. C show overprinting of the earlier deformational features by pressure solution, with abundant precipitation of solutes as veining and cements, dominantly as calcite and quartz. Later generations of veins become cleaner with less included particulates, reflecting lithification. Cycles of cataclasis, pressure solution and precipitation repeatedly occur. As temperatures rise into the 200 degree level quartz becomes more dominant over calcite. Quartz coats and cuts across shear zones. Quartz is known to be velocity weakening; its widespread mobility and presence on and across shear surfaces at temperatures correlated to seismogenic depths suggests it may be a major factor in seismic instability. In SW Japan, an example of such repeatedly cataclastized, pressure solved rock develops pseudotachylyte, indicating seismogenic behavior. Precipitates heal fault zones that would allow fluid pressures to rise and trigger fault displacement. Studies of fluid inclusions in quartz veins suggest cyclical variations in fluid pressures although the interpretation of these results is controversial.

T41A-02 0815h

A Comparative Study on Exhumed Seismogenic Faults and Modern Nankai Seismogenic Megathrust

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One of the critical questions to understanding the seismogenic subduction zone is what controls the updip limit of the zone. The question is quite significant to address why the rupture zone stops in some case or propagates to shallow portion and results in the tsunamigenesis in another case. The Nankai trough is a single most unique subduction zone in the world, where historical repetition of large earthquakes and tsumani more than 700 years are well recorded and the updip limit is located enough shallow to drill by riser vessel. That is one of the reasons why drilling into the seismogenic plate boundary has been proposed in the Nankai Trough. Before drilling, we are conducting a comparative research on exhumed seismogenic fault in ancient accretionary complex on land, which was once located in the sesimogenic depth, and the modern Nankai Trough of targeted site for drilling. Several new findings from the exhumed rocks stimulate the understanding of the sesimogenic zone and sharpen the targets by drilling. 1. Break and involvement of oceanic basement into the accretionary complex as blocks of melange is suggested to be a seismic process because of ubiquitous brittle (cataclastic to ultracataclastic) breakage of the oceanic fragment in contrast to ductile deformation of underthrusted sediments. 2. A boundary fault such as sandstone dominated coherent unit (might be off-scraped) and mudstone dominated chaotic one (might be underthrusted) is a clear seismogenic fault and a candidate for a major seismogenic plate boundary. A discovery of pseudotachyllyte from the fault strongly suggests a melting lubrication for rupture propagation around the updip limit of the sesimogenic zone. 3. Detailed analysis of the melange and the boundary fault suggests a repeated activity of pressure solution creep (interseismic) alternated with cataclastic or melting slip (coseismic) in a thick plate boundary zone. 4. Crack seal mineral veins are also developed in and around the fault. P-T condition from H2O-CH4 fluid inclusions and vitrinite reflectance suggests the development of the veins within the seismogenic zone. Vein development especially within the fault and shale dominated part below the fault suggests the place where dehydrated fluid pool and pathway is strongly controlled by structural and lithological setting. These geologic aspects suggest the plate boundary fault around the updip limit of the seismogenic zone, which is imagined from strong reflectors on the seismic profile and is a significant target of IODP (NantroSEIZE proponents).

T41A-03 0830h

Overpressures and Lithification State of Underthrust Sediments Along the Nankai Accretionary Margin: Implications for Décollement Evolution

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Porous sediments within the frontal portions of active accretionary prisms are subject to concurrent consolidation and diagenesis during burial. The competing effects of these two processes determine the in-situ porosity and effective strength of the sediments that govern the internal structure and deformation behavior of the prism, and ultimately, the mechanical strength and evolution of the underlying décollement. New evidence from experiments carried out on Ocean Drilling Program cores collected below the frontal décollement zone along the Nankai accretionary margin, suggests that the underthrust section exists in a state of enhanced lithification, capable of resisting rapid consolidation and downcutting of the décollement. This condition has implications for the early evolution of the décollement, and subsequent behavior near the up dip limit of the seismogenic zone. Uniaxial reconsolidation tests were conducted on four samples from similar stratigraphic levels below the basal décollement and seaward proto-décollement. Initial sediment yield occurred close to predicted in-situ effective vertical stress states for three of four samples tested, indicating a landward increase in consolidation state. Compared to hydrostatic stress conditions, these results imply a progressive increase in excess pore pressures from 0.35 MPa at the seaward reference, to more than 3 MPa beneath the active prism. However, significantly higher effective vertical stresses, coincident with the peak strengths of the samples, were required before the sediments experienced measurable porosity reduction and renewed consolidation. This behavior indicates enhanced sediment lithification, a result of bonding or cemention of the grain contacts. Furthermore, the ratio of effective vertical stress at peak strength and at consolidation, referred to as sediment “sensitivity”, increases down dip. This implies increased resistance of the subducting strata to low shear stress perturbations, as might occur during aseismic slip along the décollement; this may explain why the décollement thickens by preferential incorporation of accreted rather than subducting strata. Sensitive sediments, however, can undergo dramatic failure in response to rapid increases in shear stress, e.g., seismically induced. Instantaneous collapse of the sediment matrix can lead to transient increases in pore pressure that further weaken the sediment, allowing downcutting of the décollement. The lithified condition of the underthrust package and associated deformation response, may explain the apparent downstepping of the décollement fault along the Muroto transect, near the up-dip limit of the seismogenic zone.

T41A-04 0845h

Fluid Pressure in the Shallow Plate Interface at the Nankai Trough Subduction Zone

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The factors controlling the occurrence, magnitude, and other characteristics of great earthquakes is a fundamental outstanding question in fault physics. Pore fluid pressure is perhaps the most critical yet poorly known parameter governing the strength and seismogenic character of plate boundary faults, but unfortunately cannot be directly inferred through available geophysical sensing methods. Moreover, true in situ fluid pressure has proven difficult to measure even in boreholes. At the Nankai Trough, several hundred meters of sediment are subducted beneath the frontal portion of the accretionary prism. The up-dip portion of the plate interface is therefore hosted in these fine-grained marine sedimentary rocks. ODP Leg 190 and 196 showed that these rapidly-loaded underthrust sediments are significantly overpressured near the deformation front. Here, we attempt to quantitatively infer porosity, pore pressure, and effective normal stress at the plate interface at depths currently inaccessible to drilling. Using seismic reflection interval velocity calibrated at the boreholes to porosity, we quantitatively infer pore pressure to ~ 20 km down-dip of the deformation front, to a plate interface depth of ~ 6 km. We have developed a Nankai-specific velocity-porosity transform using ODP cores and logs. We use this function to derive a porosity profile for each of two downdip seismic sections extracted from a 3-D dataset from the Cape Muroto region. We then calculate pore fluid pressure and effective vertical (fault-normal) stress for the underthrust sediment section using a compaction disequilibrium approach and core-based consolidation test data. Because the pore fluid pressure at the fault interface is likely controlled by that of the top of the underthrust section, this calculation represents a quantitative profile of effective stress and pore pressure at the plate interface. Results show that seismic velocity and porosity increase systematically downdip in the underthrust section, but the increase is suppressed relative to that expected from normally consolidating sediments. The computed pore pressure increases landward from an overpressure ratio (λ^* = hydrostatic pressure divided by the lithostatic overburden) of ~ 0.6 at the deformation front to ~ 0.77 where sediments have been subducted 15 km. The results of this preliminary analysis suggest that a 3-dimensional mapping of predicted effective normal stress in the seismic data volume is possible.

T41A-05 0900h

Structure and evolution of a splay fault system in the Tokai segment of Nankai Trough.

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The Eastern Nankai Margin was investigated within the framework of the KAIKO-SFJ project by 3D reflection imaging and dense OBS surveying, which yield complementary images of the margin above the seismogenic zone. Prominent features are reflective large scale thrusts observed within the backstop beneath the forearc basin. However, these faults are inactive and distinct from the currently active splay fault system. Subducting basement topography is defined from depth migrated sections. In this area, the volcanoes associated with the Paleo-Zenisu body are not in contact with the wedge backstop and probably lie outside of the seismogenic zone. A deeper body is present but its lateral extension is not known and the uplift and folding of the forearc basin occurred in two phases during the Quaternary and cannot be entirely related to the subduction of the imaged oceanic crust topography. Comparison with the neighbouring Tonankai segment shows the same general structure (suggesting a similar accretion history), but less affected by subducting basement topography. Active splay faults in both segments root at the seaward edge of the backstop, which suggests discontinuities in the accretionary process contribute to define the seismogenic zone. Subducting basement topography is only one factor influencing the splay fault system, which may be better understood combining dynamic branching and shear partitioning processes.

T41A-06 0915h

Kumano Seismogenic Zone Imaging and Splay Fault Property

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Splay faults or out-of-sequence thrusts (OOSTs) are prominent structure in the Nankai accretionary prism. The splay faults merging to the plate interface between the subducting Philippine Sea plate and the overriding Eurasian plate. The contact area of the splay faults and decollement plane may be a possible up-dip limit of the seismogenic zone from geological interpretation point of view. The splay faults are not continuously traced nearly parallel to the trough axis. The discontinuity of splay fault system coincides with the basement structure from magnetic anomaly map. The faults are recognized as the outer-arc-high in the Kumano accretionary wedge. The splay fault system has an important scientific target that will be clarified by drilling. A new bathymetric survey and dive observations by manned submersible are carried out in the Kumano accretionary wedge. Basic morphological interpretation and dive observations give a new insight of tectonic framework of the Kumano area. Prominent splay fault system shows transpressional fault system and associated by active folding and faulting structures. One of the splay faults shows dextral slip phenomena from en-echelon structural interpretation. Several seepage sites are discovered along the splay faults. Preliminary chemical analysis of sediment pore fluids on the splay fault shows up to 10 % depletion of chloride concentration compare with bottom seawater and extremely high methane concentration of more than 600 umol/kg (Toki et al., in prep.). A significant gamma-ray anomaly also discovered from the same site (Ashi et al.). These data suggest that the origin of fluid is significantly deep and the fluid may flow along the splay fault. A recent Tsunami inversion study suggests that the rupture area during the last large earthquake (Tonankai, 1944) spread over even the splay fault system area. The splay faults show significant differences of activities from structural interpretation of each fault. The lower fault is cut by upper one and covered by slope sediments that are not deformed. This phenomenon is confirmed by surface observations by submersibles and deep-towed camera surveys. Recent MCS survey of the JAMSTEC revealed extremely clear image of plate boundary faults between the subducting Philippine Sea plate and the Eurasian plate in the Kumano area. One of the prominent features of plate boundary at near proposed up-dip limit of seismogenic zone is the highly reflective (positive polarity) splay faults. The new data will be presented and discussed the property.

T41A-07 0930h

Some Comments on Tectonic Erosion and Sediment Subduction in Convergent Margins

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Subduction plate boundaries at which tectonic erosion removes material from the overriding plate account for 57% of the total length of the global subduction system are favored where convergence rates exceed about 6 cm/yr and where the sedimentary cover is less than 1 km. Accretion conversely preferentially occurs in regions of slow orthogonal convergence (<7.5 cm/yr) and/or trench sediment thicknesses >1 km. The slope gradients and taper angle of accretionary plate margins correlates with plate convergence rates, while erosive margin slopes appear to be independent of this. Rates of trench retreat do not appear to correlate with any simple characteristic of the plate interaction, but are largely a function of the history of seamount or ridge collisions. 55% of the total continental crustal material subducted globally below forearc regions in the modern ocean comprises material removed by tectonic erosion from the over-riding plate, 45% trench sediment. Even in accretionary margins a median of only 17% of the incoming sedimentary mass is accreted over time scales of 10 my or greater, resulting in long-term net loss of continental crust along convergent margins. Average magmatic productivity in the active margins must exceed 90 km^3/my to preserve the current volume of the continental crust. Geological arguments indicate that magmatic accretion rates must be faster in oceanic arcs (91-149 km^3/my) and less in the continental arcs (27-135 km^3/my). Mass balance arguments in oceanic arcs require that their crustal thicknesses must be <36 km and the trench retreat rate <8 km/my in order to maintain long term growth. Continental growth is principally achieved through the collision of oceanic island arcs to continental margins. Although oceanic arcs are chemically distinct from continental crust, the collision process involves the loss of mafic and ultramafic lower crust and the emplacement of voluminous, high silica, light rare earth element enriched melts, transforming the net composition into something more continental in character.

T41A-08 0945h

Low Friction Subduction Erosion, a Model to Test With Ocean Drilling

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Subduction erosion models commonly invoke concepts of high friction abrasion. We present a low friction model involving reduced strength from a disintegrating hydrofractured upper plate. Our model is constructed from features in high-resolution seafloor morphology, refraction and reflection seismic sections, and

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magnetic anomalies. It consists of a frontal prism and margin wedge upper plate underlain by a bend-faulted lower plate. The frontal prism maintains its modest width and taper in equilibrium with local conditions through feedback from subduction zone dip, friction along the decollement, and material strength. The prism elevates fluid pressure in the subducting plate forcing pore fluid into fractures above the plate interface thrust that hydrofract the underside of the upper plate margin wedge. Beneath the base of the slope, upper plate fracturing is aided by the up-and-down riffling over subducting topography. Progressive fracture and upward fluid migration shift the zone of least strength upward. The interplate thrust seeks the zone of least strength and shifts with the upward migrating fluid thereby detaching underlying upper plate material and transferring it to the lower plate. This process may begin at the seismogenic zone and progress updip to the landward part of the frontal prism. Beneath the lower slope fluid pressure and fracturing weaken the upper plate so that its strength decreases to the level of the subducting sediment. The model we propose can be tested with deep scientific ocean drilling.

T41B MCC: 3007 Thursday 0800h

The Structure and Physical Properties of Grain Boundaries in Rocks I *(joint with V)*

Presiding: **A M McCaig,** University of Leeds**; O Schenk,** Aachen University

T41B-01 0805h INVITED

Synthetic Grain Boundaries in Rock Forming Minerals

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A grain boundary may be defined as the zone separating two crystals differing in crystallographic orientation, composition, or dimension of the crystal lattice. In polycrystalline, multiphase materials, grain boundaries or phase boundaries are present in many different configurations forming three-dimensional networks very much like the networks of liquid films that A constitute foams. Physical properties of rocks, as for example, strength, electrical conductivity and diffusivity are largely controlled by grain boundary properties. Most of our present knowledge on grain boundaries stems from studies of metals and alloys. Likewise, the structure and properties of grain or phase boundaries in ceramics consisting of complex ionic and covalent compounds are well investigated. However, relatively little is known about the structure and physical properties of grain boundaries in rocks. For example, grain boundary diffusivity and mobility depend on orientation, and they are different for low and high angle grain boundaries. We successfully synthesized bicrystals of rock-forming minerals with defined grain boundaries to investigate their physical properties. We used the direct bonding technique to avoid plastic deformation of the grain boundary region. We synthesized quartz, periclase (MgO), forsterite and feldspar bicrystals. In addition, we successfully produced a forsterite bicrystal directly from a melt using the Czochralski method. For each direct bonded bicrystal two oriented mineral single crystals were joined at room temperature and annealed at 400°C for one week. All bicrystals were cut in two parts and one part was annealed further at 0.9 T_m for 48h. Specimens were prepared for investigation in the transmission electron microscope (TEM) using the focused ion beam (FIB) technique. High-resolution TEM studies reveal similar grain boundary structures produced at 400°C and at 0.9 T_m between undisturbed crystals. This suggests that bonding of bicrystals was effective at or below 400°C. Common structural elements of the synthetic grain boundaries encompass dislocations, steps and disconnections.

T41B-02 0825h INVITED

The Effect of Magnesium on Diffusion in Calcite Under Static and Deformational Conditions

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In order to test the influence of solute impurities on diffusion creep and static grain growth, synthetic calcite aggregates with variable Mg contents were tested. The synthetic marbles were produced by HIPing different mixtures of dry calcite and dolomite powders at 1123K for 2 hours. During the HIP, chemically induced grain boundary migration occurred via a combination of diffusion processes and chemically induced grain boundary migration. After HIP, creep tests were performed at 300 MPa and temperatures in the range of 923-1123K. Creep experiments on aggregates with small grain sizes show that the strength of calcite aggregates correlates inversely with dissolved Mg content at flow stresses below 40 MPa. However, under static conditions, grain growth rates decrease with increasing Mg content. Thus, the inverse correlation between strength and Mg content appears to arise from suppression of grain size with increasing Mg content, i. e., the effect of Mg on strength is indirect through an extrinsic control of calcite grain size, rather than an extrinsic control on grain boundary diffusion rate during deformation. Creep tests in the diffusion creep field for samples with identical grain size, but with variable Mg content, revealed no dependence of strength on the Mg content. The creep tests seem to indicate that the rate controlling step during self-diffusion is not affected by changes in the Mg concentration. It is possible that solid solutes are segregated to the calcite grain boundaries and that impurity drag affects the boundary mobility, but not the self-diffusion rate.

T41B-03 0845h

Rapid Diffusion of Ca Along Migrating Grain Boundaries in Calcite

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Grain boundary diffusion is an important process at moderate to high homologous temperatures and one that has the potential to redistribute isotopes and other chemical species over significantly greater length scales than volume diffusion alone. When the grain boundaries are moving, this redistribution can be greatly enhanced because the incorporation of tracers into the grain interiors is not limited by the short length scale of volume diffusion, as it is in the case of static boundaries. An experimental charge consisting of a layer of fine (< 5 μm) calcite powder containing 25% ^{44}Ca-enriched calcite (98% ^{44}Ca compared with the natural abundance of 1.95%) was sandwiched between cylinders of single crystal calcite and Carrara marble and hot isostatically pressed at 900 °C 200 MPa for 10 hours. Examination of the experimental run products using the SEM in orientation contrast mode shows that during the experiment the fine calcite layer underwent static recrystallization followed by normal grain growth. The resulting mean grain size was 60-80 μm. The single crystal also statically recrystallized in a 5 mm wide layer immediately adjacent to the powder layer. The resulting grain size was 100 μm to 1 mm. The driving force for this latter recrystallization was the small amount of strain energy introduced during the initial pressurization of the charge as the powder layer compacted. There were no noticeable changes in the Carrara marble layer, which retained its initial grain size of about 150 μm. Isotopes ^{44}Ca and ^{40}Ca were imaged using the Cameca ims4f microprobe at Edinburgh University, and ion beam traverses were also made with an estimated effective beam diameter of 5 μm. Combined images of ^{44}Ca/(^{44}Ca+^{40}Ca) reveal extensive but very heterogeneous zoning of ^{44}Ca in the recrystallized single crystal, and relict cores of ^{44}Ca-enriched calcite in recrystallized grains in the powder layer. On the whole the powder layer homogenised to a composition of 22-24% ^{44}Ca, and provided a fairly fixed composition source of ^{44}Ca to diffuse into the recrystallizing single crystal. Penetration into the single crystal along mobile grain boundaries was extensive, with zones of up to 8% ^{44}Ca present locally at > 300 μm from the tracer layer. Complex isotopic zoning patterns are interpreted to result primarily from variations in boundary migration velocity. There is good evidence that parts of the original single crystal have been swept by multiple grain boundaries, and that some boundaries reversed migration direction. Mishin and Razumovski (1992) developed an analytical model for the concentration (C) of tracer in a grain behind a grain boundary that is moving parallel to an interface beyond which there is a constant composition source of tracer. They found that the gradient reaches a steady state given by $d(\ln C)/dx = (V/D_{GB}\delta)^{0.5}$, where V is the velocity of migration, D_{GB} the grain boundary diffusion coefficient and δ the grain boundary width. Although our grain geometries are more complex and our ion probe profiles are not ideally located, it is possible to estimate maximum values for d(lnC)/dx parallel to moving boundaries and minimum values for V based on the width of compositional zones and the duration of the experiment. We estimate **minimum** values for $D_{GB}\delta$ of 10^{-18} m^3/s, about 500 times greater than the value reported by Farver and Yund (1996) in static grain boundaries.

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Diffusion-Controlled Reaction rim Growth Studied in Thin Films Down to the Nano Scale

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Grain boundaries play a crucial role for diffusion in polycrystalline materials. Diffusion through polycrystalline rims of enstatite-rich pyroxene was studied in pulsed-laser deposited thin films [1] by the rim growth method. The starting samples consisted of layers of isotopically doped (^{18}O, ^{29}Si) olivine $fo_{90}fa_{10}$ (c. 500 nm thick) and pyroxene $en_{90}fs_{10}$ (c. 100 nm thick) on a polished quartz surface. Annealing experiments were performed at temperatures between 1000 and 1200 °C at fO_2 of 10^{-10} bar. Layer thickness and composition were measured by Rutherford Back-Scattering (RBS) and TEM using Focused Ion Beam preparation methods. O and Si isotope profiles were measured by SIMS depth scanning. The miniaturization of the layer assembly allows one to study growth at lower temperatures than previously possible and avoids large extrapolations to natural conditions. During the experiments the enstatite layers thicken by rates for ΔX^2 of 700 to 50000 nm^2/h at the chosen conditions. An activation energy of 398±30 kJ/mol was derived. The rim growth rates are slightly slower than expected from an extrapolation of high temperature data (1350-1450 °C) [2] but yield the identical activation energy, suggesting that rim growth over the entire temperature range is controlled by the same diffusion mechanism and that this is valid down to the nano scale. At 1000 °C enstatite rim growth in our dry experiments is slower by about 4 orders of magnitude than in high pressure experiments at 7 [3] resp. 10 kbar [4] in the presence of small amounts of H_2O. The isotope concentration profiles reveal that Si acts as a slow diffusing component compared to O. Effective diffusion coefficients D_{eff} for Si were derived from the SIMS profiles using a moving boundary diffusion model. $D_{eff}{}^{Si}$ in the dry polycrystalline enstatite rims is 2-3 orders of magnitude smaller than in polycrystalline olivine under similar conditions [5]. At 1000 °C $D_{eff}{}^{Si}$ is 4 orders of magnitude smaller than in enstatite rims during hydrous high pressure experiments [6]. Ref.: [1] Dohmen et al. (2002) Eur J Miner 14: 1155-1168; [2] Fisler et al. (1997) Phys Chem Minerals 24: 264-273; [3] Yund (1997) Contrib Miner Petrol 126: 224-236; [4] Milke et al. (2001) Contrib Miner Petrol 142: 15-26; [5] Farver & Yund (2000) Geophys Res Letters 27, 2337-2340; [6] Abart et al (2002) J Conf Abs 7, 4

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Grain Growth Kinetics of Dolomite and Magnesite

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