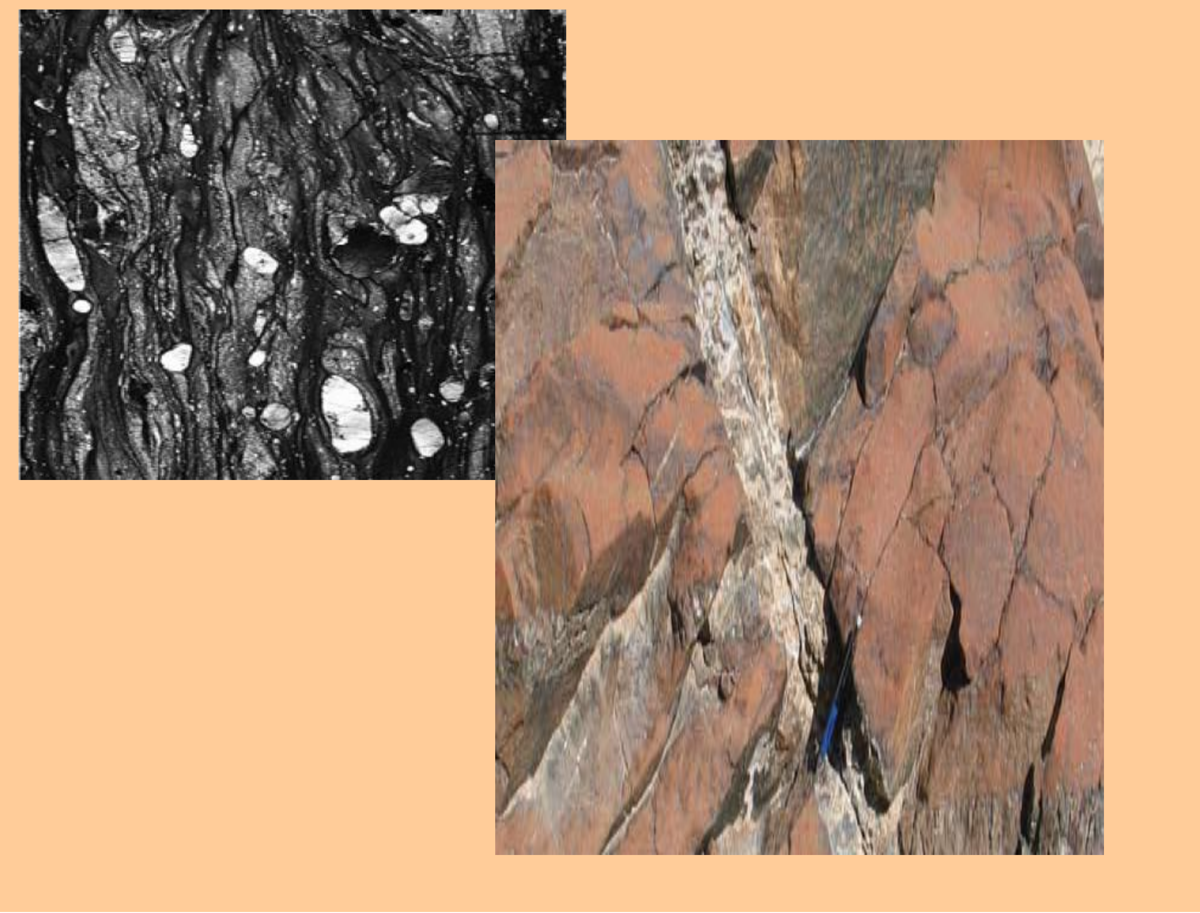
AGU Chapman Conference on Shallow Mantle Composition and Dynamics Fifth International Orogenic Lherzolite Conference



Mount Shasta, CA, USA
22-26 September 2008

AGU Chapman Conference on Shallow Mantle Composition and Dynamics Fifth International Orogenic Lherzolite Conference
31st Anniversary of Chapman Conference on Partial Melting in the Earth's Upper Mantle

MOUNT SHASTA RESORT, MOUNT SHASTA, CALIFORNIA, USA
22–26 SEPTEMBER 2008

Program Committee (AKA Organizing Committee, most affiliations as above)
Peter Kelemen, Martin Menzies, Jean-Louis Bodiner, Henry Dick, Françoise Boudier, Greg Hirth, Tim Grove (MIT), Christophe Lécuyer (Université Claude Bernard Lyons, France), Andrea Tommasi (Université de Montpellier, France), Eiichi Takazawa (Niigata University, Japan)

Conveners (AKA Scientific Committee)
Principal Conveners: Peter B. Kelemen (Columbia University) and Henry J.B. Dick (Woods Hole Oceanographic Institution, WHOI)

Primary Conveners
Martin Menzies (Royal Holloway University, U.K.), Jean-Louis Bodiner (Université de Montpellier, France), Masaaki Obata (Kyoto University, Japan), Giovanni Piccardo (Università di Genova, Italy), Dave Kohlstedt (University of Minnesota), Greg Hirth (WHOI), Françoise Boudier (Université de Montpellier, France); Additional Conveners: Shoji Arai (Kanazawa University, Japan), Fred Frey (MIT), Al Hofmann (Max Plank, Mainz, Germany), Adolphe Nicolas (Université de Montpellier, France), Kaz Ozawa (Tokyo University, Japan), Elisabetta Rampone (Università de Genova, Italy), Nobu Shimizu (WHOI), Riccardo Vannucci (Università di Pavia, Italy), Reinoud Vissers (Utrecht University, Netherlands)

Meeting at a Glance

Sunday, 21 September 2008

6:00 p.m. – 8:00 p.m.	Welcome Reception & Buffet Dinner

Monday, 22 September 2008

7:15 a.m. – 8:15 a.m.	Continental Breakfast
8:15 a.m. – 8:30 a.m.	Conference Introduction
8:30 a.m. – 10:00 a.m.	Oral Sessions
10:00 a.m. – 10:30 a.m.	Coffee Break
10:30 a.m. – 12:30 p.m.	Oral Sessions
12:30 p.m. – 1:30 p.m.	Lunch
1:30 p.m. – 3:00 p.m.	Oral Sessions
3:00 p.m. – 3:30 p.m.	Coffee Break
3:30 p.m. – 5:00 p.m.	Oral Sessions
5:00 p.m. – 6:30 p.m.	Poster Session and Refreshments
6:30 p.m. – 7:30 p.m.	Dinner (Banquet Style)
7:30 p.m. – 8:30 p.m.	Oral Sessions

Tuesday, 23 September 2008

7:30 a.m. – 8:30 a.m.	Continental Breakfast
8:30 a.m. – 10:30 a.m.	Oral Sessions
10:30 a.m. – 12:00 p.m.	Poster Session and Refreshments
12:00 p.m. – 1:00 p.m.	Lunch
1:00 p.m. – 2:30 p.m.	Oral Sessions
2:30 p.m. – 3:00 p.m.	Coffee Break
3:00 p.m. – 5:00 p.m.	Oral Sessions
5:00 p.m. – 5:30 p.m.	Refreshment Break
5:30 p.m. – 7:30 p.m.	Oral Sessions
7:30 p.m. –.	Dinner (On your own)

Wednesday, 24 September 2008

7:30 a.m. – 8:30 a.m.	Continental Breakfast
8:30 a.m. – 10:00 a.m.	Oral Sessions
10:00 a.m. – 10:30 a.m.	Coffee Break
10:30 a.m. – 12:00 p.m.	Oral Sessions
12:00 p.m. – 7:30 p.m.	Field Trip (Lunch Provided)
7:30 p.m. – 8:30 p.m.	Buffet dinner

Meeting at a Glance

Thursday, 25 September 2008

7:30 a.m. – 8:30 a.m.	Continental Breakfast
8:30 a.m. – 10:00 a.m.	Oral Sessions
10:00 a.m. – 10:30 a.m.	Coffee Break
10:30 a.m. – 12:30 p.m.	Oral Sessions
12:30 p.m. – 1:30 p.m.	Lunch
1:30 p.m. – 3:00 p.m.	Oral Sessions
3:00 p.m. – 3:30 p.m.	Coffee Break
3:30 p.m. – 5:00 p.m.	Oral Sessions
5:00 p.m. – 6:30 p.m.	Poster Session and Refreshments
6:30 p.m. – 7:30 p.m.	Dinner (Banquet Style)
7:30 p.m. – 8:30 p.m.	Oral Sessions

Friday, 28 September 2007

7:30 a.m. – 8:30 a.m.	Continental Breakfast
8:30 a.m. – 10:00 a.m.	Oral Sessions
10:00 a.m. – 10:30 a.m.	Coffee Break
10:30 a.m. – 12:30 p.m.	Oral Sessions
12:30 p.m. – 1:30 p.m.	Lunch
1:30 p.m. – 2:30 p.m.	Oral Sessions
2:30 p.m. – 3:00 p.m.	Coffee Break
3:00 p.m. – 5:00 p.m.	Oral Sessions
5:00 p.m. – 6:30 p.m.	Poster Session and Refreshments
6:30 p.m. – 7:30 p.m.	Oral Sessions
7:30 p.m. –	Dinner (On your own)

Program Overview

Sessions and events will take place at the Mount Shasta Resort, Mount Shasta, CA. The Registration/Information Desk will be in Siskiyou foyer throughout the conference.

SUNDAY, 21 SEPTEMBER

6:00 p.m. – 8:00 p.m. ♦ **Welcome Reception** ♦ Mount Shasta Resort, Outdoor Reception Area. All meeting attendees are invited to attend this kick-off event. Enjoy a relaxing evening with friends and colleagues. A buffet dinner will be provided and drinks will be available for purchase.

MONDAY, 22 SEPTEMBER

7:15 a.m. **Continental Breakfast** ♦ Siskiyou Room

8:15 AM **Welcome and Opening Remarks** ♦ Siskiyou Room
Convener: Peter Kelemen

Session 1: Rheology, Chair: Kohlstedt

8:30 AM **Warren, Jessica** *Observations of strain localization and olivine lattice preferred orientation in Josephine Peridotite Shear Zones*

9:00 AM **Skemer, Phil** *Microstructural and rheological evolution in naturally deformed peridotite mylonites*

9:30 AM **Obata, Masaaki** *Shear localization, seismic rupture and frictional melting, observed in a mylonitized ultramafic pseudotachylyte from Balmuccia peridotite, Ivrea Zone, N. Italy*

10:00 AM Coffee Break

10:30 AM **Newman, Julie** *Fabric and texture superposition in upper mantle peridotites, Red Hills, New Zealand*

11:00 AM **Tikoff, Basil** *Field-based constraints on rheology of the lithospheric mantle, Twin Sisters, Washington*

11:30 AM **Hirth, Greg** *The rheology of mantle shear zones*

12:00 PM **Behn, Mark** *Implications of grain-size evolution on the seismic structure of the oceanic upper mantle*

12:30 PM Lunch ♦ Outdoor Reception Area

1:30 PM **Tommasi, Andrea** *Structural reactivation during continental deformation due to anisotropy in the mantle lithosphere*

2:00 PM **Faul, Uli** *The Effect of Melt on the Deformation Behavior of Olivine*

2:30 PM **King, Dan** *Formation of melt-rich bands in experimentally deformed partially molten rock: Microstructural evolution and scaling to Earth's mantle*

3:00 PM Coffee Break

3:30 PM **Kaczmarek, Mary-Alix** *The influence of melt impregnation and high temperature shear zone on peridotite geochemistry in the upper mantle (Lanzo Italy)*

4:00 PM **Le Roux, Veronique** *The Lherz Massif: 2 Ga history of mantle evolution*

4:30 PM **von der Handt, Annette** *On Plagioclase Peridotites and Silica Activity*

5:00 PM **Poster Session (with refreshments) – Rheology & Ridges** ♦ Highland Room

R-01 • Sundberg, Marshall *Diffusion Creep of Harzburgite*

R-02 • Hanke, Karin *An experimental investigation of the brittle-transition of Åheim dunites*

R-03 • Homburg, Janelle *The viscosity contrast between the lower crust and upper mantle*

R-04 • Barnhoorn, Auke *Low viscosity garnet layers in the upper mantle*

R-05 • Kelemen, Peter *A periodic shear-heating mechanism for intermediate-depth earthquakes in the mantle*

R-06 • Obata, Masaaki *Contrasting fabric patterns of olivine observed in garnet- and spinel-peridotite from a single ultramafic mass enclosed in acidic granulite, Moldanubiam zone, Czech Republic*

R-06 • Piccardo, Giovanni *Seismogenetic shear zones in the mantle lithosphere: ultramafic pseudo-tachylytes in the Lanzo peridotite (Western Alps, NW Italy).*

R-08 • Toy, Virginia *Evolution of a high-temperature, harzburgite-hosted shear zone, Twin Sisters massif, NW Washington*

R-09 • Ueda, Tadamasa *Mylonitized ultramafic pseudotachylyte and associated deformation textures, Balmuccia peridotite massif, Ivrea Zone, Italy*

R-10 • Andronicos, Christopher *Melt-filled hybrid fractures in the oceanic mantle: Melt enhanced deformation during along-axis flow beneath a propagating spreading ridge axis*

R-11 • Siftar, Gordana *Grain Size Dependence of the Melt Geometry in Partially Molten Olivine Aggregates*

R-12 • Vauchez, Alain *How olivine [010]-fiber CPO did reconcile conflicting surface wave and body wave anisotropy observations in the Kerguelen Islands area*

R-13 • Soustelle, Vincent *Deformation and fluid-rock interactions in peridotite xenoliths from the Avacha calc-alkaline volcano, south Kamchatka subduction zone*

R-14 • Kruckenberg, Seth *Relationships between compositional layering, structural fabric, and the formation of melt pathways in the Twin Sisters complex, Washington State*

R-15 • Blackman, Donna *Numerical models of mantle flow & seismic anisotropy in Lau Basin*

R-16 • Boudier, Francoise *Large Shear Zones with No Relative Displacement*

R-17 • Jagoutz, Oliver *The rift-to-drift transition in the North Atlantic: A stuttering start of the MORB machine?*

6:30 PM Dinner♦ Outdoor Reception Area

7:30 PM **Riches, Amy** *The Nature of Harzburgite-Lherzolite Outcorps; The Lherz Massif*

8:00 PM **Bodiner, Jean-Louis** *Chemical variations in tectonically-emplaced mantle rocks: superimposed effects of partial melting, melt redistribution and igneous refertilization*

TUESDAY, 23 SEPTEMBER

7:30 a.m. **Continental Breakfast** ♦ Siskiyou Room

Session 3: Mid-Ocean Ridges, Chair: Hirth

8:30 AM **Takazawa, Eiichi** *Geochemical variability of the Fizh mantle section, Oman ophiolite with relevance to paleo-ridge segment structure*

9:00 AM **Boudier, Francoise** *Aspects of Ridge Segmentation in the Oman ophiolite*

9:30 AM **Piccardo, Giovanni** *Asthenosphere-lithosphere interaction at an extensional setting: Insights from the Alpine-Appenine peridotites*

10:00 AM **Rampone, Elisabetta** *Melt migration and intrusion during extension-related uplift of the Tallante lithospheric mantle (Betic Cordillera, SE Spain) as recorded by peridotite xenoliths*

10:30 AM Poster Session (with coffee & pastries) – Ridges & Petrology, ♦ Highland Room

RP-01 • Hellebrand, Eric *Chromite-hosted hydrous melt inclusions in oceanic dunites*

RP-02 • Hellebrand, Eric *Inherited depletion in the oceanic mantle*

RP-03 • Tamura, Akihiro *Geochemistry of residual peridotites from the Atlantis Massif, MAR 30°N: Inter- and intra-grain variations of clinopyroxene trace-element compositions*

RP-04 • Nagashima, Ryoko *Crystallographic orientations of symplectite minerals from the Horoman peridotites*

RP-05 • Sergeev, Dmitri *The origin of mantle pyroxenites in the Pindos Ophiolite, NW Greece*

RP-06 • Durant, Troy *Evidence and Implications of an Off-Axis Crustal Magma Chamber Along the East Pacific Rise*

RP-07 • Stremmel, Kolja *How to build a Pluton: Insights from Mapping Gabbro-Bodies in the Trinity Ophiolite*

RP-08 • Suhr, Günter *Trace elements in peridotites from Hole 1274A, ODP Leg 209 and their relation to magmatism and alteration*

RP-09 • Warren, Jessica *Mantle Refertilization: The Perspective From Abyssal Peridotite Compositions*

RP-10 • Rampone, Elisabetta *Melt Mirgration and Intrusion in the Erro-tobbio Peridotites (Ligurian Alps, Italy): Insights on Magmatic Processes in Extending Lithospheric Mantle*

RP-11 • Rampone, Elisabetta *The Spinel-Plagioclase Transition in the Shallow Upper Mantle: Subsolidus Experiments on Fertile and Depleted Lherzolite*

RP-12 • Martin, Adam *5-Phase Plagioclase-Spinel Lherzolite, Antarctrica*

RP-13 • von der Handt, Annette *Spinel in plagioclase peridotites as petrogenetic indicator*

RP-14 • von der Handt, Annette *A new potential geospeedometer for ultramafic rocks*

RP-15 • Liang, Yan *Mineral Compositional Variations in Dunite Bodies from the Trinity and Josephine Ophiolites*

RP-16 • Obata, Masaaki *A progressive increase of clinopyroxene sodium content in kelyphite after garnet from a Czech Moldanubian garnet peridotite*

RP-17 • Jean, Marlon *In-Situ LA-ICP-MS Analysis of Pyroxene in the Periodotite of the Cost Range Ophiolite, California*

12:00 PM Lunch ♦ Outdoor Reception Area

1:00 PM **Dick, Henry** *The Top of the Oceanic Mantle - How it Varies and What it Tells Us About MORB Generation*

1:30 PM **Müntener, Othmar** *Role of a mantle exhumation channel in the formation of ultramafic seafloor*

2:00 PM **Snow, Jon** *What does the Arctic Ridge System tell us about all mantle peridotites?*

2:30 PM Coffee Break

3:00 PM **Suhr, Günter** *Stacked gabbro units and intervening mantle: a detailed look at a section of IODP Leg 305, Hole 1309D*

3:30 PM **Hellebrand, Eric** *An Overview of Subsolidus Processes Relevant for Abyssal Peridotites*

4:00 PM **Djikstra, Arjan** *Abyssal peridotites on Macquarie Island - old (ancient?) depletion and recent melt percolation*

4:30 PM **Phipps Morgan, Jason** *Modelling mantle flow and deformation beneath mid-ocean ridges*

5:00 PM Refreshment Break

Session 4: Dynamics, Chair: Obata

5:30 PM **Presnall, Dean** *Plumes vs Propagating Fractures in the Ocean Basins*

6:00 PM **Anderson, Don** *The Eclogite Engine and the Subterranean Cycle*

6:30 PM **Till, Christy** *H2O-Saturated Peridotite Melting Behavior from 3-5+ GPa*

7:00 PM **Hirschmann, Marc** *Pyroxenites in basalt source regions? A review*

8:00 PM Dinner On Your Own

WEDNESDAY, 24 SEPTEMBER

7:30 a.m. **Continental Breakfast**♦ Siskiyou Room

Session 4: Dynamics, Chair: Yogodzinski

8:30 AM **Davis, Fred** *Low-degree partial melting of peridotite KLB-1 at 3 GPa. from Re melt traps and modified iterative sandwich experiments (MISE)*

9:00 AM **Rapp, Bob** *Transformative reactions between "primitive" silica-rich melts and mantle peridotite*

9:30 AM **van den Bleeken, Greg** *Controls on reaction processes between tholeiitic melt and residual peridotite in the uppermost mantle: An experimental study at 0.8 GPa*

10:00 AM Coffee Break

10:30 AM **Tenner, Travis** *The effect of water on the partial melting of peridotite at 3 GPa*

11:00 AM **Parmentier, Marc** *The effect of mantle flow and buoyant fluid migration on melting beneath convergent plate boundaries*

11:30 AM **Grove, Tim** *Field trip to Mt. Shasta and vicinity, northern California, USA*

12:00 PM Lunch – box lunch will be provided

12:00 PM Mt Shasta Volcano Field Trip

7:30 PM Buffet Dinner♦ Outdoor Reception Area

THURSDAY, 25 SEPTEMBER

7:30 a.m. **Continental Breakfast**♦ Siskiyou Room

Session 4: Dynamics, Chair: Lee

8:30 AM **Holtzman, Ben** *Coupled Melt Extraction and Lithosphere Lubrication at Plate Boundaries*

9:00 AM **Soustelle, Vincent** *Deformation and reactive melt transport in the mantle lithosphere above a large-scale partial melting domain: the Ronda peridotite massif, S Spain*

9:30 AM **Jagoutz, Oli** *Differential movement in the upper mantle due to focused melt percolation*

10:00 AM Coffee Break

10:30 AM **Ozawa, Kazuhito** *Origin of refractory dunite bodies in harzburgite*

11:00 AM **Liang, Yan** *Grain Growth and Grain Size Reduction during Melt-rock Reaction in the Mantle*

11:30 AM **Parman, Steve** *Episodic Mantle Melting Recorded by Osmium Isotopes*

12:00 PM **Schutt, Derek** *The density of melt-depleted lherzolite, and its implications for convective destabilization of the Wyoming Craton*

12:30 PM Lunch♦ Outdoor Reception Area

Session 5: Cratonic Mantle, Chair: Müntener

1:30 PM **Luffi, Peter** *Composition of the Mojave lithospheric mantle: depletion or refertilization trend?*

2:00 PM **Roy, Mousumi** *Cenozoic magmatism and rock uplift of the Colorado Plateau by warming of chemically buoyant lithosphere*

2:30 PM **Hidas, Karoly** *Significance of C-O-H-S bearing fluids and melts in the sub-continental lithospheric mantle of the central Pannonian Basin (W-Hungary)*

3:00 PM Coffee Break

3:30 PM **Szabo, Csaba** *General geochemical and rheological features of the lithospheric mantle beneath the Carpathian-Pannonian Region*

4:00 PM **Canil, Dante** *Were deep cratonic mantle roots hydrated in an Archean ocean?*

4:30 PM **Lee, Cin-Ty** *The role of serpentine in preferential craton formation in the late Archean by lithosphere underthrusting*

5:00 PM **Poster Session (with refreshments) – Arcs & Dynamics**♦ Highland Room

A-01 • Yogodzinski, Gene *Contrasting MOHO Temperatures Inferred from Ultramafic Xenoliths at Kharchinsky & Shiveluch Volcanoes, Kamchatka Arc*

A-02• Conder, James *Arc and backarc melt production and interaction of the Mariana system from geodynamical modeling*

A-03 • Lee, Changyeol *Partial Melting of the Mantle Wedge and the Subducting Slab Using a Numerical Subduction Model*

A-04 • Brown, Eric *Identifying the Roles of Potential Temperature, Active Upwelling and Source Lithology in Enhancing Melt Production in Large Igneous Provinces*

A-05 • Schutt, Derek *Three Studies on the Relationship Between Temperature and Composition, and Velocity and Density, in the Upper Mantle*

A-06 • Lee, Cin-Ty *Constraints on the depths and temperatures of basaltic magma generation: implications for planetary thermal states and differentiation processes*

A-07 • Bernstein, Stefan *Consistent olivine Mg# in cratonic mantle reflects Archean mantle melting to the exhaustion of orthopyroxene*

A-08• Bell, David *Melt-rock reaction origins of kimberlite megacryst suites and the physical-chemical structure and evolution of the continental upper mantle beneath southern Africa*

A-09 • Facer, John *Hydrous fluid metasomatism in spinel dunite xenoliths from the Bearpaw Mountains, Montana, USA*

A-10 • Zanetti, Alberto *Evidence for different styles of alkaline metasomatism during compressive continental rifting as recorded by mantle xenoliths from Mid Atlas (Morocco)*

A-11 • Kil, Young-Wu *Characteristics of subcontinental lithospheric mantle beneath Asan and Pyeongtaek, Korea*

A-12 • Luffi, Peter *Composition of the Mojave lithospheric mantle: depletion or refertilization trend?*

A-13 • Piccardo, Giovanni *The extreme structural and compositional variability of the Lanzo peridotites (Western Alps, NW Italy)*

A-14 • van den Bleeken, Greg *Controls on reaction processes between tholeiitic melt and residual peridotite in the uppermost mantle: An experimental study at 0.8 Gpa*

A-15 • Andronicos, Christopher *A composite geologic and seismic profile beneath the southern Rio Grande rift, New Mexico, based on xenolith mineralogy, temperature, and pressure*

A-16 • Roy, Mousumi *Models of mantle deformation and fabric beneath the San Andreas Fault: implications for seismic anisotropy*

A-17 • Anthony, Libby *Peridotite Xenoliths From Recent Eruptions In Western North America Correlations With Geophysical Survey*

6:30 PM Dinner ♦ Outdoor Reception Area

7:30 PM **Bell, David** *Subcalcic garnet peridotites, diamond formation, and the evolution of cratonic mantle lithosphere.*

8:00 PM **Pearson, Graham** *Genesis of cratonic lithosphere - a role for water and subduction*

FRIDAY, 26 SEPTEMBER

7:30 a.m. **Continental Continental Breakfast** ♦ Siskiyou Room

Session 6: Mantle Geochem, Chairs: Frey, Menzies

8:30 AM **Dasgupta, Raj** *Role of Minute Carbonatitic Melt in Mantle Geochemistry*

9:00 AM **Stracke, Andreas** *The importance of melt extraction for inferring mantle composition*

9:30 AM **White, Bill** *The Trace Element Signature of Recycled Oceanic Crust in the Mantle*

10:00 AM Coffee Break

10:30 AM **Coggon, Jude** *New constraints on the origin of Roberts Victor eclogites: geochemical evidence for a subducted arc or back-arc basalt protolith*

11:00 AM **Sobolev, Alex** *Crustal Recycling and Osmium Isotopes linked*

11:30 AM **Nowell, Geoff** *Laser ablation Pt-Re-Os chronometry: applications to dating mantle melt infiltration events and constraining ophiolite emplacement ages*

12:00 PM **Shervais, John** *Geochemical Flux in the Mantle Wedge: Insights from Suprasubduction Zone Ophiolites*

12:00 PM Lunch ♦ Outdoor Reception Area

1:30 PM **Nakamura, Eizo** *Isotopic (Pb-Nd-Hf) evidence for a hidden extremely depleted mantle domain from the Horoman peridotite massif, Japan*

2:00 PM **Morishita, Tamoaki** *Orthopyroxene-rich lithologies in the Horoman Peridotite Complex, Japan: as a product of partial melting of heterogeneous mantle*

2:30 PM Coffee Break

Session 7: Low Temperature Geochem, Chair: Suhr

3:00 PM **Evans, Bernard** *The phase equilibrium control of serpentinization*

3:30 PM **Kaszuba, John** *Experimental Investigations of the Potential to Sequester CO2 in Oceanic Crust*

4:00 PM **Johnson, Orion** *Geochemistry and microbial ecophysiology of The Cedars ultrabasic springs*

4:30 PM **Sonnenthal, Eric** *Multi-Continuum Reaction Transport Modeling of Low-Temperature Alteration*

5:00 PM **Poster Session (with refreshments) - Geochemistry, High Low** ♦ Highland Room

G-01 • Dasgupta, Raj *Compositions of HIMU, EM1, and EM2 from Global Trends between Radiogenic Isotopes and Major Elements in Ocean Island Basalts*

G-02 • Kelemen, Peter *High Pb/Ce reservoir in depleted, altered mantle peridotites*

G-03 • Tribuzio, Riccardo *Trace element and Nd-Hf-O isotope compositions of garnet clinopyroxenite layers from the External Liguride mantle peridotites (Northern Apennine ophiolites, Italy): insights into garnet facies mantle processes*

G-04 • Menzies, Martin *Eclogites and garnet pyroxenites: similarities and difference*

G-05 • Abe, Natsue *Petrochemistry and geophysics of the petit-spot volcanism*

G-06 • Kil, Young-Wu *Origin of late Miocene volcanic rocks in Asan and Pyeongtaek, Korea: Nature of source mantle and magma pathway to surface*

G-07 • Montanini, Alessandra *Origin of graphite and sulphides in garnet clinopyroxenite layers from the External Liguride mantle peridotites (Northern Apennine ophiolites, Italy)*

G-08 • Rajesh, V.J. *Genesis of unusual high-Mg low-Ni dunites in Achankovil Shear Zone, South India*

G-09 • Boudier, Francoise *Serpentinization Process: the Initial Stage*

G-10 • Canovas, Peter *Alteration of Peridotites and Basalts to Meet Microbial Energy Demands*

G-11 • Johnson, Orion *Low temperature geochem of alkaline springs in serpentinizing peridotite*

G-12 • Morrill, Penny *Sources of hydrocarbons at The Cedars, a site of active serpentinization in N. California*

G-13 • Streit, Lisa *Carbonation and serpentinization of peridotite in the Samail Ophiolite*

G-14 • Suhr, Günter *Evidence for prograde metamorphism in a dunite body from the Trinity Ophiolite (Cabin Meadow Lake)*

6:30 PM **Shock, Everett** *Ultramafic Alteration and Organic Synthesis*

7:00 PM **Kelemen, Peter** *In situ carbonation of peridotite for CO2 capture and storage*

7:30 PM Dinner – ♦ On Your Own

Abstracts

Session Type: *Poster Presentation*

PETROCHEMISTRY AND GEOPHYSICS OF THE PETIT-SPOT VOLCANISM

N Abe[1], N Hirano[2], K Baba[3], T Fujiwara[1], A Shito[1], H Hamamoto[3], S Machida[4], J Yamamoto[5], A Ito[1], A Takahashi[6], Y Koike[1]

1. IFREE, JAMSTEC, 2. Laboratory for Earthquake Chemistry, University of Tokyo, 3. Earthquake Research Institute, University of Tokyo, 4. Ocean Research Institute, University of Tokyo, 5. Woods Hole Oceanographic Institution, 6. School of Science, University of Tokyo

Petit-spot is a young volcanic field (<1 Ma) discovered on the Early Cretaceous (~130 Ma) northwestern Pacific Plate. The volcanoes belong to petit-spot are very small knolls on the abyssal plane (~ 6000 m water depth) and erupted strong to moderate alkaline basalt, generally including deep-seated xenoliths. The volcanic field is far 600 km away from the Japan Trench, any spreading centers and any hotspots. Therefore, the volcanic activity is not adequate for any existence volcanic models on Earth. In order to understand this petit spot volcanism, we've been taking multidisciplinary surveys. The main results for three years' research including the cruises using JAMSTEC R/V YOKOSUKA and KAIREI (YK05-06, KR05-10, KR06-03, KR07-06, KR07-07 and YK07-15) and shore-based research were listed below.
- Two other small knolls were discovered as the petit-spot volcanoes with SHINKAI 6500 submersible, and alkaline basalt samples were collected from the knolls.
- Several acoustic explorations on the petit-spot knolls and NW Pacific area with a single channel streamer (SCS).
- Five Ocean Bottom Electro-Magnetometers (OBEMs) were deployed and recovered around the volcanic field.

- The crustal heat flow measurements were taken using with Miniaturized temperature data loggers.
- Three broad band ocean bottom seismometers (BBOBSs) and three OBEMs were deployed in the volcanic field to observe the intraplate seismicity and the melt supply process in the upper mantle.
- Several mantle xenoliths included petit-spot alkaline basalts were sampled during SHINKAI 6500 dives.
- In addition to this, another petit-spot volcanic field was discovered on the outer rise near the Japan Trench.

The xenoliths included in petit-spot volcanoes are deep-seated rocks composed the old Pacific plate; such as dolerite, microgabbro, gabbro, N-MORB and spinel peridotites (lherzolite, dunite, wehrlite, pyroxenite and harzburgite). The major element chemistry of the mafic xenoliths shows these are N-MORB, and the ultramafic xenoliths have common the major element mineral chemistry with the abyssal peridotite. No serpentinite or highly altered mafic rocks have been discovered in this area. The deep-seated rock xenoliths from this kind of oceanic intraplate volcanoes provide us a lot of information about the architecture and the thermal state of the intact old oceanic plate. The geotherm in the lithospheric mantle beneath the petit-spot volcanic field was estimated using by xenoliths equilibrium temperature and is much higher than standard plate model (GDH1, Stain and Stain, 1992), while the heat flow measured on the sea floor (~ 50mW/m^2) suggest that the petit-spot volcanic field area is a standard 130 Ma old oceanic plate.

Session Type: *Oral Presentation*

THE ECLOGITE ENGINE AND THE SUBTERRANEAN CYCLE

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There is a shallow and rapid cycle of mantle fertilization that operates more or less independently of the larger slower plate tectonic cycle but does involve the mantle wedge and the top part of the slab. The mantle wedge contains most of the elements that are found in midplate volcanics and may be the crucible for OIB and LIPs. Delaminated lower continental or arc crust is the main source of mafic material; carbonatites and other fluids from the slab serve to metasomatize and enrich the shallow mantle. Ancient depleted U-poor peridotites and cumulates (FOZO) are the carriers of high 3He/4He-low 3He signatures, which also are sampled by backarc basin basalts (Manus, Lau). Mantle wedges are isolated by continent-continent collisions and ridge-trench annihilations and become the fertile patches that become mantle melting anomalies. Carbonatites from the slab carry LIL and CO2 to the shallow mantle. CO2-gas exsolves at low pressure, separating He from U and Th. The engine is driven by phase changes (basalt-eclogite, eclogite-melt) and internal heating, rather than deep heating and thermal expansion. The thickness and lateral variations of the transition region favors this kind of non-thermal convection. The intense scattering of 6-100 km seismic waves in the upper mantle is consistent with sinking and rising thermal blobs. Mass balance allows irreversible oceanic crust subduction-to laminate at the base of the TZ-if deep subduction and plate tectonics are intermittent. Delaminated continental crust density-equilibrates near and above 400 km depth but it rises upon heating to ambient temperature. Abyssal peridotites appear to be reused and continuously cycle back to the shallow mantle. The continetal eclogite cycle appears to take about 80 Myr. The Ringwood-Green version of the eclogite engine uses partial melts of eclogite to refertilize shallow periodites. This secondary pyroxenite may be the immediate parent for some OIBs and other melting anomalies.

Session Type: *Poster Presentation*

A COMPOSITE GEOLOGIC AND SEISMIC PROFILE BENEATH THE SOUTHERN RIO GRANDE RIFT, NEW MEXICO, BASED ON XENOLITH MINERALOGY, TEMPERATURE, AND PRESSURE

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A full understanding of the processes of crustal growth and recycling remains elusive, in part because data on rock composition at depth is incomplete. Seismic velocities can provide additional information about lithospheric composition and structure, however, the relationship between seismic velocity and rock composition is not unique. The xenolith suite from the Potrillo volcanic field in the southern Rio Grande rift, together with velocity models derived from reflection and refraction data in the area, provide an opportunity to place constraints on the composition of the crust and upper mantle from depths of ~60 km to the surface. We calculate seismic velocities of crustal and mantle xenoliths using modal mineralogy, mineral compositions, pressure and temperature estimates, and elasticity data. The pressure, temperature, and velocity estimates from xenoliths are then combined with sonic logs and stratigraphy estimated from drill cores and surface geology to produce a geologic and velocity profile through the crust and upper mantle. Lower crustal xenoliths include garnet ± sillimanite granulite, two-pyroxene granulite, charnokite, and anorthosite. Metagabbro and amphibolite account for only a small fraction of the lower crustal xenoliths, suggesting that a basaltic underplate at the crust–mantle boundary is not present beneath the southern Rio Grande rift. Abundant mid-crustal felsic to mafic igneous xenoliths, however, suggest that plutonic rocks are common in the middle crust and were intraplated rather than underplated during Cenozoic extension. Calculated velocities for garnet granulite are between 6.9 and 8.0 km/s, depending on garnet content. Granulites are strongly foliated and lineated and should be seismically anisotropic. These results suggest that velocities > 7.0 km/s and a layered structure, which are often attributed to underplated mafic rocks, can also be characteristic of alternating garnet-rich and garnet-poor metasedimentary rocks. Because the lower crust appears to be composed largely of metasedimentary granulite, which requires deep burial of upper crustal materials, we suggest the initial construction of the continental crust beneath the Potrillo volcanic field occurred by thickening of supracrustal material in the absence of large scale magmatic accretion. Mantle xenoliths include spinel lherzolite and harzburgite, dunite, and clinopyroxenite. Calculated P-wave velocities for peridotites range from 7.75 km/s to 7.89 km/s, with an average of 7.82 km/s. This velocity is in good agreement with refraction and reflection studies that report Pn velocities of 7.6–7.8 km/s throughout most of the Rio Grande rift. These calculations suggest that the low Pn velocities compared to average uppermost mantle are the result of relatively high temperatures and low pressures due to thin crust, as well as a fertile, Fe-rich, bulk upper mantle composition. Partial melt or metasomatic hydration of the mantle lithosphere are not needed to produce the observed Pn velocities.

Session Type: *Poster Presentation*

MELT-FILLED HYBRID FRACTURES IN THE OCEANIC MANTLE: MELT ENHANCED DEFORMATION DURING ALONG-AXIS FLOW BENEATH A PROPAGATING SPREADING RIDGE AXIS

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Mid-ocean ridges represent important locations for understanding the interactions between deformation and melt production, transport, and emplacement. Melt transport through the mantle beneath mid-ocean ridges is closely associated with deformation. Currently recognized transport and emplacement processes at ridges include: 1) dikes and sills filling stress-controlled fractures, 2) porous flow in a divergent flow field, 3) selforganizing porous dunite channels, and 4) shear zones. Our recent observations from the sub-oceanic mantle beneath a propagating ridge axis in the Oman ophiolite show that gabbronorite and olivine gabbro dikes fill hybrid fractures that show both shear and extensional components of strain. The magnitudes of shear strain recorded by the dikes are significant and comparable to the longitudinal extensions across the dikes. We suggest that the hybrid dikes form from the interactions between shear deformation and pressurized melt in regions of along-axis flow at mid-ocean ridges. The displacement across the dikes is kinematically compatible with high temperature flow recorded by plastic fabrics in host peridotites. Field observations and mechanical considerations indicate that the dikes record conditions of higher stress and lower temperature than those recorded by the plastic flow fabrics. The features of hybrid dikes suggest formation during progressive deformation as conditions changed from penetrative plastic flow to strain localization along melt-filled fractures. The combined dataset indicates that the dikes are formed during along-axis flow away from regions of diapiric upwelling at propagating ridge segments. Hybrid dikes provide a potentially powerful kinematic indicator and strain recorder and define a previously unrecognized mechanism of melt migration. Our calculations show that hybrid dikes require less melt pressure to form than purely tensile dikes and thus may provide a mechanism to tap melt reservoirs that are under-pressurized with respect to lithostatic pressure.

Session Type: *Poster Presentation*

PERIDOTITE XENOLITHS FROM RECENT ERUPTIONS IN WESTERN NORTH AMERICA CORRELATIONS WITH GEOPHYSICAL SURVEY

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We report on two mantle xenolith localities in western North America - the Cima volcanic field in the Walker Lane, CA, and the Potrillo volcanic field, Rio Grande rift, NM. The volcanic vents that transported mantle xenoliths in both fields erupted less than 100ka ago. The purpose of this study is to compare xenolith compositions, rheology, and calculated seismic velocities to geophysical surveys in these areas.

The Potrillo volcanic field xenoliths display a stratigraphic layering with fine-grained lherzolite (approx. 980° C) overlying porphyroclastic lherzolite (approx. 1050° C). Trace element analyses indicate that both types have experienced at least some metasomatism. Calculated Vp is 7.8 to 7.9 km/sec, similar to geophysical determinations in the field. These slow velocities are attributable to high mantle temperatures. The hottest xenoliths (up to 1150° C) are harzburgites and dunites that have experienced more melt extraction and metasomatism than the lherzolites. Crystal-preferred orientation studies show that these also have the greatest amount of strain. We interpret these xenoliths to represent the base of the North American lithosphere as it is infiltrated by and glides along asthenosphere.

The Cima volcanic field lies within the Walker Lane, a trans-tensional propagation of the Gulf of California rift system. Xenoliths from this volcanic field also suggest an uppermost mantle stratigraphy in which lherzolite overlies harzburgite and dunite. In addition, the xenoliths include pyroxenites and gabbros. Two principal differences exist between Cima and Potrillo volcanic field samples. First, all Cima lithologies except the harzburgite/dunite have petrographic evidence for spinel to plagioclase reaction or direct plagioclase precipitation. We interpret that Cima lithospheric mantle is presently upwelling and decompressing through spinel to plagioclase. Second, all Cima samples have interstitial melt, which lowers the seismic velocities to those observed in geophysical surveys.

Session Type: *Poster Session*

LOW VISCOSITY GARNET LAYERS IN THE UPPER MANTLE

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The rheological properties of upper mantle rocks play an important role in controlling the dynamics of the lithosphere and mantle convection. Experimental deformation studies and microstructures in naturally deformed mantle rocks usually imply that the mineral olivine is the weakest mineral in the mantle and therefore controls the upper mantle rheology. Here we show evidence from the geometry of folded compositional layering in ultra-high pressure mantle rocks from Western Gneiss region in Norway that garnet-rich mantle rocks can have lower solid-state viscosities than olivine-rich mantle rocks. Modeling of melt-free and dry rheology of garnet and olivine confirms that this reversed viscosity contrast between folded garnet and olivine layers can be achieved over a relatively wide range of temperatures and strain rates, but only when the fine-grained garnet deforms by diffusion creep while the coarse-grained olivine deforms by dislocation creep. The outcomes of the modeling shows that the folding can have occurred in specific tectonic settings: 1) in the case of a dry upper mantle environment, folding must have occurred before the Caledonian orogeny, either during Proterozoic progressive cooling stage of the peridotite body at the base of the continental lithosphere or during the Archaean diapiric upwelling stage, or 2) during the low-temperature Caledonian subduction event the reversed viscosity in the fold can only be formed when water was present in the upper mantle rocks.

Session Type: *Oral Presentation*

IMPLICATIONS OF GRAIN-SIZE EVOLUTION ON THE SEISMIC STRUCTURE OF THE OCEANIC UPPER MANTLE

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We construct a 1-D steady-state channel flow model for grain size evolution in the oceanic upper mantle using a composite diffusion-dislocation creep rheology. Grain size evolution is calculated assuming that grain size is controlled by a competition between dynamic recrystallization and grain growth [e.g., Hall & Parmentier, G3, 2003; Austin & Evans, Geology, 2007]. Comparing these two grain size evolution models to laboratory data, we find that the Austin & Evans [2007] model provides a better fit to the data over a range of temperatures and water contents. Applying this model to the oceanic upper mantle we calculate grain size as a function of depth, seafloor age, and mantle water content. The resulting grain size distribution is then used to predict shear wave velocity (Vs) and seismic quality factor (Q). For a plate age of 60 Myrs and a mantle water content of 1000 ppm, we find that grain size reaches a minimum of ~10 mm at 130 km depth and then increases to ~20 mm at a depth of 400 km. This grain size distribution produces a good fit to the low seismic shear wave velocity zone (LVZ) in oceanic upper mantle observed by surface wave studies. Further it predicts a viscosity of ~10^19 Pa s at 150 km depth and dislocation to be the dominant deformation mechanism throughout the oceanic upper mantle, consistent with geophysical observations. In contrast, for a dry upper mantle (50 ppm H_2O) the predicted variation in grain size (~7 to ~10 mm from 150 to 400 km depth) is not sufficient to explain the LVZ in the absence of water and/or melt. These results indicate that a combination of grain size evolution and a hydrated upper mantle is a plausible explanation for the LVZ.

Session Type: *Poster Presentation*

MELT-ROCK REACTION ORIGINS OF KIMBERLITE MEGACRYST SUITES AND THE PHYSICAL-CHEMICAL STRUCTURE AND EVOLUTION OF THE CONTINENTAL UPPER MANTLE BENEATH SOUTHERN AFRICA

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Megacrysts are a ubiquitous xenolithic component in kimberlite and other alkaline magmas, but their origins and relationship to the host magma are debated. Major and trace element and isotope data for >2000 megacrysts from ~50 kimberlites in southern Africa vary systematically with respect to host kimberlite type, geographic location and tectonic setting. The broadly cognate origin of megacrysts is strongly supported by distinctive differences between Group I and Group II kimberlite megacrysts.

Geochemical variations are best interpreted in terms of differentiation of kimberlite precursor liquids during melt-rock reaction processes. Reaction occurs (i) when asthenosphere- derived (Group I) megacryst magmas intrude into the lower reaches of the lithospheric chemical boundary layer, (ii) during cooling of partially-molten mantle emplaced beneath the chemical lithosphere, or (iii) during the intra-lithospheric mobilization of low melting point components by conductive heating (Group II). The compositional variations within and between suites reflect the variable influences of temperature, pressure, melt composition, wallrock composition, and melt/rock ratio. Lateral, vertical, and temporal variations in these parameters can be inferred from chemical properties of the megacrysts. Megacrysts from individual kimberlites within a given cluster typically conform to one overall differentiation pattern. The patterns vary among clusters, reflecting regional variations in the deep lithospheric mantle.

Incompatible trace elements and Sr isotopes suggest a uniform source for group I kimberlite magmatism across southern Africa, but major elements indicate variable composition of the lithosphere into which the megacryst magmas are intruded. Cr-Mg# relationships indicate that the boundary between the Kaapvaal and Zimbabwe Cratons may correspond to the seismically slow, Fe-rich region beneath the Bushveld Complex, rather than the Limpopo Belt. Beneath the southwestern Kaapvaal Craton and adjacent Proterozoic Namaqua Belt, the mantle lithosphere has been metasomatically converted to, Cr-poor, Fe-rich mantle. High integrated melt-rock ratios qualitatively inferred for suites closest to the Indian Ocean continental margin and the correspondence of this distribution with that of ultra-deep diamonds suggests the metasomatism is related to deep mantle upwelling connected to continental breakup and magmatism of the Karoo LIP.

Megacryst Ca-Mg-Fe relations reveal a decline in maximum and minimum temperature and depth of melt rock reaction broadly concentric around the cratonic nucleus. The presence of ilmenite and the transition from Cr-poor to “Granny Smith” compositions are related to the interplay between temperature, pressure, and the depth of metasomatic Fe-Ti enrichment. The pattern is locally perturbed at the craton edge and the Ventersdorp (~2.6 Ga) rift, mimicking anomalies in the ages of kimberlite eruption in these areas. This pattern indicates faster and shallower intrusion of magmas in lithospheric zones of previous tectonism, and the genesis of “transitional” trace element and isotope signatures. Megacrysts and kimberlites both reflect processes by which the emplacement and eruption of melts generated in deep-seated mantle geodynamic events is controlled by lithospheric composition and structure.

Session Type: *Oral Presentation*

SUBCALCIC GARNET PERIDOTITES, DIAMOND FORMATION, AND THE EVOLUTION OF CRATONIC MANTLE LITHOSPHERE.

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Subcalcic garnet xenocrysts, diamond inclusions, and rare peridotite xenoliths indicate the ubiquitous but volumetrically minor presence of highly refractory lithologies in Archean subcontinental mantle. A collection of ultra-refractory mantle peridotites from the Bultfontein diamond mine at Kimberley, South Africa, reveals that the rocks hosting these unique mineral compositions are orthopyroxene-poor harzburgites and dunites with minor proportions of accessory garnet and/or chromite and occasional phlogopite and diamond. Unlike Siberian counterparts (Pokhilenko et al. 1993), the dunitic xenoliths are not unusually coarse-grained.

Bulk compositions extend the range for Kaapvaal peridotites to extreme values of Mg# (96) and Cr# (76). Relationships between Cr#, Mg, Fe and Si indicate that Cr-rich spinel was present in the melting interval, contrasting with low-T cratonic harzburgites with Mg < 93. Whether this indicates shallow melting is debatable and will be discussed. Removal of the spinel depth constraint permits the hypothesis that Archean mantle roots were not initially formed in subduction zones, though the evidence presented suggests they were subsequently modified in such settings. At Kimberley, the subcalcic dunites are derived from depths overlapping those of other low-T garnet peridotites, but appear to comprise a greater proportion of the lithosphere in the deepest zones represented (140-160 km).

The trends defined by dunite bulk compositions are not continuous with those of other refractory harzburgites, suggesting that they are not simply extreme melt residues. The dunites are anomalously depleted in Fe for their Mg/Si ratios, and display a trend of increasing Mg# with decreasing Mg+Fe/Si that suggests. The presence of diamond and Cl-rich phlogopite, the high LIL concentrations in garnet, and the extreme depletion in HFSE and other magmaphile elements (Ca, Al) point to involvement of fluids, rather than melts.

It is suggested that the dunites may be local features in sub-cratonic mantle analogous to the dunite melt channels in exposed peridotite massifs. A model of concomitant dunite formation and diamond precipitation by the fluxing and redox reaction of chloride-rich potassic, carbonate-bearing hydrous fluids with previously melt-depleted cratonic harzburgite is explored. Transport by fluids derived either by direct dehydration of subducting lithosphere, or by the reaction-differentiation of siliceous slab-derived melts can play a major role in the chemical differentiation of Archean lithosphere.

Session Type: *Poster Presentation*

CONSISTENT OLIVINE MG# IN CRATONIC MANTLE REFLECTS ARCHEAN MANTLE MELTING TO THE EXHAUSTION OF ORTHOPYROXENE

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Shallow (garnet-free), depleted cratonic mantle, occurring as xenoliths in kimberlites and alkaline basaltic lavas, has a high Mg# and is poor in Al and Ca compared to off-cratonic mantle. Here we compile data for many suites of shallow cratonic mantle xenoliths worldwide, and demonstrate a remarkably small range in their olivine Mg#, with an average of ~92.8. Via comparison with data for experimental melting of mantle peridotite compositions, we explain consistent olivine Mg# as the result of mantle melting and melt extraction to the point of orthopyroxene exhaustion, leaving a nearly monomineralic olivine residue.

Session Type: *Poster Presentation*

NUMERICAL MODELS OF MANTLE FLOW & SEISMIC ANISOTROPY IN LAU BASIN

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Numerical models of mantle flow behind the plate that subducts along the Tonga trench can provide new insights on melting patterns and the magnitude of possible along-strike variations in structure. Of particular interest is the extent to which melt that supplies the volcanic arc may intermingle with melts generated during backarc spreading along the central and eastern Lau spreading centers and the Valu Fa Ridge. We have conducted a series of 2-D numerical experiments, with self consistent flow, thermal, and texture evolution, to explore the effect of assumed values for parameters such as water content off the slab and distance of the backarc spreading axis from the trench. We relate results to basic observations of along-strike lava chemistry and crustal structure, available from prior seismic and petrological sampling studies. Our numercial results provide initial estimates of controls on variation in mantle structure and are intended to guide future 3-D models which can connect results from a forthcoming Ridge 2000 seismic imaging experiment along the Eastern Lau spreading center.

Session Type: *Oral Presentation*

CHEMICAL VARIATIONS IN TECTONICALLY-EMPLACED MANTLE ROCKS: SUPERIMPOSED EFFECTS OF PARTIAL MELTING, MELT REDISTRIBUTION AND IGNEOUS REFERTILIZATION

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There is a growing body of evidence indicating that chemical variations in tectonically-emplaced mantle rocks mostly reflect melt redistribution and near-solidus reactions at decreasing melt mass superimposed onto previous depletion events. In this scheme, the convergence of the most fertile lherzolite compositions at around 4% Al2O3 is not an indication of their pristine origin. This composition may rather coincide with a threshold for melt segregation and formation of pyroxenite-peridotite “veined” mantle.

Recent studies also tend to converge on the idea that the orogenic peridotites represent thinned and/or rejuvenated lithospheric mantle, thermally eroded by asthenospheric mantle during continental rifting or early ocean initiation. Lithospheric rejuvenation is marked by annealing of deformation microstructures, overgrowth of mineral grains and km-scale modal/chemical variations resulting from partial melt redistribution. From top to base of eroded lithosphere, melt processes vary from refertilization of aged, refractory (harzburgite) lithosphere to partial melting of previously refertilized material (lherzolite and websterite). In the Ronda and Lherz massifs, both processes are associated with narrow fronts where major microstructural, modal and chemical variations occur within a few meters to tens of meters. Melting and refertilization fronts display striking resemblances (e.g., annealing of textures and small-scale chemical heterogeneities) as well as significant differences. The melting front observed in Ronda is a clear-cut structure that can be followed over > 10 km in the massif, suggesting that its formation was thermally-controlled at regional scale. In contrast, the refertilization front of Lherz is extremely convoluted, suggesting its formation by coalescence of relatively narrow (≤ 10 m) melt infiltration channels. Refertilization and melting fonts are considered as the upper and lower boundaries of transient, moving asthenosphere-lithosphere transition zones during thermo-mechanical erosion of the lithospheric mantle by upwelling asthenosphere. Further complexity arises during the waning stages of lithospheric erosion - upon conductive cooling - when partially molten lithosphere is traversed by the receding melting/refertilization fronts.

An important implication of the origin of fertile orogenic lherzolites by refertilization is that these rocks cannot be straightforwardly used to infer primitive mantle compositions. It is thus logic to wonder whether fertile mantle xenoliths with similar compositions represent refertilized or pristine mantle. Several authors have ascribed the chemical stratification of cratonic lithosphere and/or its temporal evolution to metasomatic refertilization. In this scheme, fertile (predominantly lherzolitic), off-craton lithosphere may be viewed as the ultimate transformation of cratonic lithosphere after one or several cycles of igneous refertilization. Extensive refertilization in the Western Alps (Lanzo) and Betic peridotites (Ronda) is intrinsically related to the lithospheric thinning processes that led to mantle exhumation, which might suggest that large-scale refertilization is specific of tectonically-emplaced, orogenic peridotites. However, the Lherz massif illustrates a situation where refertilization and exhumation are related to distinct events, separated in time by thermal relaxation of subcontinental lithosphere. Several suites of spinel peridotite xenoliths compositionally comparable to the Lherz massif (LREE-depleted lherzolites associated with LREE-enriched harzburgites) might also record refertilization of depleted lithospheric mantle.

Session Type: *Poster Presentation*

LARGE SHEAR ZONES WITH NO RELATIVE DISPLACEMENT

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In the Oman ophiolite, different types of segment limits are documented, based on the age of the new segment relative to its lithospheric wall. Major shear zones seem to have developed at the contact between a flowing asthenosphere and a frozen lithospheric wall, a thermal boundary inducing a characteristic asymmetry. In the Makhibiyah shear zone, an exceptional situation where a reversal of shear sense along the shear zone trend is closely associated to a divergence of the mantle flow in the asthenospheric side, the induced shearing originated without strike-slip motion. This situation calling for a new kinematic interpretation of shear zones is obviously not restricted to the mantle. It should apply to crustal shear zones, provided that they are large enough to maintain a thermal difference over time. It brings a word of caution about systematically ascribing large shear zones to large strike-slip motion.

Session Type: *Oral Presentation*

ASPECTS OF RIDGE SEGMENTATION IN THE OMAN OPHIOLITE

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Ridge segmentation along the East Pacific Rise (EPR)has been actively studied from the comparatively simple segments interaction at overlapping spreading centers (OSC) to the complexity of growing and rotating microplates. The structures of interacting segments and their kinematic evolution have been deciphered, based on the analysis of fine scale topographic features and of magnetic anomalies patterns. Petrological and geochemical differentiations from center to tips of segments have introduced a discussion on their magmatic activity. The emerging picture is that of a great tectonic regional complexity, contrasting with the overall simple structure of the EPR and its remarkable seafloor smoothness.

As a result of the extensive structural mapping, the Oman ophiolite is found to be also strongly segmented, individual segments being fed by small mantle diapirs. New, fine scale mapping in the large NW-SE ridge segment previously identified in the Oman ophiolite has revealed that this structure is itself composed of smaller nestled segments, each being centered on small mantle diapirs. Contacts with the adjacent lithosphere depend on the difference in age between the two adjacent lithospheres.

When the difference in age is in the range of 1 Ma, strike slip shear zones, 1-2 km wide, are developed in the mantle of the new segment. Oman shear zones are asymmetrical with, along one margin, an asthenospheric mantle (~1200°C) and along the adjacent margin, a lithospheric mantle (~1000°C). Tectonic and magmatic activities are entirely localized within the asthenospheric compartment and no strike-slip motion in an active shear zone is required.

When the age difference drops to ~0.5 Ma, the shear zones are small and diffuse but, in the mantle wedge at the tip of the segment which penetrates the older lithosphere, spectacular deformations are observed. The mantle and lower crust of the older lithosphere near the Moho are shoveled vertically and kilometer-sized folds develop in the gabbro unit. In contrast, the lid is little affected, suggesting that, in present day fast spreading ridges, similar major tectonic structures, that are seen in Oman thanks to deep sections, may also be present. Contacts and tips of new segments are invaded by mafic dikes and sills issued from the segment magmatic activity and trapped against these colder boundaries. An important contribution to this magmatism results from massive seawater penetration down to the Moho, possibly favored by the segment tectonic activity.

Session Type: *Poster Presentation*

SERPENTINIZATION PROCESS: THE INITIAL STAGE

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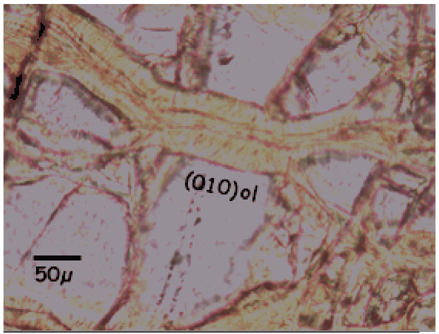
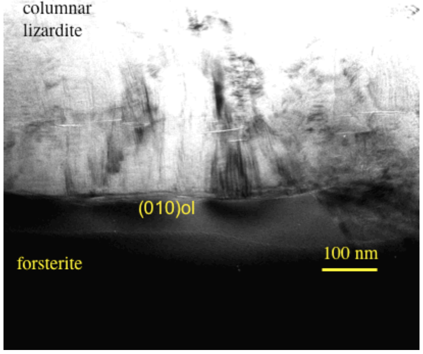
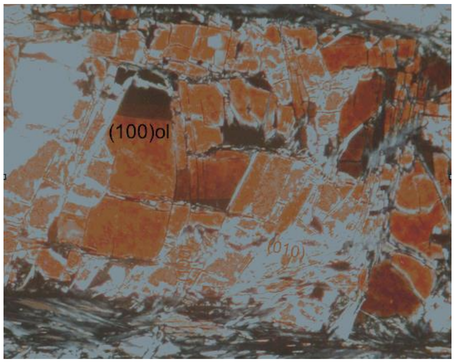
What is the process controlling fluid circulation in mantle peridotite before its incorporation in serpentine ? One key is to explore the close relationships of serpentine crystallography with its olivine host. We report on microstructural and microchemical data obtained by optical microscopy, high resolution electronic microscopy and analytical electron microscopy concerning the study of two contrasted situation:

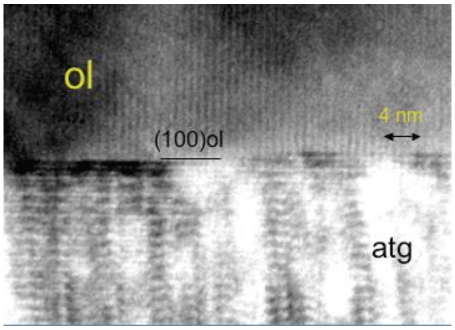
(1) development of lizardite mesh-textured in a standard oceanic harzburgite serpentinized 60%, from the Oman ophiolite,





where olivine *(ol-*Fo_{86}*)* converts first to a Fe, Ni-rich, Al-poor columnar lizardite (cliz) and ± intergrown brucite with similar Fe/(Fe+Mg) for the three phases. The joined cliz columns are perpendicular to the basal plane (001), corresponding to the pseudofibers observed optically. (001)$_{liz}$ are locally parallel to the narrow limit ol-liz ; thus columns orientations mark the interface of serpentinization. The ol-cliz relationships are not strictly topotactic, but due to preferred cracking orientation in ol, parallel to (010)ol. (2) development of antigorite in a rare sample of antigorite schist from kimberlite of Moses Rock (Colorado Plateau) representative of a suprasubduction mantle wedge.





High Resolution Transmission Electron Microscopy (HRTEM) images seen along <010>antigorite show domains with very regular modulation at ~42A, with little defects, indicative of HP-HT antigorite, and also heavily kinked regions as fingerprints of strong tectonic shear. TEM image of olivine/antigorite contact shows topotaxy between the (001) antigorite corrugated face and (100) olivine crenulated surface. The informations included in the electron diffraction pattern provide the topotaxy relationships:<100>atg//<010>ol; <010>atg//<001>ol; and planes in contact are (001)atg//(100)ol. We discuss the significance of the topotactic relationship between host olivine and antigorite, compared with the non-topotactic relationship between olivine and lizardite. We show that in both cases, the topography of olivine/serpentine interface is controlled by fluid circulation. In both cases, the fluid pathways could be identified as open voids and interface boundaries.

Session Type: *Poster Presentation*

IDENTIFYING THE ROLES OF POTENTIAL TEMPERATURE, ACTIVE UPWELLING AND SOURCE LITHOLOGY IN ENHANCING MELT PRODUCTION IN LARGE IGNEOUS PROVINCES

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Large Igneous Provinces (LIPs) represent extreme consequences of partial melting of the Earth's mantle. Characterized by anomalously high magmatic productivity relative to mid-ocean ridges, the origins of LIPs remain controversial. Three main mechanisms are proposed to explain high productivity magmatism - elevated mantle temperatures, active upwelling, and the melting of fertile source lithologies. Although these factors are not mutually exclusive, there is considerable uncertainty about their roles in LIP melt generation. To better understand the relative roles of mantle temperature, active upwelling and source heterogeneity in the formation of LIPs, we have developed a forward melting model to simulate melt generation in a heterogeneous source containing eclogite and peridotite. We incorporate experimentally - determined melt productivity functions, melting reactions, solidii and partition coefficients for eclogite and peridotite lithologies, and thermodynamic constraints. For a given mantle potential temperature, upwelling rate, and initial source compositions, the model outputs the trace element and isotopic compositions and volume for pooled melts, as well as the composition of fractional melts within the melting region. We apply the model to the North Atlantic Large Igneous Province to relate the region's compositional heterogeneity and magmatic productivity. We find that relatively constant, but elevated, potential temperatures and variable active upwelling are required to explain excess magmatism in the North Atlantic, while eclogite, needed to explain the composition of basalts, plays a relatively minor role in enhancing melt production.

Session Type: *Oral Presentation*

WERE DEEP CRATONIC MANTLE ROOTS HYDRATED IN ARCHEAN OCEAN

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Cratonic mantle hosts diamonds, represents the most ancient mantle on our planet (having mostly Archean Os ages) and forms the deep cores of continents. Cratonic mantle is depleted in Fe and has anomalously high Si/Mg. There have been various proposals for this unique composition. Those models involving ‘metasomatism’ for the elevated Si/Mg in cratonic mantle allude to enrichment in the mantle from the ‘bottom up’, by emanation of melts or fluids from slabs or deep-seated magmas.

Using a compilation of world peridotites (n ~ 2000) we statistically evaluate the frequency of anomalous Si /Mg in cratonic and all other types of mantle lithosphere. We fit arrays of peridotites in Mg – Al – Si space and define an empirical parameter (‘delta Mg/Si’) which describes the degree of Si enrichment or depletion in lithosphere relative to partial melting trends. We define the partial melting trend in Mg-Al-Si space using either continental xenoliths or ophiolite peridotites with a simple history. We find that high Si/Mg displacing samples from the partial melting trend (i.e. a strong skew to negative delta Mg/Si) occurs only in abyssal peridotites and a significant number of South African cratonic xenoliths. All other types of mantle are narrowly and normally distributed about delta Mg/Si = 0. We also evaluated whether high Si/Mg is biased to analyses from certain XRF laboratories, and none exists.

The high Si/Mg in abyssal peridotites is a well known attribute of marine weathering, with preferential loss of Mg to seawater. Modern peridotites undergoing low temperature hydrothermalism at Lost City/Atlantis Massif are also high in Si/Mg, by leaching of Si from local gabbro bodies and re-deposition into serpentinized rocks, in some cases, forming talc peridotites. Trends of O isotopes and Mg/Si in Lost City/Atlantis Massif parallel that seen in the few such data for cratonic peridotites. Cratonic mantle, diamonds and eclogites occurring as xenoliths in kimberlites have many lines of evidence linking them to the hydrosphere. We show by comparison with modern ocean floor how the Si-rich composition of some cratonic mantle can be linked to hydration either on the Archean ocean floor, or in Archean accretionary margin fluids. We demonstrate that “Silica enrichment” is not ubiquitous in the cratonic mantle, and hypothesize that where it occurs may be a heterogeneous feature imparted by marine weathering or alteration of peridotite on the (Archean) ocean floor before it was stacked to form a deep mantle root. In this scenario, a more reduced Archean hydrosphere than today may also have leached more Fe and Mg preferentially to Si into seawater, possibly explaining the Fe depletion. Our hypothesis is testable with more and better O isotope data for cratonic xenoliths with variable Si/Mg.

The chemical modification of mantle peridotite is conventionally viewed as being derived from the bottom upward, where the lithosphere acts as a 'filter paper' receiving enrichment from melts from below. We turn this idea on its head, and assert that some chemical modifications for peridotites occur at the surface before they are subducted or accreted to become deeper parts of the continental lithosphere.

Session Type: *Poster Presentation*

ALTERATION OF PERIDOTITES AND BASALTS TO MEET MICROBIAL ENERGY DEMANDS

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The deep biosphere is the largest and least understood part of the biosphere and is estimated to contain from 10% to 33% of the total living biomass on Earth. Extant populations of microbes are known to inhabit sediments and igneous rocks to a depth of nearly 5 km and may extend to even greater depths. Results suggest that the portion of the deep biosphere hosted in igneous rocks may rival that in seafloor sediments. At present our understanding of these systems and the complex biogeochemical processes involved in alteration, weathering, element cycling, and other water-mineral-microbe interactions is far from complete.

These systems host a number of diverse and novel metabolism types and pathways that have an impact in shaping the biogeochemical and geochemical cycles in the oceanic crust and sediments through their interactions with both fluid and rock. Many of the microorganisms residing in hydrothermal systems and the oceanic deep biosphere capitalize on the disequilibria between seawater and igneous rocks at a variety of temperatures, pressures, pHs, and fluid compositions. Analyses of the energy supplies available to microorganisms inhabiting these regions, which may offset the energetic costs of synthesizing biomolecules and producing cells, can be investigated using existing data on hydrothermal fluids, diffuse fluids and altered peridotites and basalts.

By combining theoretical models of rock alteration with biomolecule synthesis, a quantitative approach can be taken toward predicting microbial metabolisms as functions of temperature, pressure, fluid composition and the extent of rock alteration. These results can be presented in the form of affinity diagrams where conditions of real systems can be plotted to make quantitative comparisons between metabolism types and pathways to aid in linking the nonequilibrium thermodynamics of water-rock alteration to the nonequilibrium processes of metabolism and biosynthesis. Host rock compositions partly dictate the energy regime of the system and directly impact what types of microbes are present, and the extent to which they are able to alter their surroundings. Preliminary modeling results suggest that the utilization of ferrous iron from different minerals, together with the biochemical reactions microbes are coupling to it, will modulate the energy supply and demand. As an example, reactions utilizing ferrosilite to meet energetic demands are less favorable than those using fayalite, meaning that different coupled biogeochemical pathways may be necessary for microbes to meet their energetic demands, thereby shaping the reaction paths, rates and extent of microbial alteration that different host rocks undergo. Higher olivine and orthopyroxene concentrations in host rocks may induce accelerated rates of alteration and weathering within in ultramafic hosted systems, such as those characterized by lherzolite, through increased microbial activity due to the greater supply of energy provided by those minerals in contrast to systems more enriched in plagioclases and clinopyroxenes.

Session Type: *Oral Presentation*

NEW CONSTRAINTS ON THE ORIGIN OF ROBERTS VICTOR ECLOGITES: GEOCHEMICAL EVIDENCE FOR A SUBDUCTED ARC OR BACK-ARC BASALT PROTOLITH

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Two scenarios of formation are prevalent in the debate over the origin of deep mantle eclogites. The first proposes that the eclogite protoliths were Proterozoic and Archaean oceanic basalts and gabbroic cumulates that were subducted and accreted to the peridotitic bases of the cratons. Alternatively it has been suggested that eclogite is formed beneath cratons in a process that occurs at pressures in excess of 3GPa, by which accumulation from deep-mantle melts of an anomalous, hyperaluminous pyroxene is followed by exsolution of kyanite, garnet and sometimes silica as a result of decrease in temperature.

The Roberts Victor kimberlite is situated in the centre of the Kaapvaal craton and lies on the Colesberg magnetic lineament. This lineament is thought to represent a collisional suture between the Kimberley and Witwatersrand blocks, which converged approximately 2.9 billion years ago. Suturing was accommodated by subduction and terrane collision. A suite of 12 bimineralic eclogites, classified as Gp I and I were analysed for whole-rock major and trace elements by ICP-OES and ICP-MS. Garnets and clinopyroxenes were analysed for REE by Laser Ablation-ICP-MS. Positive Eu anomalies indicate that the protoliths of these eclogites have, at some time, experienced plagioclase fractionation in a low pressure environment (< 0.6 GPa). `Calculated bulk-rock' trace element concentrations were produced by combining modal mineral proportions with LA-ICP-MS data generated on garnet and clinopyroxene. Mantle normalised multi-element plots of both measured and calculated bulk-rock data show strong negative anomalies in Ta, Nb, and Ti (mean Nb/LaN = 0.024; mean Ti/Ti*= 0.132) and consistently positive anomalies for Sr. The eclogites have flat calculated bulk-rock HREE patterns with relative depletion in the LREEs (mean La/YbN = 0.361). These trace element patterns are strikingly similar to those observed for basalts in modern arc and back-arc environments, not only in shape but also in the range of normalised concentrations displayed. Examples of subducting back-arc basins are numerous in SE Asia today and subduction of arc rocks has been observed in modern collision zones. It has been postulated that genesis of the peridotitic root of the Kaapvaal craton took place via subduction in an arc environment and given this subduction association we believe it is reasonable to assume that arc rocks may also have been subducted in Archaean collision zones.

We propose that the Roberts Victor eclogites were formed from basalts crystallised in an arc or back-arc environment. Subsequent subduction and terrane collision processes forced the Ta, Nb and Ti depleted protoliths from their shallow crystallisation location to the base of the craton. Whole rock Re-Os isotope data will be presented, to further constrain the age of the Roberts Victor and Orapa eclogites and to more thoroughly evaluate the relative ages of the peridotitic cratonic root and the eclogite component that it contains.

Session Type: *Poster Presentation*

ARC AND BACKARC MELT PRODUCTION AND INTERACTION OF THE MARIANA SYSTEM FROM GEODYNAMICAL MODELING

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Geodynamic modeling can add to our understanding of the likely melting processes at arcs. Recent work shows that hydration, decompression, and sediment melting may each contribute to arc magma generation. However, each mechanism is sensitive to certain variable parameters that may not be constant within an arc like Mariana in either time or space, suggesting along-arc variability in relative importance of each melting mechanism. For instance, although flux melting is likely important all along the Mariana arc, sediment melting is likely more important towards the center and decompression melting more important nearer the extremities.

The asthenosphere beneath the spreading center is characterized by high attenuation and slow seismic velocities centered slightly to the west of the axis, consistent with geodynamical modeling showing that mantle corner flow affects the upwelling structure beneath the spreading center. As the arc-spreading center distance decreases, interaction with arc melts become more likely, leading to possible magma piracy and/or an excess of subduction components in the backarc. The trench-arc and arc-backarc spacing variations along strike suggest possible changes in forearc structure and degree of interaction between the two melting regimes with more communication near the extremities of the Mariana basin.

The forearc is an important control on the slab thermal structure and asthenospheric flow into the uppermost corner. Somewhat counterintuitively, larger forearcs can lead to warmer slab temperatures at depth and enhance sediment melting and dehydration of the slab beneath the arc as the forearc sequesters more cold material in the upper plate that would otherwise act as an insulating blanket atop the subducting slab. Significant serpentinization may affect forearc rheology which in turn may affect forearc structure as determined by coupling of the overlying plate and downgoing slab. The Mariana forearc shows high degrees of serpentinization suggestive of relatively cool temperatures and significant hydration during slab descent. Receiver functions suggest serpentinization possibly as deep as 50 km or more beneath Saipan, which could indicate serpentine-affected plate boundary processes near the downdip limit of the seismogenic zone. Deep serpentinization will tend to extend the cold forearc corner, leading to hotter slab temperatures, possibly leading to significant variations in slab temperatures along-strike with variability in forearc alteration.

Session Type: *Poster Presentation*

COMPOSITIONS OF HIMU, EM1, AND EM2 FROM GLOBAL TRENDS BETWEEN RADIOGENIC ISOTOPES AND MAJOR ELEMENTS IN OCEAN ISLAND BASALTS

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Sr and Pb isotopes exhibit global trends with the concentrations of major elements (CaO, SiO2, TiO2, FeO, Al2O3 and K2O) and major elements ratios (CaO/Al2O3 and K2O/TiO2) in the shield-stage lavas from 18 oceanic hotspots (including Hawaii, Iceland, Galapagos, Cook-Australs, St. Helena, Cape Verde, Cameroon, Canary, Madeira, Comoros, Azores, Samoa, Society, Marquesas, Mascarene, Kerguelen, Pitcairn, and Selvagen). Based on the relationships between major elements and isotopes in OIB lavas, we find that the mantle end members, HIMU (or high 'μ' = 238U/204Pb), EM1 (enriched mantle 1), EM2 (enriched mantle 2), and DMM (depleted MORB [mid-ocean ridge basalt] mantle) exhibit distinct major element characteristics: The four end members are clearly resolved in plots using only major element concentrations or ratios. When compared to oceanic hotspots globally, the hotspots with a HIMU (radiogenic Pb-isotopes and low 87Sr/86Sr) component, such as St. Helena, Cook-Australs and Cape Verde, exhibit high CaO/Al2O3, FeOT, TiO2 and Na2O, intermediate K2O and K2O/TiO2 weight ratio, and low SiO2 and Al2O3. EM1 (enriched mantle 1; intermediate 87Sr/86Sr and low 206Pb/204Pb; sampled by hotspots like Pitcairn and Kerguelen) and EM2 (enriched mantle 2; high 87Sr/86Sr and intermediate 206Pb/204Pb; sample by hotspots like Samoa and Societies) exhibit higher K2O concentrations and K2O/TiO2 weight ratios than HIMU lavas. EM1 lavas exhibit the lowest CaO/Al2O3 in the OIB dataset, and this sets EM1 (CaO/Al2O3 = 0.56) apart from EM2 (CaO/Al2O3 = 0.86). A plot of CaO/Al2O3 vs. K2O/TiO2 perfectly resolves the four mantle end member lavas. Melting processes (pressure, temperature and degree of melting) fail to provide explanation for the full spectrum of major element concentrations versus radiogenic isotope ratio trends in OIBs. Instead, long, time integrated history of various parent-daughter elements appear to be coupled to major element and/or volatile heterogeneity in the mantle source. End member lava compositions are compared with experimental partial melt compositions to place constraints on the lithological characteristics of the mantle end members.

Session Type: *Oral Presentation*

ROLE OF MINUTE CARBONATITIC MELT IN MANTLE GEOCHEMISTRY

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We present experimental determinations of trace element partitioning between natural fertile lherzolite and near-solidus carbonatitic melt at pressures of 6.6 and 8.6 GPa and temperatures between 1265 and 1470 °C, conditions relevant for initial generation of CO2-rich melt beneath oceanic ridges. Compared to previous experiments at lower pressures, which produced more aluminous cpx, our experimental cpx-melt pairs show lower partition coefficients for trivalent cations entering the M2 site (DLu = 0.17, DLa = 0.006). (0.002) and (0.001) also are distinctly lower than previous estimates. The garnet-carbonate melt partition coefficients for REE vary from highly incompatible La (Dgarnet/cbL ~0.006 ± 0.001 at 6.6 GPa and 0.039 ± 0.004 at 8.6 GPa) to moderately compatible Lu (Dgarnet/cbL ~2.23 ± 0.27 at 6.6 GPa and 4.6 ± 0.9 at 8.6 GPa) and are slightly lower than those from lower pressure experiments. From 6.6 to 8.6 GPa, HFSEs including Zr, Hf, and Ti range from moderately incompatible to slightly compatible, with DHf>DTi>DZr and DZr/DHf of 0.62-0.82 at 6.6 GPa and 0.75 at 8.6 GPa. U and Th remain highly incompatible in garnet at both pressures with DU/DTh of 1.2-1.25 at 6.6 GPa and 1.35 at 8.6 GPa. Estimates of , based on our newly measured partition coefficients, suggest that 30-60% of some of the highly incompatible elements can be removed by efficient extraction of 0.1% carbonatitic melt from the Earth's deep upper mantle, and that 0.1% C-rich melt extraction can create a residue that has Rb/Sr, U/Pb and Th/U ratios, respectively, 29, 12, and 6% lower and Sm/Nd ratio ~11% higher than the unmelted source. Garnet lherzolite derived carbonatitic melt has lower normalized HREEs and smaller Nb/Ta ratios than erupted natural carbonatites. Therefore, the trace element abundances of erupted carbonatites require either reaction with a shallower mantle peridotite with low modal garnet or derivation from an enriched source. The trace element abundances of deep carbonate-rich melts must become diluted by greater volumes of silicate melt produced in the shallower portions of sub-ridge basalt source regions. But, the observed 230Th and 231Pa excesses and variations of CO2/Nb in erupted MORBs may potentially derive from variable contributions of carbonate-rich melt.

Session Type: *Oral Presentation*

LOW-DEGREE PARTIAL MELTING OF PERIDOTITE KLB-1 AT 3 GPA. FROM RE MELT TRAPS AND MODIFIED ITERATIVE SANDWICH EXPERIMENTS (MISE)

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Small degree partial melts of garnet peridotite were produced experimentally at 3 GPa in a piston cylinder apparatus in order to determine its contribution to the major element chemistry of ocean island basalts (OIBs). Two different experimental approaches, Re traps and modified iterative sandwich experiments (MISE), were used to produce measurable quench pools at low extents of melting. Re melt traps are similar to diamond aggregate and vitreous carbon sphere traps, but rely upon the wetting properties of Re as well as pressure gradients to attract the melt phase. Re traps are easier to polish than diamond traps and, unlike vitreous carbon spheres, are capable of withstanding high temperatures required for peridotite partial melting at 3 GPa.

Starting materials were natural KLB-1 powders contained in Pt/C capsules. Re trap experiments were performed from 1470-1530 °C for 24 hours, and produced measurable melt pools at melt fractions between 0.050 and 0.223. In contrast with previous peridotite melting studies at 3 GPa, melts in the lowest melt fraction experiments coexisted with garnet. The results are in agreement with simple peridotite melting experiments from Walter (1998) for many major oxides, including: TiO2, Cr2O3, MnO, MgO, and Na2O; however, there are some oxides with which the Re experiments conflict. FeO* in Re trap experiments varies from 6.6-7.9%, considerably lower than the Walter (1998) melts which are never lower than 8.8% FeO* at 3 GPa. CaO and CaO/Al2O3 are much higher in the Re trap melts (11.4-14.3% and 0.96-1.05 respectively) than in Walter (1998; 7.7-10.9% and 0.79-0.87).

The Re trap method is quicker and easier to perform than MISE, but reaches the limits of its effectiveness at a minimum melt fraction ~0.05. The MISE experiments, more time effort intensive, theoretically are capable of producing more accurate results at lower melt fractions. The MISE experiments were used to find the theoretical “zero percent melt,” which is close to the low melt fractions (<0.01) expected to be relevant to OIB production. Preliminary results show good agreement with Re trap melts for some but not all major oxides. TiO2, MnO, MgO, and Na2O fit well with melt trends from Re trap experiments, while Cr2O3 and Al2O3 are less consistent. FeO*, CaO, and CaO/ Al2O3 predicted by preliminary MISE experiments are in good agreement with the low FeO* and high CaO and CaO/ Al2O3 measured from Re trap experiments.

Session Type: *Oral Presentation*

THE TOP OF THE OCEANIC MANTLE - HOW IT VARIES AND WHAT IT TELLS US ABOUT MORB GENERATION

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Large scale systematic global variability of the trace element and isotopic composition of abyssal basalts was discovered over 20 years ago (e.g.: Schilling, 1973; White et al. 1976, Melson, 1976; Schilling, 1983). As predicted by plate tectonics,the composition of abyssal peridotites was found to correlate to the major element composition of MORB, with a major element signature reflecting higher degrees of mantle melting in proximity to mantle hotspots (Dick et al., 1984; Klein & Langmuir, 1987). These correlations remain largely valid for the Atlantic, Arctic and Indian Oceans. Given the large variability in abyssal peridotite compositions at local and regional scales this is remarkable. Nearly the full range of mantle major, trace and isotopic composition can be found in peridotites dredged from a single fracture zone or ridge segment. Detailed analysis of large peridotite suites from the Gakkel Ridge (Dick, Hellebrand & Snow, unpub. data), and in the central Atlantic from 14° to 16°N also show large magma starved regions with highly depleted mantle compositions that must be inherited from prior melting events. The large local-scale variability that exists down to the scale of a single dredge could be inherited from an early melting event, though most variability at this scale likely relates to the most recent event. Direct evidence for this exists at the Kane Megamullion on the MAR, where direct evidence is found for focused flow of melt through the shallow mantle to feed local volcanic centers along the paleo-ridge axis.

All this leaves one wondering what, if anything the “global” (actually regional) variability of MORB and abyssal peridotites defined by Dick et al. (1984) and Klein and Langmuir (1987) means. For abyssal peridotites the correlations only show up when the mineral and modal compositions of large numbers of samples are averaged by locality. Moreover, the peridotite samples on which the correlations are based are almost exclusively fracture zones. Thus, the samples come from the same geodynamic environment with the same P-T-Melt flux history, and therefore do not reflect the full variability produced beneath a ridge segment, but only the melting history at the distal end of a magmatic segment. We would contend, therefore, that the correlations found by the cited authors remain valid and show that MORB aggregates from large regions and therefore the melt aggregation process averages out the variability seen in the source at local scales. As the previously analyzed peridotites are from fracture zone walls 0.5 to 14 m.y. old, and the ‘spatially associated basalts’ are largely from the modern ridge axis, this argues for a long-term stability in magma composition and therefore mantle composition as well. There remains the question, however, as to what degree the lateral variability of MORB major element compositions reflect varying degrees of mantle melting of a uniform source, and to what degree this is a function of varying mantle composition. It is certainly the case that trace and isotopic compositions vary, and we suggest that it is equally likely that mantle major element composition varies significantly as well. Direct evidence of the volume of crust produced at individual ridge segments from mapping basement rocks in oceanic core complexes gives contradictory results from predictions based solely on inversion of MORB compositions, but can be explained by differences in the prior extents of melting of the source mantle.

Session Type: *Oral Presentation*

ABYSSAL PERIDOTITES ON MACQUARIE ISLAND - OLD (ANCIENT?) DEPLETION AND RECENT MELT PERCOLATION

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Macquarie Island (Southern Ocean) is a fragment of young (Miocene) ocean crust and upper mantle formed at a slow-spreading ridge system, uplifted and currently exposed above sea-level. As such, it is unique in the world and it is generally considered as an important type-locality of oceanic crust and mantle.

The crustal rocks on the island have unusual compositions: N-MORB are rare, ultramafic cumulates, gabbros and most dykes were made from E-MORB magmas (La/Sm=1-5), and volcanic rocks are E-MORB to ultra-EMORB (La/Sm=2-8). Trace element compositions are strongly correlated with isotopic compositions, with very little overlap between gabbros (e.g., epsilonNd(9Ma)=+7.8-9.3) and volcanics (epsilonNd(9Ma)=+7.2-8.3). These compositions are consistent with the slow-spreading ridge setting, where degrees of melting in the underlying mantle are small and where there is a high proportion of melts from low-melting point mantle heterogeneities such as pyroxenites.

Peridotites on the island, however, are ultra-depleted harzburgites which can be modeled as residues of >20% of near-fractional melting. Clinopyroxene is rare, and all clinopyroxene present was either exsolved from orthopyroxene or was formed by late-stage melt-rock reactions. Clinopyroxenes show classical U-shaped trace element patterns, the shape of which varies between samples and in some cases even within samples. Within-sample variation is controlled by texture, with reaction-textured clinopyroxene (e.g., from clinopyroxene-spinel 'symplectites') showing the deepest U, and clinopyroxenes from diffuse veins showing the flattest patterns. The peridotites have a very strong imprint of melt-consuming melt-rock reactions, melt percolation and sub-solidus re-equilibration, all in a thick (>10 km) thermal boundary layer at the Macquarie Island ridge system. These sub-solidus processes occurred in the absence of any significant crystal-plastic deformation, as the peridotites have preserved high-temperature, 'asthenospheric' microstructures. The extremely depleted character of the peridotites is inconsistent with the slow-spreading ridge setting as well as with the enriched character of the overlying crust, and must indicate a previous depletion event. Nd isotope ratios reflect the composition of the late-stage percolating melts and give no information about the age of the depletion event. This leaves open the question whether the depletion event is young or ancient.

There is a striking similarity with the abyssal peridotites from the Fifteen-Twenty Fracture Zone at the Mid-Atlantic Ridge (ODP Leg 209; Seyler et al., 2007; Kelemen et al, 2007). Peridotites at this site are also ultra-depleted, much more depleted than peridotites from nearby sites along the Mid-Atlantic and also much more depleted than expected from a slow-spreading setting. Also, the peridotites from this site show evidence for extensive melt-rock reactions and sub-solidus re-equilibration in an abnormally thick thermal boundary layer. Osmium isotope ratios of these abyssal peridotites are among the least radiogenic in young mantle rocks, and are consistent with an ancient (1-2 Ga) depletion history (Harvey et al., 2006).

We are currently attempting to get age constraints from Os isotope ratios in whole-rocks, silicate separates and chromitite from the Macquarie Island mantle, in order to test the hypothesis that the depletion event recorded in the peridotites was an ancient event, and we hope to present these results at the meeting.

Session Type: *Poster Presentation*

EVIDENCE AND IMPLICATIONS OF AN OFF-AXIS CRUSTAL MAGMA CHAMBER ALONG THE EAST PACIFIC RISE

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We report on a crustal magma chamber detected on the flanks of the East Pacific Rise (EPR). The magma chamber is located ~20 km east of the rise axis near 9deg20minN, at a depth of ~2 km below the seafloor and in crust that is over 300,000 years old. The magma chamber produces significant waveform anomalies that include: (i) an amplified *P*-to-*S* reflection from a solid-melt interface (*PmeltS*), (ii) *P* waveforms that diffract around a low-velocity body in the mid-crust and (iii) a *P* wave shadow zone. The associated travel time effects, however, are small and would go undetected by delay-time tomographic methods. We use a combination of travel time and finite-difference waveform modeling to resolve the magma chamber's geometry and physical properties. Waveform modeling shows the *PmeltS* phase is particularly strong on ocean bottom seismometers located within 2 km of the magma chamber. Diffracted waveforms observed on several ocean bottom seismometers compare well with waveform modeling, providing further constraints on the size and location of the magma chamber. The *P* wave shadow zone results from attenuation or a negative velocity gradient in the mid- to lower crust. Our interpretation of the seismic data and modeling results is that the off-axis magma chamber is a relatively small body – compared to the axial magma chamber – that is comprised of a melt lens underlain by a mid- to lower crustal zone of attenuation or low velocity. A recent study shows that the pattern of mantle flow and melt delivery is skewed beneath the EPR, resulting in regions of on- and off-axis melt delivery. The off-axis crustal magma chamber is located near to a region of off-axis delivery of mantle melt. We suggest that the off-axis delivery of mantle melt produces off-axis crustal magma chambers that will act as driving forces for hydrothermal circulation and volcanic eruptions on the flanks of the EPR.

Session Type: *Oral Presentation*

THE PHASE EQUILIBRIUM CONTROL OF SERPENTINIZATION

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Quantitative phase-equilibrium calculations show that the chemical potentials of the Fo and Fa components of reactive olivine in mantle peridotite induce conditions of low fO2 (close to IM) and low a(SiO2) in low-temperature serpentinization (e.g., Frost 1985; Frost & Beard, 2007). The mineralogy of natural serpentinites is fully in accord with these conclusions (presence of awaruite, brucite, hydrogarnet, perovskite, and SiO2-poor minerals in related rocks).

It then follows that the difference in these potentials, the exchange potential Fe2+Mg-1, is what governs the X(Fe2+) of the product minerals serpentine and brucite. The global average (n=460) of mesh and bastite lizardite in mantle metaperidotites is X(SFe) = 0.058±0.030 (1s). The X(SFe) of antigorite and olivine in equilibrium-textured prograde serpentinites correlate according to a "KD" ~ 0.05, such that X(SFe)Atg = 0.05 when X(SFe)Ol = 0.10. Progress of the low-temperature serpentinization reaction is not accompanied by Fe/Mg re-equilibration among the minerals. Only when olivine and orthopyroxene are eliminated or suitably armored, or overwhelmed by major H2O influx, will the control by DmFeMg-1 cease. As a result, mass balance of the serpentinization reaction requires the continued precipitation of an Fe-rich mineral which is usually magnetite, and in an oxygen-conserved reaction the change in redox state of Fe will be accompanied by the evolution of hydrogen.

Whole-rock analyses of strongly to fully serpentinized peridotites show Fe3+/SFe ratios in the range 0.4 to 0.9; in other words, roughly as much ferric iron is accommodated in lizardite as in magnetite. This is consistent with two major studies of lizardite using Mössbauer spectrometry. Thus the average Fe2+ content of lizardite in serpentinized mantle peridotites is more likely to be about 3 mol.%. Similarly, Nernst (Fe/Mg) and Roozeboom (XFe) plots of Atg-Ol pairs extrapolite to 2 mol.% Fe-Srp at %Fa = 0.0, implying this amount of Fe3+-Srp in the average antigorite. Global chrysotile (n=198) has X(SFe) = 0.034±0.018 (1s), which suggests smaller amounts of Fe3+ are present, in agreement with Mössbauer work.

Except in some seafloor occurrences, SFe pfu in lizardite correlates inversely with Si pfu, which suggests that uptake of additional Fe in lizardite is due not to Fe2+ but to Fe3+ in a cronstedtite end-member. This substitution is favored at low T and low fH2. In the exceptional cases, Fe3+ is taken up via an M-vacancy substitution at constant Si pfu.

Session Type: *Poster Presentation*

HYDROUS FLUID METASOMATISM IN SPINEL DUNITE XENOLITHS FROM THE BEARPAW MOUNTAINS, MONTANA, USA

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The Bearpaw Mountains are situated on the northern margin of the Archean Wyoming craton and form part of an extensive Eocene high-K magmatic province. It has been suggested that the magmatism here was triggered by fluids or melts from the subducted Farallon plate interacting with the overlying asthenospheric wedge beneath the Wyoming cratonic keel. Here we report on a suite of nine Fe-rich spinel dunite xenoliths from the Bearpaw Mountains which contain evidence of fluid-rock interaction in the mantle lithosphere.

Olivine grain boundaries in the dunite xenoliths are surrounded and penetrated by veinlets which connect with small intergranular pockets. These "reaction pockets" are commonly associated with spinel showing extensive alteration including skeletal and embayed crystal forms and scalloped or ragged margins. Reaction pockets also contain metasomatic clinopyroxene ("cpx"), orthopyroxene ("opx") and amphibole. Some xenoliths contain veins of fibrous opx which include spherulitic or radiating textures comparable to those described in modern sub-arc mantle xenoliths. In one such vein, opx crystals have euhedral terminations indicating that they grew unrestricted into a fluid filled space. Chlorite growing on the rims of the euhedral opx has delicate crenulated features and was clearly being precipitated at the time when the xenolith was erupted.

Major element and trace element mineral analyses were obtained at Birkbeck by electron microprobe and LA-ICP-MS, respectively. Whole-rock analyses were made by XRF at Royal Holloway, University of London and by solution ICP-MS at the University of Montpellier. Olivine ranges from Fo86 to Fo83. Spinel is mainly chromite (Cr# 31-72) but Ni-rich (2.3 wt.% NiO) magnetite is also present. The pyroxenes are diopside and enstatite and the amphibole, pargasite. The xenoliths also contain small disseminated grains: those identified by microprobe include magnetite, barium sulphate and Fe-Ni sulphide. Many chromite spinels are compositionally zoned: Al2O3 contents at the rim can be as much as 50% lower than at the core while Cr2O3 hardly varies at all. In the pyroxenes and amphibole, the overall trend as metasomatism progresses is one of falling Al2O3 contents. In opx veins, Al2O3 is as low as 0.27 wt %. Temperatures estimated using the Ca in opx method of Brey & Köhler (1999) were 1042-1078 °C for opx veins and 812-1062 °C for reaction pockets. Oxygen fugacity calculated after Ballhaus et al. (1991) at an assumed pressure of 2 GPa gave Δ(f O2)FMQ values from 0.4 to 2.3.

The mantle-normalised whole-rock trace element patterns show strong enrichment in the aqueous fluid mobile elements Cs, U and Pb and in the LILE, Rb, Sr, and Ba and significant troughs at the HFSE, Nb-Ta and Zr-Hf with Ta being exceptionally low. These are characteristic patterns associated with subduction zones. REE are all extremely depleted and show a concave U-shaped pattern with HREE enriched relative to LREE. Mantle-normalised trace element patterns for cpx and amphiboles are broadly similar to the whole rock patterns but there is more variation and overall enrichment in those minerals in the opx-veined xenoliths. In particular, some show enrichment in Ta and in the MREE to HREE.

The petrographic evidence is that the Bearpaw dunite xenoliths have undergone progressive metasomatism as a result of infiltration by an aqueous fluid and which was continuing at the time they were erupted. The veins of Al-poor opx, with textures similar to those in modern sub-arc xenoliths, and the trace element patterns characteristic of subduction zones, suggest that the fluid derived from a subducting slab which was part of the subducting Farallon plate.

Session Type: *Oral Presentation*

THE EFFECT OF MELT ON THE DEFORMATION BEHAVIOR OF OLIVINE

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The intergranular distribution of melt in partially molten upper mantle rocks is determined by surface energy, so that melt is optimally dispersed as a secondary phase to affect bulk rock physical properties. Even minute amounts of melt (~ 0.01%) are fully interconnected along three grain edges and provide fast diffusion pathways to aid deformation. In order to determine the effect of melt on deformation behavior it is therefore necessary to have a completely melt-free reference material. Such material can be manufactured by a solution-gelation method, which allows control of the impurity content, as well as the olivine-orthopyroxene ratio of the sample. A melt phase can be introduced by adding oxide-derived powder with basaltic composition. Deformation experiments in a gas-medium rig at 300 MPa and 1150 to 1350ºC show that relative to pure, melt-free reference materials samples with small amounts of melt (around 1 %) are substantially weaker in the diffusion creep regime (by 1.5 to two orders of magnitude in strainrate for a given grainsize and stress). This indicates that small amounts of melt in the mantle can substantially reduce the viscosity of a partially molten region deforming in the diffusion creep regime. However, small amounts of melt (< 1%) have no measurable effect on strain rate in the dislocation creep regime. In this regime deformation data from genuinely melt-free, Fo90 sol-gel olivine samples fall directly on top of San Carlos olivine derived samples containing small amounts of melt, and melt-added sol-gel samples. This lack of an effect of melt on deformation behavior is consistent with the notion that the strain is produced intragranularly in this deformation regime. Grain size reduction due to recrystallisation in partially molten mantle deforming in the dislocation creep regime can therefore induce a substantial weakening if the grain size becomes small enough for diffusion creep to operate.

Session Type: *Oral Presentation*

FIELD TRIP TO MT. SHASTA AND VICINITY, NORTHERN CALIFORNIA, USA

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This field trip will examine compositional variability present in the lavas of the Mt. Shasta region (Christiansen et al., 1977). We will also show the field relationship of the primitive basaltic andesite and magnesian andesite lavas to the andesite and dacite lavas of Mt. Shasta. The first stop will be on the northwest side of Mt. Shasta at the Lava Park andesite (Grove et al., 2005) to examine the andesitic lavas characteristic of the Shastina – age eruptive activity that occurred between ~10,000 and 9,400 years before present (ybp). This stop will also examine the debris avalanche of ancestral Mt. Shasta that occurred ~300,000 ybp (Crandall et al., 1984). The second stop will visit the primitive magnesian andesite (PMA) and high alumina olivine tholeiite (HAOT) vents north of Mt. Shasta in the saddle between Whaleback and Deer Mtn. (Grove et al., 2002). Here we will see a nearly anhydrous HAOT and an H2O-rich PMA (~6.5 % H2O). We will then proceed to the south side of Mt. Shasta and examine the Sargents Ridge – age andesite and dacite lavas (~ 250,000 – 130,000 ybp). Finally we will hike to Red Butte, a satellite andesite dome that contains abundant quenched magmatic inclusions spanning the compositional range from PMA to andesite. These inclusions contain petrologic evidence of the crystallization processes that led to the production of the voluminous eruptive products of the Mt. Shasta stratocone (Krawczynski et al., 2006).

References and suggested Pre-Trip Reading

Christiansen et al. (1977) Resource appraisal of the Mt. Shasta wilderness study area, Siskiyou County, California. Open-file Report 77-250, US Geol Surv.

Crandall et al. (1984) Catastrophic debris avalanche from ancestral Mount Shasta volcano, California. Geology 12, 143-146.

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Session Type: *Poster Presentation*

AN EXPERIMENTAL INVESTIGATION OF THE BRITTLE-TRANSITION OF ÅHEIM DUNITES

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Samples of Åheim dunite (Norway) were deforme4d in conventional triaxial compredssion tests at confining pressures of 1.0 to 2.5 GPa, room temperature to 900°C and strain rates of 1 and 4*10-5¬ s-1 using a modified Griggs apparatus. Tin served as confining pressure medium at room temperature, sodium chloride at elevated temperatures, respectively. Åheim dunite is predominantly composed of olivine grains with a size of ~100 to 500 nm. While a moderate strain rate dependence of strength is observed in experiments performed so far, the high differential stress levels above the confining pressure indicate that brittle deformation prevails up to a temperature of at least 600°C. Microscopic investigations will help to identify operating deformation mechanisms. The objective of this experimental study is to delineate the transition from brittle to plastic deformation as a function of pressure, temperature and eventually strain rate for olivine-rich rocks. This transition affects the transport of fluids into peridotites for example and thus the extent of hydrothermal convection and ultimately the degree of serpentinization in the oceanic lithosphere.

Session Type: *Poster Presentation*

CHROMITE-HOSTED HYDROUS MELT INCLUSIONS IN OCEANIC DUNITES

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Dunites are commonly interpreted to serve as melt transport channels to the crust at mid-ocean ridges. This interpretation is based on field observations in the mantle section of ophiolites, and is supported by petrological studies and numerical physical models. Both observations and models emphasize that such dunites are replacive features, which are formed by focused reactive melt transport at high melt-rock ratios. On the ocean floor, mantle rocks are directly exposed on the ocean floor, but are confined mainly to fracture zones of slow to ultraslow spreading ridges. Along the “Sparsely Magmatic Zone” (SMZ) of the ultraslow spreading Gakkel Ridge (Arctic Ocean), partly serpentinized mantle peridotites represent the dominant lithology exposed along the axial valley walls. Orthopyroxene-free dunites are significantly more abundant at Gakkel Ridge compared to other mid-ocean ridges, which is apparently inconsistent with the high melt production that is required to form dunites. If recent melting and focused melt transport generated the Gakkel Ridge dunites, these melts should have generated a magmatic crust of near-normal thickness, rather than leading to widespread exposures of mantle rocks along the axial valley walls.

We present preliminary results of a petrological investigation of dunites and dunite-hosted melt inclusions from the central part of the SMZ. Preliminary investigations have shown that these homogeneous chromian spinels have a very limited compositional range at intermediate Cr#s (30-40) and can contain abundant multiphase inclusions, which may offer a clue to formation of these dunites. Among the included phases detected as yet are olivine, albite, cpx, amphibole, micas (K- and Na-phlogopite, muscovite), ilmenite and apatite. The presence of such unusual (hydrous) phases is in apparent contrast to the moderately LREE-depleted interstitial cpx in the dunite matrix, which is equilibrium with a MORB-type liquid. These cpx postdate the formation of the chromite-hosted melt inclusions.

Thus, the trace element composition of the homogenized melt inclusions should provide us with an earlier stage of focused reactive melt transport, which then can be associated with the LREE-depleted lherzolites, or the LREE-enriched harzburgites collected from the same location.

Session Type: *Poster Presentation*

INHERITED DEPLETION IN THE OCEANIC MANTLE

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What is the evidence for the presence of old depleted harzburgites in the convecting mantle? Osmium isotopes and geology, ideally in combination.

These are the observations: (1) Liu et al. (2008) reported low (unradiogenic) 187Os/188Os values in moderately depleted harzburgites from two locations along Gakkel Ridge. More fertile lherzolites from the same dredge haul have higher, somewhat variable osmium isotopic compositions. One of these locations is in the ‘amagmatic zone’, a 100-km long section of ridge at which exclusively mantle peridotites are exposed. This means that the melt generation was insufficient to produce a normal magmatic crustal sequence. A similar combination of modal depletion and unradiogenic osmium isotopes can be found in 15-degrees north area along the Mid-Atlantic Ridge (Harvey et al., 2006). In contrast to the small-scale isotopic heterogeneity at Gakkel Ridge, the ancient depletion at MAR 15N is more uniform. (2) The other area for which an ancient depletion has been proposed is the Gakkel Ridge around 18E. Extremely refractory harzburgites with spinel Cr# around 0.6 start occurring abruptly in a 50-km long axial section, immediately east of the inferred geochemical boundary between the western and eastern Gakkel mantle (Goldstein, et al, 2008). There is no indication for the presence of a more fertile component: the lowest spinel Cr# is 0.50 (out of 124 samples). All harzburgites are plagioclase-free. Basalts and gabbros are absent. No melt, no recent melting. The LREE enrichment in the interstitial cpxs indicates that a low-degree melt percolating along grain boundaries was the last asthenospheric event these otherwise extremely depleted harzburgites encountered. Unfortunately, osmium isotopic compositions have not been obtained on this sample suite.

What are the implications? (a) DMM is not a reservoir, but it may represent a mixture that includes ancient refractory components unsampled by and thus invisible in MORB. (b) Partial melting models based on peridotite spinel Cr# and cpx REE are not as useful as previously thought. (c) There is no evidence that ancient oceanic harzburgites do *not* represent recently released SCLM slivers, but it would make matters more complex and it is completely unnecessary.

We need to develop strategies to estimate the presence, scale and abundance of such ancient depletions. Without systematic osmium isotopic and highly detailed local-scale petrological studies, however, we will never leave the armwaving stage.

Goldstein et al. (2008) Nature 453, 89-93

Harvey et al. (2006) EPSL 244, 606-621
Liu et al. (2008) Nature 452, 311-316

Session Type: *Oral Presentation*

AN OVERVIEW OF SUBSOLIDUS PROCESSES RELEVANT FOR ABYSSAL PERIDOTITES

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Abyssal peridotites record partial melting, melt migration and melt stagnation conditions under mid-ocean ridges. In the past, most of us have directly interpolated the measured major and trace element mineral compositions to near-solidus conditions, without considering potential distorting effects of subsolidus chemical exchange between minerals. Here we present an overview of recent efforts to address following issues: (1) temperature-dependent interpyroxene trace element exchange on a grain- to submicron scale, with an emphasis on (a) cpx compositions: The high Kd(cpx/opx) for most incompatible lithophile trace elements will hardly affect trace element concentrations in cpx during cooling and exsolution because of its overall high trace element budget. This means that partial melting estimates, particularly the extent of melting in the garnet-field, are only slightly modified as a result of cooling [1]. (b) opx compositions: Here, the temperature-dependent D(cpx/opx) has most dramatic effects, leading to pronounced core-rim zoning [2]. Using these systematics, von der Handt et al. will present an application for high-T geospeedometry (900-1200°C) in a separate contribution at this meeting.

(2) spinel compositions: Temperature-dependent major element exchange between pyroxenes, spinels and olivine leads to the well-known core-rim Al-Cr zoning in pyroxenes. We evaluate to which extent the Al and Cr loss from pyroxenes can modify spinel compositions. In particular the spinel Cr#, which is a proxy for the inferred degree of partial melting, can be modified to lower values, depending on the near-solidus cpx/opx/spinel modes, and the cooling rate [3].

References:

[1] Hellebrand et al., (2005) Contributions to Mineralogy and Petrology 150, 486-504.
[2] von der Handt (2008) PhD thesis, University of Mainz
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Session Type: *Oral Presentation*

SIGNIFICANCE OF C-O-H-S BEARING FLUIDS AND MELTS IN THE SUB-CONTINENTAL LITHOSPHERIC MANTLE OF THE CENTRAL PANNONIAN BASIN (W-HUNGARY)

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Individual fluid inclusions and silicate melt inclusions (smi) entrapped along healed fractures of orthopyroxene and in the rim of clinopyroxene of amphibole-bearing spinel lherzolite peridotites from the central Pannonian Basin have been studied. Silicate melt inclusions contain glass and daughter minerals (clinopyroxene and an OH-bearing phase) together with fluid bubble(s). Both the individual fluid inclusion and the fluid phase of smi are CO2-dominated. Raman analysis of the frozen fluids confirmed that the fluid phase of the smi is pure CO2, whereas it also shed light on the presence of additional H2O (3000-3100 cm-1) and H2S (2611 cm-1) beside CO2 (1281 and 1388 cm-1) in the individual fluid inclusions. Infrared spectroscopy using FPA detectors show the distribution of C-O-H components inside the individual fluid inclusions. Clinopyroxene-hosted silicate melt inclusions have major- and trace element composition extremely similar to that of the orthopyroxene-hosted ones. The residual glass show evolved, mainly trachyandesitic composition with low totals (~ 94-95 wt%) and elevated SO2 content (0.15-0.25 wt%). Primitive mantle normalized trace element patterns of the bulk silicate melt inclusions show enrichment in incompatible trace elements (LILE, P and LREE) compared to compatible elements and also show negative Hf-anomaly. LA-ICP-MS study on the individual fluid inclusions proved that fluid inclusions also show positive anomaly in highly incompatible trace and fluid mobile LIL elements, especially in K, Rb, Sr, Pb, Th and U with respect to the host minerals.

Our results suggest that not only fluid-bearing silicate melt but quasi-pure fluids were also entrapped together at the same time. Fluid-bearing silicate melt inclusions and individual fluid inclusions have been enclosed in the rims of clinopyroxene and along healed fractures of orthopyroxene. The composition of the fluids in the two different inclusion-types was the same regardless of host minerals and petrographic appearance. This suggests that fluid-silicate immiscibility took place at the time of entrapment and the original fluid-rich evolved silicate melt was entrapped as an immiscibled, silicate melt-poor fluid phase and a homogeneous silicate melt containing significant amount of dissolved fluid. The supposed immiscibility should take place at mantle conditions, because melting of the rim of clinopyroxene is required for the entrapment of fluid inclusions and silicate melt inclusions, the density of fluids in the individual fluid inclusions shows mantle values (~1 g/cm3) and silicate melt inclusions and fluid inclusions of clinopyroxene and orthopyroxene show the same compositional and chemical features. Generation, migration and evolution of such fluids and melts have been rarely mentioned from mantle peridotites worldwide and have never been published from the Pannonian Basin yet.

Session Type: *Oral Presentation*

PYROXENITES IN BASALT SOURCE REGIONS? A REVIEW.

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The hypothesis that pyroxenites play a key role in the sources of oceanic basalts continues to receive considerable attention, with many studies both supporting and debunking the model. In this presentation I will review some of the considerations and problems that shed light on the present status of the hypothesis: Some of the key considerations that are favorable to the pyroxenite hypothesis are (1) widespread signatures of crustal recycling in oceanic island basalts (2) compositional features of OIB that may not easily be explained by partial melting of peridotite, including major element (high FeO*, CaO, CaO/Al2O3, TiO2), trace element (Ni and other transition elements), and Os isotopic compositions (3) correlations between isotopic, trace, and major elements in OIB that provide a strong link between the geochemical origin of mantle heterogeneities and their petrologic behavior in basalt source regions. On the other hand, many of these features have alternative explanations and there are also problems explaining key features of basalts with partial melting of pyroxenite. These include (1) the physics of melt extraction from pyroxenite layers may not permit preservation of distinct pyroxenite partial melt signatures unless the layers are very large (2) some features of OIB seem to require melt fractions and melting rates that are more easily explained by partial melting of peridotite (3) correlations predicted by partial melting of a compound pyroxenite/peridotite mantle are not always observed. Some of these considerations have lead to autometasomatism models, in which partial melts of pyroxenite react with surrounding peridotite, which in turn partially melt to produce OIB parental liquids. These more complex models have considerable appeal, though in some forms they seem to require very large proportions of pyroxenite in basalt source regions.

Session Type: *Oral Presentation*

THE RHEOLOGY OF MANTLE SHEAR ZONES

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A combination of geological and geophysical observations demonstrates that plastic deformation is often localized within shear zones in the mantle. We will outline the mechanisms that promote strain localization – building on the structures observed during the field trip to the Josephine Peridotite on the previous days, and the presentations by Warren et al. and Skemer et al. To first order, we understand that the viscosity of shear zones must be lower than the country rock for strain to remain localized. Based on the extrapolation of experimental data – and applying the assumption that stress remains continuous across a viscous shear zone – we can evaluate likely mechanisms including: variations in grain size (through activation of grain size sensitive creep mechanism such as diffusion creep and grain boundary sliding), melt content, water content and lithology. Furthermore, strain localization will be enhanced by feedbacks among these processes, such as grain size evolution (owing to grain size pinning and dynamic recrystallization), organization of melt during deformation, formation of LPO resulting in viscous anisotropy and dissipative heating. We will outline experimental and theoretical constraints on these processes to evaluate the origin of the Josephine shear zones – and provide a test necessary to evaluate mechanisms responsible for strain localization at larger scales, including plate-scale transform faults. Finally, we will use the combination of geologic and experimental constraints to speculate on the origin of intermediate depth earthquakes and interactions between viscous and brittle deformation at the base of the seismogenic zone.

Session Type: *Oral Presentation*

COUPLED MELT EXTRACTION AND LITHOSPHERE LUBRICATION AT PLATE BOUNDARIES

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In our current understanding, plates are defined by their weakest boundaries and discontinuities in displacements. By an ensemble of interactions, melt and other fluids may contribute significantly to the low strength of plate boundaries. Based on experimental and theroretical considerations, we develop the idea that melt organizes from the grain-scale upwards into networks of melt-rich shear zones, during deformation of the mantle. These networks organize along the lithosphere-asthenosphere boundary (LAB) and effectively weaken it, while transporting melt towards the surface. We discuss seismic and geologic signatures of such organization processes.

Session Type: *Poster Presentation*

THE VISCOSITY CONTRAST BETWEEN THE LOWER CRUST AND UPPER MANTLE.

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The viscosity contrast between the lower crust and upper mantle controls key tectonic processes such as lithospheric coupling between the crust and mantle and the origin and transmission of plate driving forces. While experimental data provide a basis to predict viscosity contrast, pertinent geologic observations of synchronously deformed gabbro and peridotite are not well documented. We are investigating this problem by analyzing microstructures in deformed gabbronorite dikes (~10-50 cm) and host harzburgite from the Oman ophiolite. Outcrop scale observations demonstrate that deformation is highly localized in 1-50 mm wide mylonitic shear bands within the gabbronorite. We constrained the conditions of deformation using pyroxene thermometry, petrology, grain size piezometry and EBSD analyses of lattice preferred orientation (LPO). Syn-deformation temperature ranged from ~600-800C, based on Fe-Mg-Ca exchange between recrystallized orthopyroxene-clinopyroxene pairs using QUILF (Andersen et al., 1993) and tremolite/actinolite thermal stability. Pressure was ~300 MPa based on structural thickness of the section. Interpretation of plagioclase grain size indicates stress was ~80 MPa during localized, low T deformation in gabbronorite shear bands. In contrast, olivine grain size in peridotite corresponds to a stress of ~10 MPa, probably during earlier, high T, distributed deformation. Plagioclase exhibits a LPO throughout the analyzed sample. However, plagioclase fabric strength does vary with variations in grain size (from ~30 - 50 μm). This observation suggest that while deformation of the gabbronorite involved a significant component of dislocation creep, there is some indication that diffusion creep also played a role. Olivine fabrics in the harzburgite, indicative of deformation by dislocation creep, are consistently oriented throughout the outcrop area of interest with the [100] axis at ~45 to the shear plane/dike orientation. The presence of amphibole as an active participant in the deformation may indicate that deformation occurred at a relatively high water content. Our observations indicate that gabbroic rocks were weaker than mantle peridotite during low T hydrous deformation.

Session Type: *Oral Presentation*

DIFFERENTIAL MOVEMENT IN THE UPPER MANTLE DUE TO FOCUSED MELT PERCOLATION

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Focused melt percolation may importantly be responsible for density differences in the upper mantle. That might ultimately trigger differential movements unrelated to far-field tectonic forces and so could also provide a mechanism to exhume high-pressure rocks. However, our understanding of melt percolation on upper mantle dynamics is very limited. We present field and petrological evidences for melt-induced deformation from two locations as well as numerical simulations to understand the parameters that control melt-percolation induced deformation. Field evidence for the mechanism comes from the Kohistan arc and the BeniBoussera ultramafic massifs.

In the Kohistan arc, km-scale ultramafic bodies are exposed within the so-called Chilas Complex. Detailed field observations document emplacement of these bodies within a semi-crystallized gabbronorite crystal mush. Even though isotope and mineral trace elements document that ultramafic rocks and the surrounding gabbronorite stem from a common parental magma, there is petrological evidence for different fractionation mechanisms, possibly related to different fractionation pressures (Jagoutz et al. 2006, 2007).

BeniBousera, in northern Morocco, is generally described as a homogeneous lherzolitic body associated with pyroxenitic dyes. Detailed field observations document that pyroxenitic dykes are not homogeneously distributed throughout the massif but are clustered within restricted hundred of meters wide zones. Multiple field relations document the importance melt-rock reactions within these zones; peridotites are dominantly harzbugite with subordinate dunite and secondary lherzolite. A visible difference in strain intensity within the pyroxenites can qualitatively be correlated with inferred relative fractionation pressures. Rocks with high fractionation pressure have a stronger fabric than rocks with lower fractionation pressure. The surrounding homogeneous lherzolite, texturally distinct from the secondary lherzolite is separated from these pyroxenite-rich zones by high-strain zones and generally appear significantly less deformed. We interpret the field relationships for both examples to document melt differential movement induced by melt percolation. However, both examples document the effect for hundred of meter wide percolation zones. Smaller scale percolation features (e.g. isolated dunitic dykes in Lanzo) show no evidence for differential movement along their border. We interpret these field relationships as due to an interplay between the volume of the lower density area and the magnitude of density difference at a given instance. A set of simple numerical experiments are performed to obtain a better understanding in the physical processes that might be responsible for the observed structures.

Session Type: *Poster Presentation*

THE RIFT-TO-DRIFT TRANSITION IN THE NORTH ATLANTIC: A STUTTERING START OF THE MORB MACHINE?

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It is generally accepted that rupturing of continents is followed by localized seafloor spreading at mid ocean ridges (MOR), which are considered, on geological time scales, to be symmetric and steady state. The continuity of this process is documented by the correspondence of crustal accretion ages and magmatic ages. While these processes are well studied at present-day MOR, little is known about how stable these systems are during their embryonic stage. Even though our understanding of the mechanisms associated with extension and rifting of continents improved significantly in the last decade the processes that ultimately start the MOR basalt (MORB) engine and the switch from rifting to drifting are still poorly constrained. One of the most striking results of ODP drilling along the Iberia-Newfoundland conjugate margins was the scarcity of effusive magmatism and only minor volumes of intrusive rocks even in areas with undisputed oceanic magnetic anomalies. This observation is in conflict with numerical melting models that generally predict large volumes of MORB type melt. The genetic and temporal relationships of alkaline and MORB type magmatism associated with the onset of seafloor spreading may clarify the rift-to-drift transition. Mineral U-Pb and ^{40}Ar-^{39}Ar age data from ODP samples across the conjugate Iberia-Newfoundland magma-poor margins have document the igneous history related to the onset of seafloor spreading in the southern North Atlantic (Jagoutz et al. 2007). Here we present additional mineral- major and trace element data and isotopic data on leached plagioclase mineral separates from MORB type gabbroic clasts and alkaline dykes which have similar Pb, Sr and Nd isotopic composition to present day MORB. Indicating a common source for the different magmatic rocks. Our results document an interplay between tectonic and magmatism. Isotopic data document the variable magmatic products stem from a common MORB type source and are likely the result of variable degree of partial melting. Based on these results we will present a refined model for the rift-to-drift transition in the Northern Atlantic.

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IN-SITU LA-ICP-MS ANALYSIS OF PYROXENE IN THE PERIDOTITE OF THE COAST RANGE OPHIOLITE, CALIFORNIA

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The geochemical flux in the mantle wedge is critical to our understanding of arc volcanism, and forms an important aspect of the subduction factory. Studies of arc volcanism are commonly used to understand this flux. This approach is limited because the composition of the mantle is unknown and the flux can only be inferred. An alternative approach is to examine outcrops of lithospheric mantle that underlie supra-subduction zone (SSZ) ophiolites, which allows us to directly examine their petrology and geochemistry. The Coast Range Ophiolite (CRO) offers the best evidence of this interaction between flux and the mantle wedge because the CRO represents, in large part, supra-subduction zone (SSZ) formation by fore-arc extension.

We employed Laser Ablation-Inductively Coupled Plasma-Mass Spectrometry (LA-ICP-MS) to analyze unaltered pyroxenes. We analyzed in-situ clinopyroxene and orthopyroxene from Cuesta Ridge, Chrome (Grey Eagle Mine), Del Puerto Canyon, and Stonyford. Pyroxenes fall into two categories: (1) Al-rich, spinel lherzolite-harzburgite (compositionally similar to abyssal peridotites), and (2) Cr-spinel harzburgite and dunite (SSZ peridotites). Abyssal clinopyroxenes are enriched in minor elements (TiO2 ≈0.3%, Na2O~1%) and have rare-earth element (REE) compositions that reflect equilibrium with MORB-like melts; abyssal orthopyroxenes are lower in minor elements, but still require REE in equilibrium with MORB. In contrast, SSZ pyroxenes (clino- and ortho-) have extremely low minor element contents (TiO2 ≈0.05%, Na2O<0.1%) and LREE concentrations that are below detection (<0.01x primitive mantle). MREE-HREE patterns indicate equilibration with an extremely refractory melt.

We propose a 2 stage melting model. Abyssal peridotite (Stage 1) represents ~7% – 12% partial melting of MORB-source mantle in the garnet-lherzolite field. SSZ peridotite (Stage 2) represents further partial melting, up to 30% in the spinel-lherzolite field, after Stage 1 partial melting. Elevated fluid mobile element concentrations (Li, B, Rb, Pb) indicate hydrous melting in all samples. We expect that our study will constitute a major advance in understanding the magmatic flux through the mantle wedge portion of the subduction factory, identify primary rock compositions, add to the literature concerning the CRO, and champion the use of LA-ICP-MS.

Session Type: *Oral Presentation*

GEOCHEMISTRY AND MICROBIAL ECOPHYSIOLOGY OF THE CEDARS ULTRABASIC SPRINGS

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Fluids emerging from non-saline ultrabasic (pH > 11.0) springs on the Cedars peridotite near Cazadero, California are being investigated to determine the geochemical nature of the springs and the ecophysiology of the indigenous microbial community. Modern serpentinization processes occurring at this site produce an abundance of Ca-OH type springs that include some of the most basic (pH 12.0) and most reduced (Eh < -700 mV) natural spring waters in the world. The Cedars ultrabasic springs invariably contain mg/l levels of H2, CH4, and N2, as well as smaller amount of Ar and traces of a very unusual mixture of hydrocarbons that is dominated by alkylated cyclohexane and cyclopentane compounds. The source of these presently remains a mystery. Chemical profiles of three springs revealed a sizable range in salt concentrations (e.g. 1.0 – 22.9 mM Na+) showing the highest concentrations in the lowest elevation springs and much lower ion concentrations in two springs at higher elevations. With the exception of methane, hydrocarbon concentrations also decreased with elevation, indicating a potentially deep source for those compounds. One spring, NS1, is among the most basic non-saline natural waters reported to date (pH 11.6 with 1.0 mM Na+). Unlike deep-sea serpentinization, which is high in Na+, the observed combination of non-saline ultrabasic spring water represents an environmental extreme that strikes at one of the most fundamental features of life, the electrochemically charged membrane. The Cedars springs are energy-rich, but are severely electron acceptor-limited to the extent that they may exceed the environmental limits for maintenance of a proton (or sodium) motive force, which is widely considered to be one of the most fundamental features of all known life. Extreme disequilibrium between the emerging ultrabasic waters and the atmosphere leads to in situ precipitation of travertines which typically grow 1-2 mm/year, but in some areas can exceed 1 mm/day. 14C ages of these structures shows kiloyear scale stability of spring complexes, with one formation dating to 7 kyr before present. Ultrabasic spring waters contain extremely low concentrations of most dissolved ions, which are additional obstacles for potential inhabitants. Nevertheless, microbial life is shown to inhabit most solid surfaces albeit in thin layers. The present work returns to one of the original sites that connected Ca-OH type waters with modern serpentinization over forty years ago and provides a new perspective on an historical site that is one of the most active sites of terrestrial serpentinization in the modern world.

Session Type: *Oral Presentation*

THE INFLUENCE OF MELT IMPREGNATION AND HIGH TEMPERATURE SHEAR ZONE ON PERIDOTITE GEOCHEMISTRY IN THE UPPER MANTLE (LANZO ITALY).

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Different mantle domains characterize present-day and ancient ocean-continent transition zones and many of them show signs of melt/rock reaction, but their relationships to deformation processes in the thermal boundary layer are poorly understood. Studies on orogenic peridotites and mantle xenoliths proposed that melt migration and reaction is a major process in controlling textures, mineralogy and geochemistry of mantle peridotite. To explore the effects of deformation on melt migration processes in the upper mantle we investigate the relationships between deformation, melt-rock reaction, peridotite geochemistry and mafic dike emplacement in the Lanzo massif (NW-Italy).

The major shear zone, between the northern and central parts of the massif, is characterized by an asymmetric spatial distribution of deformation with respect to the mylonite and increase from south to north. Textures are from porphyroclastic to mylonite. Discordant gabbroic dikes are asymmetrically distributed and concentrated in the southern part of the shear zone.

The Lanzo massif peridotite indicates high temperature (~1100ºC) from the spinel facies and retrogression (860-800ºC) in the plagioclase facies. Cr# and TiO2 concentrations in spinel show an extreme variability and cover the entire range from spinel to plagioclase peridotites, indicating disequilibrium. The largest variation is observed in the porphyroclastic rocks, while in mylonite the composition is more homogeneous suggesting a faster equilibration under the influence of grain size reduction. This indicates exhumation to shallower depth must have been rapid, in order to preserve disequilibrium chemical compositions. Some cpx and ol porphyroclasts show signs of previous reaction textures with a melt (cpx +liq -> opx + plg ± ol and Liq. 1 + ol -> opx (± Liq. 2). These textures are present in the entire massif and became rare in the mylonite zone, indicating that the mylonite formation postdates melt/rock reactions.

The peridotites display a large range of composition from fertile plagioclase peridotite to refractory harzburgite and dunite. Deformed peridotites tend to be compositionally more homogeneous and fertile than weakly deformed peridotites. The compositions of the peridotite from the deformed zone display major (e.g. Al, Na) and REE (e.g. La, Yb) enrichment. On average, the REE composition of the northern body is less enriched than the central body. The chemical composition of ~20% of plagioclase peridotite could be explained by a simple melting model of a primitive mantle source. Others 60% combined refertilization model consisting of melt increments from both garnet pyroxenite and spinel peridotite sources reasonably reproduces the plagioclase whole rock composition.

This study highlights the initial polarity of the shear zone: the central part is the footwall and the northern part is the hanging wall. The preservation of chemical disequilibrium of minerals suggests a rapid exhumation and a rapid temperature decrease, which corresponds to an asymmetric structure toward the shear zone. The Lanzo shear zone exhumed mantle from near asthenospheric to lithosphere conditions. Our results indicate that melt migration and high temperature deformation are juxtaposed both in time and space. Melt migration occurred on a km-scale over the entire massif, but local differences exist. The particular mylonite area, seems to be the most melt enriched part, clearly indicating the mutual relationships between melt accumulation and deformation. Melt migration, peridotite composition and the concentration of dikes in the footwall suggest that the shear zone acted as a melt barrier and a melt conduit.

Session Type: *Oral Presentation*

EXPERIMENTAL INVESTIGATIONS OF THE POTENTIAL TO SEQUESTER CO2 IN OCEANIC CRUST

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A promising solution to the problem of anthropogenic greenhouse carbon is through carbonation of ultramafic minerals. Investigations of the carbonation potential of magnesium silicate minerals in industrial settings have been conducted, but the process is energy intensive and expensive. Direct injection of carbon dioxide into seafloor hydrothermal systems that are rich in magnesium silicate minerals may provide an alternate, viable pathway for sequestering carbon dioxide. Experiments were conducted on seawater-oceanic crust-carbon dioxide systems to simulate injection of carbon dioxide into a seafloor hydrothermal system and determine the extent of fluid-rock reaction. The solid reactant was comprised of 71.4% olivine, 18.4% diopside, and 10.2% enstatite. This proxy for oceanic crust was reacted at 300 C and 500 bar in a synthetic seawater solution to approach steady state, then injected with supercritical carbon dioxide and reacted for 550 hours. Three mole percent of carbon dioxide relative to water was injected into the experimental system. The experimental pressure decreased 17 bars in three hours following carbon dioxide injection due to initial dissolution and mineralization of carbon dioxide. The pressure decreased an additional 20 bars due to mineralization during the remainder of the experiment. Approximately 20% of injected carbon dioxide was mineralized, and the remainder was dissolved into the aqueous fluid. Brine-rock reaction decreased pH from 7.4 to 5. Aqueous calcium was consumed following carbon dioxide injection, whereas magnesium and silica concentrations increased due to increased brine acidity. Mineral reactants dissolved, as indicated by surface pits and etching on mineral fragments and the increase of aqueous magnesium and silica concentration. Mineral reactants were serpentinized, and then reacted to talc and magnesite following carbon dioxide injection. Magnesite comprised approximately 30 weight % of the reaction products. Carbon dioxide dissolution and attendant magnesite precipitation indicates that direct injection of carbon dioxide into oceanic crust may be a viable means of sequestering anthropogenic carbon.

Session Type: *Poster Presentation*

A PERIODIC SHEAR-HEATING MECHANISM FOR INTERMEDIATE-DEPTH EARTHQUAKES IN THE MANTLE

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Intermediate-depth earthquakes, at depths of 50–300 km in subduction zones, occur below the brittle–ductile transition, where high pressures render frictional failure unlikely. Their location approximately coincides with 600 to 800°C isotherms in thermal models, suggesting a thermally activated mechanism for their origin. Some earthquakes may occur by frictional failure owing to high pore pressure that might result from metamorphic dehydration. Because some intermediate-depth earthquakes occur 30 to 50 km below the paleo-sea floor, however, the hydrous minerals required for the dehydration mechanism may not be present. Here we present an alternative mechanism to explain such earthquakes, involving the onset of highly localized viscous creep in pre-existing, fine-grained shear zones. Our numerical model uses olivine flow laws for a fine-grained, viscous shear zone in a coarse-grained, elastic half space, with initial temperatures from 600–800°C and background strain rates of 10-12 to 10-15 s-1. When shear heating becomes important, strain rate and temperature increase rapidly to over 1 s-1 and 1,400°C. The stress then drops dramatically, followed by low strain rates and cooling. Continued far-field deformation produces a quasi-periodic series of such instabilities.

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IN SITU CARBONATION OF PERIDOTITE FOR CO2 CAPTURE AND STORAGE

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We discuss formation of ophicalcite, which Evans and Trommsdorff called ophi@#$t. I often interpret the phrase “fools rush in where angels fear to tread” as a call to action. We’re hoping that this well-trained audience will help us find the correct path. Given concern about atmospheric CO2 and global climate, one can dream of creating ophicalcite for carbon storage. Adding 1 wt% CO2 to the peridotite of the Samail ophiolite in Oman would consume ¼ of atmospheric CO2. Converting all olivine to magnesite + quartz would consume ~1017 kg of CO2. Worldwide, there are several ophiolites this size plus seafloor peridotite exposures. Rate, not capacity, is the key.

High pH, Ca-OH, low carbon waters form via alteration of peridotite, and precipitate travertine where they combine with atmospheric CO2. Clarke & Fontes 1990 dated a travertine terrace in Oman, and underlying veins in peridotite, using 14C; terrace and veins were<45,000 years old. We thought carbonate veins in peridotite far from springs were Cretaceous, formed by hydrothermal alteration at an ocean ridge or during ophiolite obduction. Instead, 14C data reveal that these are also <45,000 years old. Peridotite carbonation in Oman consumes ~107 kg of CO2 per year. The increase in atmospheric CO2 due to anthropogenic input is ~1013 kg per year. To provide a “significant” carbon sink, the rate in Oman must increase by a factor of 104 to 106.

Drilling and hydrofracture can expose sub-surface peridotite to fluid at elevated pressure and temperature. Supplying pure CO2 also enhances rates. Thermal models incorporating advection, diffusion and exothermic heating reveal a self-heating regime where rapid reaction sustains high temperature. Together, these could yield a factor of >106 increase in carbonation rates. We are also investigating less efficient, but less expensive carbonation via reaction between shallow sea water and submarine peridotite.

Session Type: *Poster Presentation*

HIGH PB/CE RESERVOIR IN DEPLETED, ALTERED MANTLE PERIDOTITES

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We find consistent, high Pb/Ce in ICP-MS data for residual peridotites from the Mid-Atlantic Ridge (MAR, from ODP Leg 209), mid-ocean ridges (MOR) worldwide [1], Oman, Josephine and Trinity ophiolites, and the Jurassic Talkeetna arc. (MAR and Oman data from Montpellier; Josephine, Trinity and Talkeetna from WSU; some Pb concentrations checked by ID at WHOI). If time permits, we will add recent data from the Feather River peridotite [2].

These samples have average Pb/Ce ~ 10x primitive mantle (PM), with only 3 of 180 samples < PM. REE patterns and Ce concentration < PM in 165 of 180 samples are consistent with depletion via melt extraction, plus some magmatic refertilization. High Pb, averaging ~ 1x PM, might be due to (a) retention of Pb in residual sulfide, (b) addition of Pb in sulfide (and perhaps plagioclase in some cases) during 'impregnation' by crystallizing melt, and/or (c) addition of Pb in sulfide (and perhaps carbonate …) during alteration. Pb/Ce is correlated negatively with Ce concentration, suggesting some role for (a), but the high Pb concentrations, coupled with experimental crystal/liquid partition coefficients and observations of MORB indicate that a residual origin alone is an unlikely explanation. Pb concentration is most strongly correlated with Th, Nb and Ce. These elements are commonly considered immobile during hydrothermal alteration, and correlations with Pb are positive, suggesting an important role for (b) and a limited role for (c).

All samples except Talkeetna have Th/Pb < PM. All samples except some MOR peridotites also have U/Pb < PM. DRILLED MAR peridotites show U/Pb > PM in shallow, oxidized samples and < PM in downhole, reduced samples. Thus, high U/Pb in DREDGED MOR peridotites [1] is attributed to seafloor weathering. Given that oxidized weathering only extends tens of meters below the seafloor, we infer that most MOR peridotites have Th/Pb and U/Pb < PM. If they form with Pb isotope ratios similar to MORB, these rocks will evolve to values less radiogenic than the geochron. The effect of subduction modification on Th/Pb and U/Pb is unclear. For example, if elevated Pb is common in unaltered residual peridotites, subduction modification is likely to be minor.

The size of the high Pb/Ce, low Th/Pb and U/Pb reservoir represented by these rocks depends on the reason for elevated Pb. We discuss three possibilities as outlined above. (a) Pb enrichment is most marked in highly depleted residues, abundant in the upper 30 km of the oceanic mantle. (b) Crystallization of igneous sulfide and plagioclase from cooling melt migrating along peridotite grain boundaries may be common in the upper 20 km in plates formed at slow spreading ridges. (c) Hydrothermal alteration of shallow mantle peridotite at slow spreading ridges might extend to 10 km. Based on these estimates, over geologic time tens of percent of mantle Pb could be sequestered in such a reservoir. This offers a potential solution to the "first lead paradox".

[1] Niu, J. Petrol. 2004; [2] Li & Lee, Chem. Geol. 2006

Session Type: *Poster Presentation*

CHARACTERISTICS OF SUBCONTINENTAL LITHOSPHERIC MANTLE BENEATH ASAN AND PYEONGTAEK, KOREA

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Geochemical characteristics of spinel peridotite xenoliths, enclosed in Miocene volcanic rocks from Asan and Pyeongtaek, area, Korea, provide important clues for understanding the lithosphere composition, equilibrium temperature and pressure conditions, and depletion and enrichment processes of subcontinental lithospheric mantle beneath Asan and Pyeongtaek area. The spinel peridotite xenoliths with protogranular textures were accidentally trapped by the ascending magma. The spinel peridotite xenoliths from both areas originate from depths between 56 and 74 km, determined by heat flow data, O'Neill (1981) geobarometer, and Brey and Köhler (1990) geothermometer. The ranges of equilibrium temperature obtained from the investigated materials are about 987˜1164 °C for Asan spinel peridotites and 937˜1045°C for Pyeongtaek spinel peridotites. Modeling using HREEs indicates that the mantle xenoliths from Asan and Pyeongtaek have been undergone 1˜5% and 1˜10% fractional melting, respectively. The LREE-enriched characteristics of the analyzed samples are considered to have been attributed to cryptic metasomatism. Sr and Nd isotope compositions of subcontinental lithospheric mantle beneath both areas are similar to those beneath East China and South Korea (Cheju Island and Boeun) rather than Japanese Island Arc.

Session Type: *Poster Presentation*

ORIGIN OF LATE MIOCENE VOLCANIC ROCKS IN ASAN AND PYEONGTAEK, KOREA : NATURE OF SOURCE MANTLE AND MAGMA PATHWAY TO SURFACE

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The Late Miocene Asan trachybasalt and Pyeongtaek basanite are derived from about 160 km depth at the end of an opening of the East Sea (Japan Sea) back-arc. Whole-rock geochemistry, and pressure and temperature conditions of mineral phases within magma chamber indicate that source mantle of both volcanic rocks was an enriched garnet peridotite. According to a non-modal batch melting model, the Asan trachybasalt and Pyeongtaek basanite was generated from about 4 - 6 % and 2 - 3 % partial melting, respectively. Crystallization pressures and temperatures of olivines and clinopyroxenes within ascending magmas of both areas indicate that olivines in Asan trachybasalt and Pyeongtaek basanite were crystallized at 90 - 120 km and 60 -110 km, respectively, and clinopyroxenes were crystallized at 30 - 80 km and 30 - 60 km, respectively. Ascending magma of both areas enclosed mantle xenoliths at about 56 - 74 km depth. Plagioclases in Asan trachybasalt were crystallized at about 20 - 30 km. The ascending magma of the Asan trachybasalt stagnated for short time at Moho depth, because of density difference between upper mantle and crust. The small size of the plagioclases in the Pyeongtaek basanite indicates that the ascending magma beneath Pyeongtaek may was stagnated for a shorter time than ascending magma beneath Aasn..

Session Type: *Oral Presentation*

FORMATION OF MELT-RICH BANDS IN EXPERIMENTALLY DEFORMED PARTIALLY MOLTEN ROCK: MICROSTRUCTURAL EVOLUTION AND SCALING TO EARTH'S MANTLE

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Investigating the interactions between deformation and melt migration is of great importance to understanding shear localization at plate boundaries and melt transport mechanisms in Earth's upper mantle. Experimentally deformed partially molten samples of olivine-rich rocks have shown the emergence of patterns in the distribution of melt in response to an applied shear stress. Melt pockets have a shape preferred orientation with long axes aligned ~20 degrees antithetic to the shear plane. Under some conditions melt segregates into an interconnected network of distinct bands of elevated melt fraction of the same orientation. To explore the dynamics of stress-driven melt segregation and scaling of this process to the conditions of Earth's mantle, we have preformed a series of torsion experiments on fine grained aggregates of olivine + 4% mid-ocean ridge basalt with and without the addition of chromite, which decreases the permeability of the aggregate. Experiments were preformed across an order of magnitude in strain rate under both constant rate and constant stress conditions (2x10^-5 to 3x10^-4 /s, corresponding to shear stresses ranging from ~40 to 120 MPa). Samples were deformed to finite shear strains ranging from 0.8 to 6.7. Observations from experiments with strain markers reveal strain localization within the melt-rich bands. One intriguing result from these (and previous) experiments is that the band angle of ~20 degrees to the shear plane is maintained across the entire range of shear strains observed. Observations from samples quenched at different stages in the development of melt-rich bands provide information about the microstructural and kinematic evolution of the material that leads to this constant band angle. Another goal of these experiments was to test the relationship between band spacing and compaction length (the characteristic length scale for compaction driven flow) as a way to scale this process to conditions in Earth's mantle. Preliminary results show a preferred thickness (~20 microns) and spacing (~250 microns) of bands that is constant across the range of compaction lengths (~400-1300 microns) explored in this set of experiments. We hypothesize that another length scale, such as the grain size, may play an important role in limiting the thickness of melt-rich bands. Further experiments are needed to determine the effects of grain size on band properties. The results of these experiments have important implications for the interpretation of dunite networks in ophiolites, which are widely interpreted to represent melt-rich channels. These experiments also show evidence for phase segregation leading to strain localization, which may be an important process in the formation of shear zones and plate boundaries.

Session Type: *Poster Presentation*

RELATIONSHIPS BETWEEN COMPOSITIONAL LAYERING, STRUCTURAL FABRIC, AND THE FORMATION OF MELT PATHWAYS IN THE TWIN SISTERS COMPLEX, WASHINGTON STATE

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The Twin Sisters complex is a large (~6 by 16 km), virtually unaltered (little serpentinization) ultramafic body located in the North Cascades, Washington State. We present geological observations from a well-exposed, 60 m by 70 m area of the eastern Twin Sisters complex. The study area was surveyed using a total station and provides information on the relationships between compositional banding, fabric development, dike intrusion, and the development of melt pathways in naturally deforming mantle. Within the surveyed area, centimeter to meter-scale compositional layering is defined by alternating layers of orthopyroxene-absent dunite (>95% olivine) and orthopyroxene-present (~15% orthopyroxene; ~85% olivine) harzburgite aligned parallel to a roughly N-S striking and steeply dipping foliation. Discontinuous, cm-wide chromite seams occur in both the dunite and harzburgite domains and range in band thickness from ~3 to 45 centimeters. Orthopyroxene- and clinopyroxene-bearing dikes occur throughout the study area and crosscut the host dunite and harzburgite layering. Orthopyroxene-bearing dikes range in thickness from <1 - 9 cm and are variably oriented. Unlike other areas of the Twin Sisters massif where deformed (folded and boudinaged) orthopyroxene-bearing dikes have been reported, in the study area these dikes are dominantly tabular though some are locally folded. Clinopyroxene-bearing dikes are generally tabular, display less variation in thickness (<1 - 2.5 cm), and are more consistently orientated (~007/55W average orientation) than orthopyroxene-bearing dikes.

A series of roughly N-S oriented, m-scale dunite zones occur throughout the study area and cross-cut the host dunite-harzburgite compositional layering at a low angle and, more obviously, cross cut the orthopyroxene-bearing dikes. We interpret these zones to represent former melt channels. These melt channels commonly show an increase in the size of olivine grains relative to the host dunite-harzburgite layers with individual olivine crystals up to 10 cm in length, and often display porphyroclastic texture. Abundant chromite seams also occur within these melt channels and are aligned parallel to the channel margins. Otherwise continuous orthopyroxene-bearing dikes are commonly obliterated within these melt pathways and the along-strike continuity of these dikes across some of the dunite zones suggest that at least some melt pathways did not act as shear zones. However, in at least one case an orthopyroxene-bearing dike was displaced rigidly by ~20 cm southward from its continuation in the host rock. A brecciated zone was observed on the western side of another interpreted melt channel with drag indicators suggesting southward sense of shear of the center part of the zone. Clinopyroxene-bearing dikes in the study area cross cut these zones and all other structural features in the study area (with the exception of ~E-W oriented late-stage serpentinite-filled faults), indicating that they are younger. Ongoing investigation in the Twin Sisters complex will allow for quantitative estimates of compositional, fabric, and deformation heterogeneity within the lithospheric mantle.

Session Type: *Oral Presentation*

THE LHERZ MASSIF: 2 GA HISTORY OF MANTLE EVOLUTION.

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Differentiation of the Earth's mantle occurred principally through partial melting and extraction of basaltic melt. Among the mantle rocks occurring at the Earth's surface, harzburgites are widely considered as refractory mantle residues left after extraction of a basaltic component. In contrast, fertile lherzolites are generally regarded as pristine mantle, only weakly affected by partial melting. However in the Lherz Massif (France), structural mapping shows that the lherzolites are secondary rocks formed at the expense of Archean harzburgites (2.3 Ga, Os ages). Variations of major, minor and trace elements across the harzburgite-lherzolite contacts indicate that the lherzolites were formed through a refertilization process

involving interaction of refractory, lithospheric mantle with upwelling asthenospheric partial melts. The refertilization likely occured during the post-collisional thermal event recognized in the Variscan belt in Pyrenees, and was probably associated with strain localization. Rare-earth elements (REE) in clinopyroxenes display variable chondrite-normalized patterns. Massive harzburgite bodies have U-shaped REE patterns whereas lherzolites show the classic N-MORB REE pattern observed in orogenic lherzolites worldwide. However, at the contact, both lherzolite and harzburgite show more LREE-enriched clinopyroxenes than their distal counterparts, a feature that cannot be explained by partial melting. These enrichments rather lead to interpret the contact as a percolation-reaction front.

To further constrain the mechanisms involved in the refertilisation process, we investigated the Sr, Nd and Hf isotopic compositions of 16 samples (whole-rocks and clinopyroxene separates) across a harburgite-lherzolite contact, as well as of "distal" samples, using TIMS and MC-ICP-MS techniques. Combined with previous works, these new data indicate that: a) the Lherz peridotites show a wide range of isotopic signatures almost covering the whole domain of cratonic and non-cratonic peridotites worldwide, notably for Hf and Nd; b) the distal harzburgitic protolith and refertilized lherzolites have well-individualized isotopic signatures defining two different poles; c) near the contact, the isotopic signatures of the harzburgites and lherzolites show intraplate-like isotopic signatures that do not plot on a mixing line between the two poles. However, structural observations preclude a third pole to account for these data. We show that these particular isotopic signatures could be generated by diffusional processes associated with melt transport rather than by mixing between individual reservoirs.

The refertilization in Lherz is part of a ~2 Ga-long history of a fragment of subcontinental lithospheric mantle involving three main stages: (1) individualization of refractory lithosphere by high degrees of partial melting during the Archean; (2) thermo-mechanical erosion and rejuvenation of the lithosphere associated with infiltration of asthenospheric melts, possibly in the late Variscan; this second stage was followed by thermal relaxation and integration of the refertilized peridotites in the lithospheric mechanical boundary layer (3) alkaline vein-metasomatism that occurred in the Cretaceous, shortly before the exhumation of the peridotite bodies along the N-Pyrenean fault.

Session Type: *Poster Presentation*

PARTIAL MELTING OF THE MANTLE WEDGE AND THE SUBDUCTING SLAB USING A NUMERICAL SUBDUCTION MODEL

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The geochemistry of arc magmas, high seismic wave speed attenuation and geoid anomalies indicate the presence of melt in the mantle wedge and/or subducting slab in the subduction zones. For decades, laboratory experiments have provided melting temperatures of the mantle peridotite and the upper part of the subducting slab (oceanic crust and sedimentary rocks) and show large differences in the melting temperatures with respect to water-saturated/undersaturated conditions. Recently, numerical subduction models with realistic mantle rheology measured from laboratory experiments generate temperature fields of the mantle wedge and subducting slab, which can be used to evaluate the characteristics of the partial melting in the wedge and slab. We evaluate the partial melting in the mantle wedge and the upper part of the subducting slab using a 2-D compressible subduction model with pressure-temperature dependent viscosity of the mantle minerals. For the evaluation of the partial melting in the mantle wedge, we consider the lowest end-member solidus and a higher solidus of water-saturated mantle peridotite. With the solidi, we also consider a very high liquidus of water-undersaturated mantle peridotite based on the geochemical analyses of the arc magmas. For the evaluation of the partial melting in the upper part of the subducting

slab, we consider a water-saturated solidus of the oceanic crust compiled from diverse laboratory experiments. Our numerical experiments show very different distribution of the melt in the mantle wedge with respect to solidi/liquidus of the mantle peridotite. Especially, the solidi we use in our study allow very extensive and broad distribution of melt in the mantle wedge, which might be difficult to reconcile the restricted locations of the arc volcanoes. Consistent with previous studies, partial melting of the oceanic crust might be expected in younger (hotter) subducting slab only. Because we do not consider fluid transfer mechanisms and the effects of melt and free water on the mantle viscosity, our evaluation is first-order analysis only.

Session Type: *Poster Presentation*

CONSTRAINTS ON THE DEPTHS AND TEMPERATURES OF BASALTIC MAGMA GENERATION: IMPLICATIONS FOR PLANETARY THERMAL STATES AND DIFFERENTIATION PROCESSES

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Basaltic magmatism is a common feature of dynamically active terrestrial planets. The compositions of basalts reflect the temperatures and pressures of magma generation, providing windows into a planet's thermal state. We calibrate a new Si-based barometer against the most recent compilation of experimental data. This new barometer is applicable over a wide range of major element compositions and water contents, provided that the primary magma of interest is multiply saturated in olivine and orthopyroxene. For internal consistency, we also present a new Mg-thermometer calibrated against the same experimental data used in our calibration of the Si-barometer.

We apply these thermobarometers to estimate the pressures and temperatures of basaltic magma generation on Earth and other terrestrial planets. Beneath ridges, melting is driven by adiabatic decompression of passively upwelling mantle at 1300-1400 oC. Similar temperatures of melting are found for some arcs, suggesting that hot, decompression melting dominates in arcs and that enhanced melting by hydrous fluxing is only superimposed on this background upwelling. However, in arcs (Izu-Bonin) where melting temperatures are low (1200 oC), hydrous fluxing seems necessary to generate cold magmas at pressures within the mantle. Temperatures hotter than ridges (>1400 oC) are primarily found away from plate boundaries: beneath thick continental lithosphere and oceanic "hotspots" like Hawaii. Oceanic "hotspots" are thought to derive from deep thermal upwellings ("plumes"), but some hot anomalies beneath continents are not associated with deep-seated plumes and hence must have different origins, such as thermal insulation or radioactive heating of metasomatized zones. Melting on Venus, as constrained from spectral data of its surface, occurs at higher temperatures (1500 oC) and pressures than on Earth, perhaps because Venus is characterized by a thick and stagnant upper thermal boundary layer that retards convective heat loss. In this regard, Venus's upper thermal boundary layer may be analogous to thick continents on Earth. Mars appears to have cooled off to <1300 oC within its first billion years, but considerable controversy exists over the interpretation of young (<500 My) basaltic meteorites that record temperatures of 1550 oC.

As for the first billion years of Earth's history, its upper mantle was hotter than 1700 oC as constrained by thermobarometry of 3.5 Gy Barberton komatiites. Pressure estimates indicate that melting commenced at pressures greater than 8 GPa. Because the temperature of the Earth, prior to eruption of the earliest komatiites on record, was likely to have been hotter, even deeper melting is implied during the Early Earth. At pressures greater than 9 GPa, we calculate that ultramafic melts are denser than their solid residues. Such melts would have migrated downwards, solidifying into "negative" veins. We show that after a critical fraction of veins is met, the veined layer would convectively sink into the lower mantle. Such melts would have been characterized by high Fe contents and enrichment in incompatible trace elements, including K, U, Th, and primordial He, hence their downward transport would lead to the generation of a dense and hence stable chemical boundary layer enriched in incompatible elements. The tops of these thermochemical piles could be the roots of thermal plumes that give rise to hotspots. We show that thermal plumes generated from mid-mantle boundary layers would have their excess temperatures substantially reduced, perhaps explaining why hotspot magmas are hot, but not as hot as one would expect if they came directly from the core-mantle boundary.

Session Type: *Oral Presentation*

THE ROLE OF SERPENTINE IN PREFERENTIAL CRATON FORMATION IN THE LATE ARCHEAN BY LITHOSPHERE UNDERTHRUSTING

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Cratons form the cores of continents and were formed within a narrow window of time (2.5-3.2 Gy ago), the majority having remained stable ever since. Petrologic evidence suggests that the thick mantle roots underlying cratons were built by underthrusting of oceanic and arc lithosphere, but paradoxically this requires that the building blocks of cratons are weak even though cratons must have been strong subsequent to formation. Here, we propose that one form of thickening could be facilitated by thrusting of oceanic lithospheres along weak shear zones, generated in the serpentinized upper part of the oceanic lithosphere (crust + mantle) due to hydrothermal interaction with seawater. Conductive heating of the shear zones eventually causes serpentine breakdown at ~600 oC, shutting down the shear zone and culminating in craton formation. However, if shear zones are too thin, serpentine breakdown and healing of the shear zone occurs too soon and underthrusting does not occur. If shear zones are too thick, serpentine breakdown takes too long so healing and lithospheric thickening is not favored. Shear zone thicknesses of ~18 km are found to be favorable for craton formation. Because the maximal depth of seawater-induced serpentinization into the lithosphere is limited by the depth of the isotherm for serpentine breakdown, shear zone thicknesses should have increased with time as the Earth's heat flux and depth to the serpentine breakdown isotherm decreased and increased, respectively, with time. We thus suggest that the greater representation of cratons in the late Archean might not necessarily be explained by preferential recycling in the early Archean but may simply reflect preferential craton formation in the late Archean. That is, our model predicts that the early Archean was too hot, the Phanerozoic too cold, and the late Archean just right for making cratons.

Session Type: *Poster Presentation*

MINERAL COMPOSITIONAL VARIATIONS IN DUNITE BODIES FROM THE TRINITY AND JOSEPHINE OPHIOLITES

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Detailed transects were sampled across a dunite body in the Trinity ophiolite. The major peridotite lithologies sampled in the Trinity transect is a sequence of dunite, harzburgite, lherzolite and plagioclase lherzolite (DHL-PL). Major, minor, and selected trace element abundances in olivine, orthopyroxene, clinopyroxene, and spinel were measured. The composition profile from the Trinity transect has revealed several concentration gradients: two within the dunite, one in the harzburgite and at least two in the plagioclase lherzolite. The composition profiles record complex histories of melt transport, melt-rock reaction, and subsequent subsolidus re-equilibration. Analyses of closure distance suggest that compositional variation trends for a majority of major and minor elements in olivine, clinopyroxene, orthopyroxene, and spinel reported in this study were magmatic in origin. Subsolidus re-equilibration may reduce the range or magnitude of variations for the 2+ cations such as Fe and Mg in olivine and spinel and significantly redistribute Ca and Li in coexisting minerals. Numerical simulations exploring the coupling of diffusion and advection in a porous matrix were used to explain compositional variations across the peridotite sequences. Melt flow from the host harzburgite into the dunite produces composition gradients near the dunite-harzburgite contacts similar to those from the Josephine transect. In contrast, melt flow from the dunite into the surrounding peridotite lithologies can produce concentration gradients similar to those observed in the Trinity transect. At least two chemically distinct episodes of melt flow within the same dunite channel system are proposed. Results from this study show that concentration gradients developed around the dunite-harzburgite and DHL-PL sequences can be used to infer part of the melt flow history of the dunite channel systems in the mantle. Concentration profiles in dunite and the surrounding peridotite lithologies are highly variable even among differing peridotite sequences within the same ophiolite, suggesting that the composition of instantaneous melt flowing through individual dunite channel is quite variable and the mantle source regions are heterogeneous.

Session Type: *Oral Presentation*

Grain Growth and Grain Size Reduction during Melt-rock Reaction in the Mantle

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Melt-peridotite reaction happens when the melt and its surrounding peridotite are out of chemical equilibrium. It occurs in almost all major active tectonic regimes within the upper mantle and is responsible or partly responsible for a wide range of petrologic and geochemical observations. The purpose of this study is to document and explore how olivine and spinel grain sizes vary during melt-rock reaction in the mantle. Grain size is important in determining the closure temperature and permeability and viscosity of partially molten rocks. We have documented systematic variations in olivine and spinel grain sizes across dunite-harzurgite-lherzolite sequences through peridotite reactive dissolution experiments, ophiolite field studies, olivine-spinel geothermometry calculations, and numerical simulations. Results from these studies show that olivine grain size in the dunite increases as a function of reaction time (in the lab) or dunite layer thickness (in the field). This can be understood in terms of preferential dissolution of pyroxene and precipitation of olivine as olivine normative basalt percolating through a harzburgite or lherzolite matrix. Expansion of olivine primary phase volume may also contribute to olivine grain growth in the dunite. An increase in olivine grain size will result in an increase in the permeability of dunite channel or conduit in the mantle. Melt-rock reaction can also result in grain size reduction if a mineral in the peridotite is initially undersaturated with respect to the reacting melt. As an example, we will discuss the systematic variations in spinel grain size across a 20+ m wide dunite-harzburgite-lherzolite-plagioclase lherzolite sequence at the Trinity ophiolite and their implications for the closure temperatures calculated using the olivine-spinel geothermometer. We will show that it is possible to infer spinel grain size variations across a peridotite sequence using the olivine-spinel geothermometer.

Session Type: *Poster Presentation*

COMPOSITION OF THE MOJAVE LITHOSPHERIC MANTLE: DEPLETION OR REFERTILIZATION TREND?

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The possibility that composition arrays defined by some peridotite suites from various tectonic environments may represent refertilization trends rather than melt-depletion trends, has long been addressed, and has gained growing attention over the past decade. Reconsidering the petrological significance of peridotitic composition trends has important implications to understanding the origin and evolution of lithosphere and, ultimately, may influence our view on the composition of Earth's primitive mantle. Here we discuss the origin of composition trends observed in mantle xenolith from Dish Hill, California. Peridotite whole rock chemistry, clinopyroxene trace element and Nd isotope data in combination with two-pyroxene geothermometry indicate kilometer scale compositional layering of the lithospheric mantle beneath the Mojave Desert. The shallowest mantle domain, represented by harzburgites with εNd = -13 to -6.4, is interpreted as relic of the ancient continetal lithosphere. In contrast, the deeper xenoliths, on which the present study focuses, range from harzburgites to fertile lherzolites, are moderately LREE depleted, consistently enriched in radiogenic Nd (εNd = +5.7 to +16.1), and define two superposed, downwards depleted mantle slices. Bulk MgO, Al2O3 and HREE contents of harzburgites indicate 25-28% liquid extraction at low pressure, which is consistent with extensive (near-) fractional melting beneath mid-ocean ridges, but preclude deep melting beneath the Mojave. Nevertheless, a sub-MOR adiabatic partial melting scenario alone cannot explain the composition-depth correlations, texture, and LREE and Na2O contents observed in the studied xenoliths. To account for all of these observations, melt refertilization is required. Based on major and trace element modeling we demonstrate that progressive batch addition of MORB-like liquids to harzburgites is the most reasonable explanation for all of the features displayed by the deeper mantle lithosphere from beneath the Mojave. Altogether, our results strongly suggests that much of the Mojave lithosphere consists of underplated oceanic slab, most likely of Farallon origin, in which duplex structures developed during its underthrusting. The addition of MORB-like component might have occurred along a post-adiabatic cooling path beneath a mid-ocean ridge (perhaps the ancestral northern extension of the East Pacific Rise), as the harzburgitic residua moved away from the spreading ridge axial zone. In this context, the peridotite composition trends seen in the high-Nd samples may be a manifestation of refertilization, wherein the colder (shallower) parts of the lithospheric mantle were most affected by capture and freezing in of infiltrated melts.

Session Type: *Poster Presentation*

5-PHASE PLAGIOCLASE-SPINEL LHERZOLITE, ANTARCTRICA.

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Rare plagioclase-spinel lherzolites (PSL) and pyroxenites, and numerous spinel Cr-diopside and Al-augite series xenoliths, have been collected from Quaternary aged basanites located on the margin of the active West Antarctic Rift. The xenoliths may be divided into 4 textural categories: coarse; porphyroclastic; tabular granuloblastic and equant granuloblastic - grading to mylonitic. Rare, cm-scale mineralogical banding, juxtaposing Cr-diopside-rich layers against olivine-rich layers, are also observed. Compared to other worldwide examples, plagioclase is atypically fresh and has 120° triple point junctions and straight grain boundaries with the minerals spinel-clinopyroxene-orthopyroxene-olivine. Plagioclase in textural equilibrium with mantle phases is rare, as the pressure-temperature space where equilibration is reached is normally occupied by crustal material. No modal metasomatism of the Antarctica PSL is evident, and in-situ trace element analysis is being undertaken to determine the degree of cryptic metasomatism. Modelling of possible melt evolution is planned once the PSL mineral chemistry has been collected.

The Antarctica xenoliths are atypically large (up to 50cm diameter), and 52 XRF and 14 LA-ICP-MS whole rock chemical analyses have been determined. Major element mineral chemistry of 13 xenoliths, and in-situ trace element mineral determination of 5 xenoliths have been completed. 6 Mössbauer spectroscopy measurements of spinel Fe_2O_3 / $\sum FeO$ values used to calculate fugacity from oxybarometry have also been completed.

Preliminary results indicate the Antarctica xenoliths formed at temperatures between 786 – 981°C and at $\Delta \text{Log}\ f\ O_2$ (FMQ) values between 0.1 and -1.0, values that are typical of continental rift environments worldwide. The texturally and modally diverse suite of xenoliths reflect a heterogeneity in the mantle within the West Antarctic Rift System which the PSL indicates extends to very shallow levels. Ongoing measurements will provide useful information about PSL and the Antarctica mantle.

Session Type: *Poster Presentation*

ECLOGITES AND GARNET PYROXENITES: SIMILARITIES AND DIFFERENCE

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The elemental and isotopic geochemistry of garnet pyroxenites from continental and oceanic settings (e.g., Malaita, Hawaii, Kakanui, & Bultfontein) reveals a role for polybaric mantle processes in their formation. This best explains their (a) homogeneous mineral chemistry, (b) LREE depleted chondrite-normalised patterns, (c) restricted range in O isotope ratios (equiv. mantle peridotites) for garnet and clinopyroxene, and (d) relatively homogeneous Hf-Nd-Sr isotope ratios. In contrast cratonic and circum-cratonic eclogites have somewhat more heterogeneous mineralogy, chondrite-normalised patterns indicative of more complex protoliths, heterogeneous Hf-Nd-Sr data, and light to heavy oxygen isotope ratios (i.e., in clinopyroxene and garnet) that extend beyond the range for peridotitic mantle.

Hf-Nd-Sr data for clinopyroxene and garnets from eclogites and garnet pyroxenites reveal that the Lu-Hf system is more robust than the Sm-Nd system. Lu-Hf data define cooling ages that are older than the Sm-Nd ages, in some cases by as much as 1Ga. Ironically the oldest protolith age for a Roberts Victor eclogite is a Rb-Sr model age for a clinopyroxene (3.15Ga). Such eclogites define unique Archean reservoirs with low Hf, Nd and Sr isotopes (and a range in O isotopes). Indeed the extreme Hf-Nd-Sr isotopic variability of eclogites (compared to garnet pyroxenites) indicates that they are unlikely to provide a major contribution to the source of basaltic volcanism in ocean basins or continents. In contrast garnet pyroxenites have isotopic similarities with oceanic volcanic rocks.

While these data confirm the widely held view that garnet pyroxenites are related to melt transfer processes within the upper mantle, our data from Kakanui indicate a possible ultradeep origin (i.e., majorite) for such melts. Eclogites remain enigmatic with some of the characteristics of garnet pyroxenites but sufficient differences to make then distinct.

Session Type: *Poster Presentation*

ORIGIN OF GRAPHITE AND SULPHIDES IN GARNET CLINOPYROXENITE LAYERS FROM THE EXTERNAL LIGURIDE MANTLE PERIDOTITES (NORTHERN APENNINE OPHIOLITES, ITALY)

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The presence of elemental carbon in orogenic mantle bodies is exceedingly rare, having being described only for the Ronda (Davies et al., 1993) and Beni Bousera (Pearson et al., 1993) massifs. Here, we report the occurrence of high-temperature graphite in mantle rocks from the Alpine orogenic system, i.e. the External Liguride garnet clinopyroxenites from the Northern Apennines. These rocks crop out as layers in a mantle section of subcontinental lithospheric origin, which was exhumed at an ocean-continent transition in the Mesozoic (Montanini et al., 2006). Although largely affected by decompression-related evolution, pristine high-pressure assemblages (garnet + Al- and Na-rich clinopyroxene + accessory Fe-Ni-Cu sulphides + graphite) are locally preserved, thus testifying for an early stage of equilibration under high pressure and temperature conditions (~2.8 GPa and ~1100 °C). Graphite occurs as small dispersed euhedral flakes and stacks of flakes with grain size up to 2-3 mm. No pseudomorphs with octahedral or cubic simmetry indicative of the former occurrence of diamond were found. Structural characterization by microRaman spectrometry indicate a highly ordered structure, compatible with a high-T mantle origin, similar to that of graphite crystallised at high temperature in peridotite and eclogite xenoliths (Pearson et al., 1994). C isotope composition of graphite fall in the range of typical mantle (MORB/OIB) CO2. Sulphides occur both as blebs included into silicates (Type 1) and as interstitial grains (Type 2). The sulphide assemblage (Ni-free pyrrhotite, Cu-Fe sulphides, pentlandite) mainly reflect subsolidus exsolution from high-temperature, metal-deficient Fe-Ni-Cu monosulphide solid solutions with variable Ni (up to 18 wt%) and Cu contents (up to 7 wt%). The origin of Type1 and 2 sulphides require the existence of an immiscible Fe-Ni-Cu sulphide melt, which may have been segregated from the partial fusion of the enclosing garnet pyroxenite (see Tribuzio et al., this meeting). Following this hypothesis, the sulphide melt was partly trapped into the residuum, thus yielding sulphides enclosed (Type 1) or interstitial (Type 2) with respect to the residual minerals. Graphite precipitation in the pyroxenite was presumably related to reduction of a more oxidized C species (e.g. CO2 with mantle isotopic signature under closed-system conditions) interacting with the sulphide liquid as reducing agent (Palyanov et al., 2007).

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Session Type: *Oral Presentation*

ORTHOPYROXENE-RICH LITHOLOGIES IN THE HOROMAN PERIDOTITE COMPLEX, JAPAN: AS A PRODUCT OF PARTIAL MELTING OF HETEROGENEOUS MANTLE

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Partial melting of heterogeneous mantle materials consisting of peridotite and subducted crustal rocks may produce different melts in compositions and volume as compared with those of homogeneous mantle peridotites (e.g., Takahashi et al., 1998). Melts generated from subducted oceanic crust are so high in SiO2 contents as to react with surrounding peridotites as they are passing through the mantle (e.g, Kelemen et al., 1998). Details of melting processes of heterogeneous mantle materials under upper mantle conditions are, however, still not clear, in particularly in the field.

The Horoman peridotite complex, Japan, is known to have a conspicuous layered structure consisting of peridotite with minor amounts of mafic rocks (e.g., Niida, 1984; Toramaru et al., 2001). Although the mafic rocks are now mainly composed of plagioclase, olivine and clinopyroxene suggesting their equilibration at low-pressure conditions, it is interpreted that some of them ascended with surrounding peridotites from the upper mantle conditions (Takazawa et al., 1999; Morishita & Arai, 2001; Morishita et al., 2004). Hence, the Horoman complex is an example of heterogeneous mantle materials alternating with peridotites and mafic rocks (Takazawa et al., 1999; Toramaru et al., 2001; Morishita & Arai, 2001; Morishita et al., 2004).

Melting experiments using both peridotite and basaltic compositions as starting materials indicate that reaction between a SiO2-rich partial melt from basaltic compositions and surrounding peridotites forms SiO2-rich lithologies, i.e., orthopyroxenites, at initial lithological boundary between peridotite and basaltic compositions (e.g., Yaxley & Green, 1998; Rapp et al., 1999).

In the case of the Horoman Peridotite Complex, orthopyroxene-rich lithologies rarely occurs, but are restrictedly found closely associated with mafic layers. We present petrology and geochemistry of orthopyroxene-rich lithologies in the Horoman Peridotite Complex in the context of partial melting of heterogeneous mantle materials.

Session Type: *Poster Presentation*

SOURCES OF HYDROCARBONS AT THE CEDARS, A SITE OF ACTIVE SERPENTINIZATION IN N. CALIFORNIA

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Geochemical and isotopic evidence suggests microbial methanogens, methanotrophs, ethanogens and propanogens in ultrabasic nutrient poor groundwaters at the Cedars, a continental site of serpentinization in Northern California. Carbon and hydrogen isotope values of CH4 (-68.4 to -57.5 ‰ and -368 to -302 ‰ respectively), gaseous compositions (CH4/C2+ ranging from 136 to 5178), and isotopic separation between CO2 and CH4 (13C ranging from 33 to 44) indicate that the primary source of CH4 was microbial acetotrophic methanogenesis. Additionally, there is evidence of a secondary process, which results in decreasing concentrations of CH4 and enrichment of residual CH4 in 13C. Isotopically light inorganic carbon (≥-25.6 ‰) was also found in the springs where the 13C enriched CH4 was sampled. This correlation between 13C enriched CH4 and isotopically depleted inorganic carbon reflects the input of isotopically light carbon in to the DIC pool via methanotrophy, suggesting that the secondly process is microbial methane oxidation. A small carbon isotope fractionation factor of 1.002 calculated from the field data is the lowest kinetic isotope effect reported for methane oxidation. Higher molecular weight gaseous alkanes were also detected exsolving from the groundwater. The ethane and propane are geochemically and isotopically similar to those produced by microbial ethanogenesis and propanogenesis recently discovered in the deep marine subsurface. The hydrocarbon gases at the Cedars, are unlike gases classified as thermogenic or abiogenic due to ethane/propane ratios ranging from 0.9 to 1.5, and a lack of compositional and isotopic trends normally attributed to these types of low molecular weight alkanes. While other continental sites of serpentinization studied in the Philippines, Oman, and Turkey have attributed hydrocarbon gas formation to abiogenic processes, the Cedars is the first reported continental, hydrothermal site associated with serpentinization to show microbial pathways active in ultrabasic, reducing environment produced by the serpentinization.

Session Type: *Oral Presentation*

ROLE OF A MANTLE EXHUMATION CHANNEL IN THE FORMATION OF ULTRAMAFIC SEAFLOOR

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Mantle peridotites from ocean-continent transition zones (OCT's) illustrate the distribution of the scale of upper mantle heterogeneity in extensional systems that evolve from rifting to (ultra-) slow seafloor spreading. We summarize research on mantle processes of the conjugate Iberia-Newfoundland rift and from the Alps that show that the basement of OCT's consists of different mantle domains. Thermally undisturbed, 'cold' subcontinental mantle formed the ocean floor next to thinned continental crust. This 'subcontinental domain' is separated by ductile shear zones from an 'infiltrated (e.g. 'hot') domain' dominated by plagioclase peridotite. The footwall of these mantle shear zones display complex refertilization processes and high-temperature deformation. These rocks are highly heterogeneous and are juxtaposed with depleted lherzolites and dunites ('extraction domain').

Upwelling of partial melts through the conductive lithospheric mantle inevitably leads to freezing of the melt and to the formation of a chemical and rheological barrier, which we term mantle exhumation channel. We will discuss an example that displays km-scale refertilization with active deformation (and melt focusing?) on top, and the formation of a domain that represents focused melt extraction at the bottom. We show that an actively deforming refertilization front in Alpine plagioclase peridotites and in the Iberia Newfoundland rift moved ahead of a melting front. Melt lubricated shear zones (or melt bands) focus melt flow. Continuous uplift lead to crystallization and ultimately to the exposure of infiltrated peridotites on the seafloor. We combine petrologic data and numerical models to illustrate that these processes play a key role in the rejuvenation and erosion of the lithospheric mantle and ultimately form ultramafic seafloor in ocean-continent transitions and ultra-slow spreading ridges.

Session Type: *Poster Presentation*

CRYSTALLOGRAPHIC ORIENTATIONS OF SYMPLECTITE MINERALS FROM THE HOROMAN PERIDOTITES

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Symplectites consisting of orthopyroxene, clinopyroxene and spinel in the Horoman Peridotite Complex, Japan, are thought to be the subsolidus reaction product between garnet and olivine during decompression of the complex （Kushiro and Yoder, 1966; Takahashi and Arai, 1989; Ozawa and Takahashi, 1995; Morishita and Arai, 2003）.Automated electron backscattered diffraction (EBSD) analysis using a field-emission gun SEM on symplectitite minerals revealed systematic crystallographic orientations between minerals in the Horoman symplectites (Odashima et al., 2008). The results were summarized as follows: (a) the (100) and (010) planes and [001] axis of orthopyroxene are parallel to the (100) and (010) planes and [001] axis of clinopyroxene, respectively, and (b) the (100) and (010) planes of pyroxenes are parallel to the {111} and {101} planes of spinel, respectively (Odashima et al., 2008). The crystallographic relationships between orthopyroxene and clinopyroxene in the Horoman symplectites are the same as those of Bushveld-type exsolution in pyroxenes. We constructed three-dimensional image of spinel grains from X ray-CT scanning at SPring-8, Japan. Separated symplectite spinels in two dimensional area are likely to be connected each other in three-dimensions. This result coupled with crystallographic observations suggest that Horoman symplectite is not an aggregate of fine grained minerals but consists of a few, complicated shape grains. Shape of symplectite spinels shows a preferential elongation direction. Relationships between crystallographic orientations of minerals and elongation direction of symplectite spinels are not clear. In conclusion, crystallographic orientations of symplectite minerals were operated by crystallographic character of minerals at the early stage of their formations. The textures were then developed along a direction not related to the crystallographic orientations of minerals.

Session Type: *Oral Presentation*

ISOTOPIC (PB-ND-HF) EVIDENCE FOR A HIDDEN EXTREMELY DEPLETED MANTLE DOMAIN FROM THE HOROMAN PERIDOTITE MASSIF, JAPAN

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The most depleted mantle end-member generates mid ocean ridge basalts (MORB) that form the oceanic crust and therefore traditionally, is referred as “Depleted MORB source Mantle (DMM)”. Isotopic characteristics of the DMM perceived as sampling of MORB are frequently obscured by mixing with “enriched” components. Direct samples of the DMM (xenolith, orogenic or abyssal peridotites) are also disturbed because of later-stage melt/fluid impregnation. On the other hand, precise trace element and isotopic systematics of pristine depleted mantle residues are often challenged due to their extremely low elemental concentrations. It, therefore, remains unclear if the DMM is absolutely ‘hypothetical’ or really exists in the Earth’s mantle.

We performed Pb-Nd-Hf isotope analyses together with major and trace elements on plagioclase lherzolites, spinel lherzolites and harzburgites which occur as thick (>1m) layers and thin (few cm) layers from the Horoman peridotite massif, Japan. In the Pb isotope systematics, the plagioclase lherzolites are less radiogenic than the other peridotites. Further, most of the plagioclase lherzolites are significantly more depleted than any known mantle samples so far reported (ultra depleted), and even fall to the left of the 4.5 Ga geochron. The more refractory spinel lherzolites and harzburgites have more enriched/radiogenic isotopic compositions with a linear mixing relationship extending from the ultra-depleted to the global subducting sediments (GLOSS) field. Thus, contribution of metasomatic fluids derived from the sediments, possibly adjacent subducting Hidaka meta-sediments, therefore, is discernible. Specifically, the peridotites from thin layers depict a linear trend between the ultra depleted to the average Pacific MORB. Sm-Nd and Lu-Hf isotope systematics of the massive plagioclase lherzolites define isochron ages of 1.16±0.16 Ga (2SD, MSWD=7, initial 143Nd/144Nd=0.5114±3) and 1.06±0.28 Ga (2SD, MSWD=19, initial 176Hf/177Hf=0.2825±3) respectively. Higher 143Nd/144Nd and 176Hf/177Hf of many of the samples than the normal DMM are consistent with their low Pb isotopes, and reflect original old ultra-depleted mantle character.

Initial isotope ratios of the plagioclase lherzolites are consistent with the DMM values at 1 Ga, suggesting that these residues were formed from a mantle similar to the present MORB source, and have survived for at least 1 Ga without being eroded by the mantle convection. This indicates the physical existence of the DMM end-member that has been considered so far as a “hypothetical” component, postulated from MORB data. Assuming that the ultra-depleted samples belong to an unknown mantle domain, we have determined that this “hidden” reservoir contains “hidden Pb” equivalent to 30-40% of the total upper mantle Pb and hence, is a plausible candidate to resolve the Pb isotope paradox of the Earth.

Session Type: *Oral Presentation*

FABRIC AND TEXTURE SUPERPOSITION IN UPPER MANTLE PERIDOTITES, RED HILLS, NEW ZEALAND

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The Red Hills ultramafic massif, the South Island, New Zealand records multiple deformation events interpreted to have occurred under mantle pressure and temperature conditions. Field relations, mineral compositions and olivine lattice preferred orientations (LPO) reveal 4 generations of superposed fabrics with evidence for strain localization on at least 2 scales. The oldest fabric, found in the Central Domain, is defined by north-dipping compositional bands of harzburgite, dunite and minor lherzolite. Second-generation fabrics that cross-cut the Central Domain fabric include cm-scale, south-dipping shear zones and a ~50 m-thick zone of south-dipping shear (South-dipping Domain). A third, younger, fabric occurs in a >1 km–thick package on the west side of the field area (West Domain), and is characterized by a steeply west-dipping foliation with isoclinal folds of older compositional banding. The East Domain contains the youngest fabric in the field area, and is preserved in a ~50 m-thick zone on the east side of the field area. It is composed of lherzolite, and contains cm-scale compositional bands that define a microstructurally distinct, shallowly east-dipping foliation.

The olivine LPO in the Central Domain suggests (010)[100] slip, typical of high-temperature upper mantle conditions. The cm-scale shear zones (within the Central Domain), the South-dipping Domain and the East Domain LPOs all show diffuse patterns and double maxima are common. Fourier transform infra-red spectroscopy analyses of cm-scale shear zone olivines indicate that they are not water-rich relative to the host rock, suggesting that water content did not affect slip-system activity in shear zone rocks. The West Domain LPO differs from the other domains and suggests possible (100)[001] slip.

When olivine LPOs are considered within the same (geographic) reference frame, it is apparent that the South-dipping and East Domains, as well as cm-scale shear zone samples, retain evidence for the dominant LPO of the Central Domain rocks. The poorly clustered data and double maxima reflect changes resulting from superposed deformation. These data, therefore, demonstrate the influence of pre-existing LPO on texture development during deformation at two scales: during localized shear in cm-scale zones, as well as in km-scale domains during the development of a superposed mesoscopic fabric.

These structural relationships suggest that the upper mantle may experience a complex deformational history, and thus acquire a heterogeneous deformational fabric. However, the LPOs of these rocks do not fully reflect the mesoscopic fabrics. The possibility of multiple overprinting fabrics in the upper mantle, and the lack of complete resetting of LPO, should be considered when interpreting deformation at upper mantle conditions.

Session Type: *Oral Presentation*

LASER ABLATION PT-RE-OS CHRONOMETRY: APPLICATIONS TO DATING MANTLE MELT INFILTRATION EVENTS AND CONSTRAINING OPHIOLITE EMPLACEMENT AGES

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The Re-Os isotope system has proved an enormously important tracer and chronometer of mantle processes over the past two decades. In contrast, the Pt-Os isotope system has been far less utilised, due mainly to the difficulties of analysing the low abundance 186Os isotope and 190Pt isotopes (1.58% an 0.0136% respectively). Nevertheless, in the last decade Pt-Os has become increasingly important in tracing mantle processes [eg 1-2]. The exceptionally long half-life of 190Pt (~469Ga) and the limited range in Pt/Os ratios in most mantle minerals has severely restricted the use of Pt-Os as a chronometer. Advances in mass spectrometry, however, have allowed us to develop a method for the rapid (40s) and simultaneous acquisition of Pt-Os and Re-Os and isotope data on individual Platinum Group Alloys (PGAs) by laser ablation MC-ICP-MS [3]. The large variation in Pt/Os ratios in PGA grains allows us to exploit the Pt-Os system as a chronometer.

We have begun a study aimed at developing the use of the Pt-Os chronometer to date melt infiltration events in oceanic lithosphere as represented by chromitite bodies and hence, by inference, constraining the emplacement ages of ophiolite complexes, which hitherto, have proved difficult to date. We have so far focussed on the analysis of detrital PGA grains closely associated with ophiolite complexes. Preliminary Pt-Os isotope data for PGA grains derived from the Meratus ophiolite, Borneo, will be presented that yield a Pt-Os isochron age of 207.6±6.5Ma (MSWD 1.5), close to the best stratigraphical estimates for the ophiolite. The calculated initial 186Os/188Os ratio for the Borneo grains is also entirely consistent with mantle values. Preliminary Pt-Os data will also been presented for detrital grains from the Californian coast, thought to be linked to various peridotite bodies in the West Coast Ranges.

Obvious caution needs to be exercised when interpreting isochron ages based on detrital PGAs which may be temporally or genetically unrelated or could be derived from multiple parent bodies. Some of this ambiguity can be avoided by dating detrital PGA grains obtained from as close to the parent body as possible, grains separated from the parent body itself, and/or by developing methods for dating single PGA grains. In terms of the latter approach data will also be presented for both multi-gain and the first ever single-grain Pt-Os ages for PGA grains associated with the Central Lapland Greenstone Belt (CLGB).

We will also illustrate that where Re-Os and Pt-Os ages can be obtained on the same PGA grain, or group of grains, there is always an age discordance between the two isotopic systems, with Re-Os always providing the younger and greater spread in ages. This will be shown to be an analytical limitation of laser ablation Re-Os dating.

[1]: Brandon et al., Science 280, 1570-1573, 2008. [2]:Luguet et al., Science 319, 453-456, 2008. [3] Nowell et al., Chem Geol., 248, 394-426, 2008.

Session Type: *Poster Presentation*

A PROGRESSIVE INCREASE OF CLINOPYROXENE SODIUM CONTENT IN KELYPHITE AFTER GARNET FROM A CZECH MOLDANUBIAN GARNET PERIDOTITE.

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Keywords: garnet, kelyphite, Czech, Mohelno, material transfer

We report a case that sodium was progressively introduced to a kelyphite during its growth replacing garnet. The sample we studied is a garnet peridotite from a ultramafic mass enclosed in a high-pressure acidic granulite, the Czech Moldanubian zone, Bohemian massif. The massif is mostly spinel peridotite; garnet peridotite occurs only in the marginal zone adjacent to the granulite. The garnet has partly transformed to kelyphite, which is a fine-grained symplectitic intergrowth of Opx, Cpx and spinel with only trace amount of amphibole. It is found that the kelyphite is concentrically zoned with respect to sodium content in Cpx that steadily increases inwards from 2.0 wt % at outer margin to up to 2.8 Na2O wt %(Jd 20 mole%) inside. The observed inward increase of sodium content appears to be intuitively inconsistent with the inferrence that sodium was externally introduced. The paradox may be resolved if we suppose the sodium increase was brought about by a progressive increase of chemical potential of sodium of a hypothetical fluid that was introduced during the development of the kelyphite. Because kelyphite develops from outside inward replacing garnet, inner zone represents later stages. Thus the kelyphite Cpx chemistry records the temporal change of chemsitry of the externally introduced material, probably fluid, during the kelyphite formation. A likely source of the fluid is the acidic granulite enclosing the ultramafic mass.

Session Type: *Poster Presentation*

CONTRASTING FABRIC PATTERNS OF OLIVINE OBSERVED IN GARNET- AND SPINEL-PERIDOTITE FROM A SINGLE ULTRAMAFIC MASS ENCLOSED IN ACIDIC GRANULITE, MOLDANUBIAM ZONE, CZECH REPUBLIC.

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The Mohelno peridotite is a medium-sized ultramafic mass (2km x 4km in size) enclosed in the Gföhl granulite at the eastern part of the Bohemian Massif. It consists of mainly coarse spinel peridotite (harzburgite and dunite); garnet peridotite occurs only in the sheared and deformed margins of the body. In order to decipher the origin and history of this mantle derived peridotite, we measured mineral chemistry by electron microprobe analyzer and olivine fabric pattern by electron backscattered diffraction (EBSD) method for each rock types. We found two distinct patterns of olivine fabrics (CPO) developed in the mass which may be correlated with mineralogy and thermal histories of each. Olivine CPO in coarse-grained spinel peridotite shows a strong concentration of [100] slightly oblique to the lineation and [010] and [001] girdles normal to the lineation (which is the so called {0kl}[100] pattern typical of medium-temperature deformation). Olivine in the coarse-grained garnet peridotite, on the other hand, shows a strong concentration of [010] normal to the foliation and a concentration of [100] parallel to the lineation, (which is the so called (010)[100] pattern typical of high-temperature deformation). These fabric patterns become diffuse as the grain size is reduced for each mineralogical type.

We interpret the development of these constrasting fabric patterns and mineralogical types considering pressure-temperature histories obtained from applying published geothermometers and barometers to the minerals as follows. Starting from a high temperature (>1200 °C) spinel peridotite, during exhumation and cooling by ambient granulite, marginal part transformed to garnet peridotite while the interier remained to be spinel peridotite because cooling is slower inside. Because of the slow cooling and continuous deformation in the interia of the body, the original high-temperature fabric pattern in the spinel peridotite was converted to a lower-temperature type. Reduction of grain size that occurred in later low-temperature deformation, partly obliterated the high-temperature fabric patterns for both garnet and spinel peridotites. The initial rapid cooling at high temperatures associated with the deformation probably occurred after the mantle peridotite was emplaced in the crustal granulite, which implies that spinel- to garnet-peridotite transformation took place in the continental crustal environment.

Session Type: *Oral Presentation*

SHEAR LOCALIZATION, SEISMIC RUPTURE AND FRICTIONAL MELTING, OBSERVED IN A MYLONITIZED ULTRAMAFIC PSEUDOTACHYLYTE FROM BALMUCCIA PERIDOTITE, IVREA ZONE, N. ITALY

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Ultramafic pseudotachylyte is a rare but important natural material that testifies seismic melting in upper mantle. Low seismic efficiency (i.e., percentage of elastically radiating energy per total seismic moment released in a single shot) observed in deep mantle earthquakes (e.g. Bolivian earthquake, Kanamori, et al, 2006) indicates that a large proportion of seismic energy is used in heating and converting solid rocks to a melt. Direct evidence for such seismic melt is difficult to obtain for deep earthquakes because of limited exposure of mantle rocks and because of the loss of textural evidence for pseudotachylyte due to substantial recrystallization after solidification even if it were generated. We observe mylonitized ultramafic pseudotachylytes developed in a narrow shear zone of protomylonite of spinel lherzolite facies in Balmuccia peridotite (Ueda et al, 2008). Important textural observation includes that a ductile shear localization took place before a rupture (brittle) occurred that produced frictional melting and that the fault vein pseudotachylyte layer went further shear and recrystallization forming an ultramylonite. Whole sequence of event took place in the spinel lherzolite facies. We do not observe any signs of temperature increase during the pre-seismic shear localization but observe substantial hydration, i.e., formation of hornblende in protomylonite matrix in the host. Considering the hydration and the formation of carbonate in mylonitized pseudotachylytes, we propose a hypothsis that compositional evolution of metamorphic fluid from H2O rich to CO2 rich played a critical role to switch the rock rheology from ductile to brittle nature, culminating in a seismic rupture and melting. Shearing within the pseudotachylyte layer furthermore testifies that the cessation of seismic slip was slightly delayed after the solidification of the seismic melt. A recognition of such a subtle timing difference obtained from microstructural observation of sheared pseudotachylytes will put important constraints in deciphering detailed processes and to better understanding the focal mechanism of mantle earthquakes.

Session Type: *Oral Presentation*

ORIGIN OF REFRACTORY DUNITE BODIES IN HARZBURGITE

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Dunite bodies occurring in harzbrugite often observed in the mantle section of ophiolites on various scales have been inferred to have formed by reaction between the host peridotite and migrating basaltic melt on the basis of field and petrochemical evidence (e.g., Kelemen, 1990; Suhr, 1999). One type of such dunite is characterized by less magnesian olivine and higher Cr# of spinel than those of the host harzburgite. The Fo# of olivine in dunite is usually less than 91 and the Cr# of spinel is typically less than 70. The NiO content of olivine in the dunite is similar to or slightly lower than that of the host harzburgite, which is contrasting to cumulus peridotites featuring significant depletion of NiO in olivine as Fo# decreases with limited change in Cr# of spinel. The TiO2 content of spinel in the dunite is notably higher than that of harzburgite. This type of dunite is most plausibly explained by net melting (Ma/Mc>1) reaction involving dissolution of orthopryoxene and precipitation of olivine induced by a focused influx of fractionated basaltic melt into harzbrugite or lherzolite.

Another type of dunite features more magnesian olivine and higher Cr# of spinel than those of the host peridotite (refractory dunite hereafter; e.g., Kubo, 2002; Suhr et al., 2003). The Fo# of olivine in refractory dunite is usually greater than 91, and the Cr# of spinel often attains greater than 80. The NiO content of olivine is lower than that of the host in the range of Fo# less than ~93.5, but it tends to increase with further increase in Fo# to the same level as or higher than that of the host harzburgite. The TiO2 content of spinel in refractory dunite is very low, often below the detection limit of EPMA, and does not show notable difference from that of the host. The negative correlation between NiO with Fo# up to Fo#~93 and the positive correlation above this Fo# is a robust constraint on the formation mechanism of refractory dunite. These correlations are quantitatively examined by applying reaction models for quantitative estimation of reaction conditions by constraining the reaction stoichiometry, melt influx rate, and influxed melt composition. Two reaction stages are required to explain the full spectrum of mineralogical characters of refractory dunites: dissolution of orthopyroxene with precipitation of olivine followed by dissolution of olivine after complete consumption of orthopyroxene. Extensive modeling shows that the followings are required to quantitatively reproduce all the mineralogical variations: (1) Ma/Mc~1 (or even smaller than unity) during the first stage, (2) extensive dissolution of olivine with influx of melt in equilibrium with less magnesian olivine and spinel with moderate Cr# during the second stage. These quantitative results are critical to constrain the formation processes of dunite at an asthenosphere-lithosphere boundary in various tectonic environments.

Session Type: *Oral Presentation*

EPISODIC MANTLE MELTING RECORDED BY OSMIUM ISOTOPES

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Melting at mid-ocean ridges differentiates the upper mantle into an enriched upper part (oceanic crust) and a depleted lower part (oceanic mantle lithosphere). These heterogeneities are both returned to the convecting mantle at subduction zones. While most isotopic systems in use (Sr, Nd, Pb…) track the recycled crustal components, only the Re-Os system robustly tracks the depleted heterogeneities, since Os is compatible during melting. The growing number of analyses in this relatively new system now allow the distribution of the isotopic values to be statistically evaluated, and reveals that the melting history of the Earth's mantle has not been smoothly varying, but has been punctuated by a few periods of apparently extensive, high-degree melting.

Whole rock peridotite samples of abyssal and orogenic peridotites show similar ranges, with maximum Re-depletion ages of about 2.0 Ga. Such old depletion ages from single samples are quite remarkable and indicate that coherent pieces of depleted mantle survive for billions of years against the homogenizing forces of convection. While the abyssal data are fairly evenly distributed, several of the orogenic localities have a distinct distribution peak at 1.2 Ga. However, the whole-rock data are too few (~200) to be statistically robust.

Much more data (over 1000) is available on individual Os-rich grains (platinum group element alloys – PGA, and sulfides) from ophiolites, thanks to laser-ablation multi-collector ICP-MS. These data show that localities around the world have peaks in their 187Os/188Os distribution equivalent to Re depletion ages of 1.2 Ga, confirming the whole rock results. There are also hints of peaks at 1.9 and 2.7 Ga. What is particularly interesting about the peaks in Re-depletion ages at 1.2 Ga, and possibly at 1.9 and 2.7 Ga, is that these are the same ages suggested to be times of accelerated crustal growth. As the continental crust was extracted from the mantle by melting, it makes sense that pulses of crustal growth would produce similar pulses of depleted mantle. It appears that these pulses of depleted mantle have survived mantle convection and are recorded in the abundance peaks of the Re depletion ages.

The downside to the laser-ablation data is that most comes from PGA grains in placer deposits. Thus it is not clear how the distribution of Os isotopic values in the placers relates to the real distribution in mantle lithosphere itself, or how this might relate to heterogeneity in the convecting mantle source of the parental magmas that formed the grains. Our current research is focusing on increasing our global database of Os analyses, as well as field studies to understand the spatial distribution and overall extent of Os heterogeneity in the mantle.

Session Type: *Oral Presentation*

THE EFFECT OF MANTLE FLOW AND BUOYANT FLUID MIGRATION ON MELTING BENEATH CONVERGENT PLATE BOUNDARIES

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Melting at convergent boundaries is thought to occur as hydrous fluid released by dehydration reactions, and possibly sediment or crustal melt, rise from near the top of a descending slab into the overlying region of the mantle wedge where the temperature is high enough to cause wet mantle melting. Melting is expected to occur primarily in a thin region, or melting front, through which rising slab-derived fluid equilibrates with solid mantle. Solid flow influences melting both by controlling the temperature distribution in the wedge and by bringing fertile mantle to this melting front. Melt production is limited both by the rate at which solid flow brings fertile mantle into the region and the rate at which hydrous fluids rise upwards through the melting front. Above the melting front, melt migrates upward through mantle flowing into the wedge. Even in the absence of further melting, this melt may exchange trace elements with the mantle flowing into the wedge and ultimately reaching the melting front. Melts arriving at the top of the melting region have a complex history and spatial distribution of incompatible elements. Highly heterogeneous melts should thus be expected.

The rate of rise of fluids or melt by porous flow depends significantly on the scale of the permeability. Permeability may be significantly enhanced if flow occurs in channels rather than along grains edges. However, to generate the same amount of melt, strong localization in the region of melting would require larger degrees of melting for the smaller amount of solid through which fluid percolates.

Upward transport may also occur due to buoyant upwelling of solid. The relative magnitude of the upwelling melt flux due to fluid migration and buoyant solid flow depends on the permeability of mantle rock to melt and the viscosity characterizing solid state creep. This picture is very different from melting beneath spreading centers where plate spreading generates mantle upwelling and decompression. In the absence of plate driven upwelling, the high viscosity of solid flow in the mantle wedge (~1018 Pa-s) requires significantly larger density differences and may be important only for solid-state upwelling of serpentinized mantle or sediment.

Session Type: *Oral Presentation*

GENESIS OF CRATONIC LITHOSPHERE - A ROLE FOR WATER AND SUBDUCTION

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Cratonic lithospheric mantle plays an integral role in defining the physical behaviour of ancient continents and their mineral potential. Bulk compositional data show that modern-day melting residues from a variety of tectonic settings can be as depleted in Al and Ca as cratonic peridotites. Cratonic peridotites are strongly affected by secondary introduction of pyroxenes and garnet such that the extent and depth of melting cannot be reliably determined from major element bulk compositions. We concur with Bernstein et al. (2006) that olivine compositions are probably the most reliable tracer of the original melting process and indicate that typical cratonic peridotites have experienced 40% or more melt extraction. Homogenous levels of depletion indicated by olivine compositions, combined with mildly incompatible trace element evidence indicates that melting took place at shallow depths, dominantly in the spinel stability field. Consideration of melt production models shows that shallow (<3GPa) anhydrous melting is not capable of producing residues dominated by large degrees of melt extraction. Instead, a critical role for water is indicated, implicating the formation of cratonic peridotites within Archaean subduction zones. This melting occurred in the Neoarchaean in some cratonic blocks, initially forming dunitic residues that are still evident in the xenolith inventory of some cratons. Release and migration up-section of siliceous melt produced during orthopyroxene breakdown metasomatises the proto-lithospheric mantle via re-enrichment in orthopyroxene crystallising from this hydrous Si-rich melt, forming the variably orthopyroxene rich refractory harzburgites typical of most cratonic roots. Melting in Archaean subduction zones is followed by subduction stacking/shortening to form the cratonic root. A mechanism is then required for "cleansing" the lithosphere, possibly via gravity-driven over-turn.

Dating of lithospheric mantle remains an issue. Despite some early promise using Lu-Hf isotopes it is clear that this system reflects the recent addition of clinopyroxene is most cratonic peridotites. The Re-Os system remains the best option. Recent work has show considerable Os isotopic diversity in modern-day mantle, making the dating of melting events difficult when applied to peridotite suites that are 2 Gy old or younger and where only a small fraction of the data are indicative of older ages. In contrast, all cratonic lithosphere suites show uniform evidence of Archean melt extraction. An unresolved question is the proportion of cratonic residues created in the mid- and late-Archean respectively. These issues will be addressed.

Session Type: *Oral Presentation*

MODELLING MANTLE FLOW AND DEFORMATION BENEATH MID-OCEAN RIDGES: PASSIVE? ACTIVE? SIDEWAYS?

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Session Type: *Oral Presentation*

ASTHENOSPHERE-LITHOSPHERE INTERACTION AT AN EXTENSIONAL SETTING: INSIGHTS FROM THE ALPINE-APENNINE PERIDOTITES

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Alpine-Apennine (AA) ophiolitic peridotites are lithosphere remnants of the Ligurian Tethys oceanic basin that separated the Europe and Adria (Africa) continental blocks during Middle Jurassic - Cretaceous times. AA ophiolitic peridotites were exhumed from the sub-continental Europe-Adria lithospheric mantle during passive lithosphere extension driven by far-field tectonic forces and were exposed at the sea-floor after Middle Jurassic continental break-up.

Lithosphere extension driven by km-scale extensional shear zones was already active during Triassic (220-225 Ma) times. Lithosphere thinning induced asthenosphere adiabatic upwelling and decompression melting along the axial zone of the extending system, from Early (180-170 Ma) to Late (163-150 Ma) Jurassic times, as indicated by the age of melt percolation/intrusion.

MORB-type melts from the asthenosphere migrated via porous flow through the overlying lithosphere, exploiting the shear zones network and infiltrating the host mantle lithosphere.
The peridotite bodies from the more internal settings of the Ligurian Tethys basin record the following magmatic events: i) early diffuse percolation under spinel-facies conditions of silica-undersatureted melts, consisting of single melt increments produced by variable degrees of fractional melting of spinel-facies DM asthenospheric sources, ii) subsequent diffuse percolation and interstitial crystallization (impregnation and refertilization) under plagioclase-facies conditions of silica-saturated melts, consisting of single melt increments produced by variable degrees of fractional melting of spinel-facies DM asthenospheric sources, iii) focused melt migration within harzburgite/dunite channels, iv) intrusion of MORB gabbroic/basaltic dikes.

Early silica-undersaturated melt fractions percolated under open-system conditions and high melt/rock ratios, causing significant met/rock interaction and progressive depletion of pyroxenes (pyroxene dissolution and olivine precipitation) of the percolated mantle lithosphere, forming depleted reactive spinel harzburgites. The subsequent silica-saturated melt fractions caused olivine dissolution and orthopyroxene + plagioclase precipitation, refertilizing with basaltic components the peexisting reactive peridotites. Strongly localized deformations along shear zones occurred under plagioclase-facies conditions. These structural discontinuities facilitated the late focused open-system reactive migration of silica-undersaturated melts and the formation of high permeability replacive harzburgite/dunite channels that were exploited for uprising and shallow level delivery of aggregate MORBs. Progressive clogging of the melt pathways was induced by crystallization as conductive heat loss became dominant on convective heating by melt percolation during progressive exhumation to shallow lithospheric levels. The uprising melts were expelled and intruded in fractures, forming MORB gabbroic and basaltic dykes.

Melt/peridotite interaction caused the thermochemical/mechanical erosion of the lithospheric mantle which resulted in a significant decrease in Total Lithospheric Strength (TLS). Softening of the lithospheric mantle was potentially sufficient to cause whole lithosphere failure under appropriate far-field tectonic forces. Accordingly, the melt-induced thermo-mechanical erosion of the mantle lithosphere could have been a controlling factor in the transition from distributed continental deformation to localized oceanic spreading in the Ligurian Tethys realm.

Session Type: *Poster Presentation*

THE EXTREME STRUCTURAL AND COMPOSITIONAL VARIABILITY OF THE LANZO PERIDOTITES (WESTERN ALPS, NW ITALY)

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Distinct rock groups have been identified in the Lanzo ophiolitic peridotites (Western Alps, NW Italy) on the basis of their structural and compositional features: (1) Porphyroclastic spinel lherzolites; (2) Pyroxene-poor/free spinel harzburgites and dunites; (3) Plagioclase-rich peridotites. Pristine porphyroclastic peridotites (lithospheric spinel lherzolites) were infiltrated by melts and transformed into a variety of rocks by melt-rock interaction. Lithospheric peridotites were transformed to pyroxene-depleted harzburgites and dunites (reactive spinel peridotites) and were impregnated by basaltic components and transformed to plagioclase-rich peridotites (impregnated plagioclase peridotites). Harzburgite-dunite channels (replacive spinel peridotites) later crosscut the peridotites. Lithospheric peridotites preserve structural relics of pristine garnet-facies assemblages and widespread spinel pyroxenite bands: they represent the old sub-continental lithospheric mantle. Reactive spinel peridotites formed by percolation of MORB-type melts through lithospheric peridotites. Plagioclase peridotites formed by impregnation/refertilization of spinel peridotites by fractional MORB melts and aggregate MORBs. Replacive harzburgites and dunites were formed by reactive percolation of MORB melts within shear zones and were locally exploited for focused migration of alkaline melts. The strong compositional heterogeneity of the Lanzo mantle is well documented by the Cpx trace element composition: (1) Lithospheric peridotites document variable garnet- and spinel-facies melting processes; (2) Spinel pyroxenites show very high HREE (and Sc) contents suggesting a precursor garnet-bearing assemblage; (3) Reactive, impregnated and replacive peridotites show relatively low (La/Yb)N values at increasing YbN, confirming percolation/ impregnation of MORB melts; (4) Some refractory replacive peridotites show very high (La/Yb) N values which documents interaction with strongly LREE enriched - HREE depleted melts. Lithospheric peridotites from North Lanzo show DMM signatures and Proterozoic DM model ages. Reactive, impregnated and replacive peridotites from the different Lanzo bodies record the MORB affinity of percolating melts. OIB signatures are recorded by interstitial magmatic Cpx in refractory replacive peridotite channels from Central-North Lanzo.

Our study documents the extreme compositional heterogeneity of Lanzo mantle peridotites in terms of rock types and modal and chemical compositions (i.e. extremely variable Cpx modal contents and Cpx trace element and isotopic compositions) and evidences the mantle processes that modified the composition of pristine sub-continental lithospheric mantle during lithospheric extension and rifting in the Ligurian Tethys realm prior to oceanic opening.

Session Type: *Poster Presentation*

SEISMOGENETIC SHEAR ZONES IN THE MANTLE LITHOSPHERE: ULTRAMAFIC PSEUDO-TACHYLYTES IN THE LANZO PERIDOTITE (WESTERN ALPS, NW ITALY).

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At Mt. Moncuni (South Lanzo, Western Alps) ophiolitic plagioclase peridotites and early MORB gabbroic dykes are deformed by extensional shear zones which contain cm- to dm-wide, dm- to m-long veins of extremely fine-grained fault-vein and injection-vein type pseudotachylytes. Later MORB porphyritic mafic dykes cut across shear zones and pseudotachylytes. The tectonite-mylonite and cataclastic bands of the shear zones show successive neoblastic plagioclase-peridotite-facies, amphibole-peridotite facies and amphibolite-facies assemblages. The matrix of the larger, dm-wide injection veins is crystallized to spinifex-type textures, formed by radial aggregates of elongated orthopyroxene crystals and microgranular olivine. Pseudotachylyte bulk rock compositions are peridotitic (SiO2 = 42.9-44.3, Al2O3 = 2.4-3.8, CaO = 2.3-3.1, MgO = 39.4-41.9 wt%) and the C1-normalized REE patterns are variably fractionated in LREE. Pseudotachylyte minerals preserve peculiar major element compositions (e.g. very high CaO in Ol and Opx) indicating very high crystallization T. Opx in host peridotite has CaO up to 3.3 wt%, implying that very high T (up to 1430°C) were locally reached in the shear zones. Above data indicate that pseudotachylytes originated by localized, nearly complete melting of the host peridotite. The spinifex textures denotes very rapid crystallization of the ultramafic melt. The ultramafic pseudotachylytes of the Lanzo Massif are evidence of upper mantle seismicity at shallow depth ($P < 0.5$ GPa) during lithosphere extension related to the formation of the Ligurian Tethys. The ductile shear zones containing the pseudotachylytes formed at $T \sim 900$ oC and predate pseudotachylyte formation. Their maximum age (~160 Ma) is constrained by the pre-existing MORB gabbroic dykes. Near-total frictional melting of the ambient peridotites occurred at low temperatures ($T \sim 500$-600 oC) during exhumation and lithospheric thinning. It is not possible to determine the number of pseudotachylytes generated by each seismic event, nor the associated displacements. However, related evidence suggests that (i) fault-vein thickness is not a reliable indicator of displacement, and (ii) once melting occurs, the local nonlinear viscous shear resistance is orders of magnitude less than the frictional shear resistance. An estimate of the total volume of pseudotachylytes can be used to infer the cumulative seismic energy and moment of the associated earthquakes. This estimate is subject to large and unquantifiable uncertainties. The best possible value at present is of the order of 107 m3, corresponding approximately to a total seismic moment of 1019 N m. The seismic energy release rate can be evaluated if the duration of seismic activity can be estimated. The presence of a second generation of MORB mafic dykes, following the emplacement of the first generation and the formation of shear zones, and simple exhumation scenarios, suggest a duration < 10-20 Ma. If this estimate is correct, the annual seismic energy release rate during the opening of the Ligurian Tethys was within the range of present-day values at divergent plate boundaries.

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PLUMES VS PROPAGATING FRACTURES IN THE OCEAN BASINS

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Major volcanic centers on or close to mid-ocean ridges, such as Iceland, Azores, Afar, and Easter, are thought to be caused by hot mantle plumes ascending from the core-mantle boundary. Among off-ridge plume candidates in the ocean basins, Hawaii is usually considered to be the strongest. Here we examine the petrological evidence for elevated temperatures at these localities. Phase equilibrium data for model systems at pressures up to 6 GPa indicate that the presence or absence of olivine-controlled crystallization in low-pressure magma chambers is a useful marker that distinguishes high-temperature from low-temperature conditions of melt extraction from the mantle. In the system CaO-MgO-Al2O3-SiO2-Na2O-FeO, this boundary occurs at ~1280°C, 1.5 GPa, just at the upper P-T boundary of the plagioclase-spinel lherzolite transition at the solidus. These are the maximum P-T conditions for avoiding olivine-controlled crystallization trends at low pressures. We find that CIPW normative plots of 6,937 globally distributed mid-ocean ridge basalt glass compositions (389 from Iceland) show no indication of olivine-controlled crystallization. Therefore, no support exists for hot mantle plumes anywhere along oceanic ridges. Instead, the data are consistent with MORB melt-extraction at ~1250-1280°C, 1.3-1.5 GPa from a lherzolitic mantle (Presnall and Gudfinsson, 2008, J. Petrol., 49, 615-632). These P-T conditions are decoupled from the underlying geotherm and tied to the maximum temperature at which flashing of CO2 from melt to vapor can occur. Explosive flashing of CO2 is supported by the constant association of effusive and strombolian eruptive features at ridges (Clague et al., 2003, Mon. 140, AGU, 111). In contrast to oceanic ridges, Kilauea Volcano, Hawaii, shows a clear trend of low-pressure, olivine-controlled crystallization. Also, at the extinct and heavily eroded Koolau Volcano in Hawaii, dunite xenoliths are found in the throat of the volcano. The Fe-rich olivines in these xenoliths indicate that they are cumulates from shallow, olivine-controlled crystallization, not residues of partial melting (Sen and Presnall, 1984, J. Petrol., 27, 194-217). Comparison of CIPW normative plots of Hawaiian glass compositions with model-system phase relations indicates melt-extraction at P-T conditions of ~4.5-5 GPa, 1500-1600°C. These conditions are generally consistent with the presence of diamond in garnet-clinopyroxenite xenoliths from Salt Lake Crater, Oahu, and with values expected for a normal oceanic geotherm near the bottom of the thermal boundary layer at about 150-160 km depth. Therefore, an anomalously hot Hawaiian geotherm, relative to geotherms beneath mid-ocean ridges is not indicated. We conclude that hot plumes are not supported anywhere in the ocean basins and that oceanic volcanism is best explained by propagating fractures that extend through the seismic lithosphere and into the partly melted low-velocity zone.

Session Type: *Poster Presentation*

GENESIS OF UNUSUAL HIGH-MG LOW-NI DUNITES IN ACHANKOVIL SHEAR ZONE, SOUTH INDIA

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We present detailed electron microprobe, Laser ablation ICPMS and stable isotope analyses of constituent minerals from a highly magnesian spinel dunite that forms part of an ultramafic intrusion in Achankovil Shear Zone, South India. The olivines in this dunite are unusually Ni-poor as well as highly magnesian (Fo = ~96), and contains high-Mg spinel, phlogopite, calcite, graphite and sulfides. The phlogopite also shows very high-Mg# (Mg/{Mg + Fe} atomic ratio) around 0.95-97. These high values are similar to the phlogopites reported from many mantle-derived peridotites. Their high K/(K+Na) ratios (0.93-1.00) may also suggest a deep-seated origin for the melts involved .Ilmenites are the predominant Fe-Ti oxide and dominated by geikilite end member; the Mg# of which varies from 0.56 to 0.62. The mode of occurrence of calcite as an interstitial mineral showing sharp contact with spinel, phlogopite and olivine is indicative of its primary nature. The calcites exhibit LREE-enriched nature with (La/Yb)N ratios ranging from 11 to 13. They are also characterized by a steep negative chondrite-normalized REE pattern with a pronounced negative Eu anomaly. Ni-bearing pyrrhotite is the main metallic sulfide phase. The stable isotopic compositions of calcite, graphite and sulfides are indicative of their derivation from a mantle source. An evaluation of the origin of this unusual dunite in terms of the Fo contents of olivine and Cr# of spinel shows that the dunite is plotted far beyond the olivine spinel mantle array (OSMA), falling in higher Fo and lower Cr# field. Therefore the origin of this dunite has to be considered from a different angle from the normal processes of the upper mantle rocks. The data obtained in this study converge to suggest the formation of the spinel dunite from a parental melt enriched in volatiles such as C, CO2, S and H2O. A possibility of low Fe and Ni in olivine in the rock can be attributed to the presence of mantle derived sulfides in these rocks, i.e. a chance of noticeable depletion of Ni and Fe in olivine is indicative of Fe-Ni exchange between olivine and sulfide under very high sulfur fugacity. This partition can lead the residual melts to be enriched in magnesia. The spinel dunite is interpreted in this study as the crystallization product of the highly magnesian melts that were generated from the upper mantle levels, the magma moving through the deep-seated fractures extending below the shear zone. The lower abundance of Cr and Ni in the melts can also be explained by the depletion of these elements in the parental melts or they were fractionated prior to the crystallization of the rock. Since this volatile-rich ultramafic rock is totally undeformed, as against the highly deformed granulite facies supracrustals into which the rock is intruded, we infer that the ultramafic magmatism marks the final stage of the extensional collapse of the orogen following the collisional assembly of the Gondwana supercontinent during the Late Neoproterozoic. Reactivation of mobile belts combined with incipient continental rifting is now widely acknowledged as a vital mechanism for the generation of alkaline ultramafic rocks.

Session Type: *Poster Presentation*

THE SPINEL-PLAGIOCLASE TRANSITION IN THE SHALLOW UPPER MANTLE: SUBSOLIDUS EXPERIMENTS ON FERTILE AND DEPLETED LHERZOLITE

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Plagioclase-bearing peridotites are diffuse in passive continental margin and mid-ocean ridge settings and can be related either to melt impregnation or metamorphic recrystallization at plagioclase-facies conditions. The two processes can be concomitant and difficult to discriminate, although having distinct geodynamic implications, because detailed petrologic criteria are not yet available to properly define the metamorphic origin. Melt impregnation has been described in many plagioclase peridotites and its structural and chemical effects have been largely investigated, whereas few studies have documented the spinel-plagioclase subsolidus transition in mantle peridotites from both on-land and oceanic settings. Moreover, available experimental data at subsolidus conditions ($T<1200$°C) are limited to simplified chemical system, and no experimental work has been so far developed in complex system for compositions representative of mantle peridotites at extensional setting. Estimates of the P conditions of plagioclase appearance and plagioclase modal budget that can crystallize in peridotites as a function of bulk composition are fundamental parameter in modelling of the geodynamic and physical properties of the upper mantle. Here we present the results of experimental investigations performed on fertile and depleted lherzolites modelled in anhydrous complex system Cr,Ti-NCFMAS, at P from 0.25 to 1.0 GPa and T from 900 to 1200°C. Major aims of this work are i) to locate the spinel to plagioclase transition in the P-T space as a function of the compositional variability of mantle peridotites, and ii) to define the compositional and modal variations in minerals resulting by the plagioclase-in reaction. Reasonable grain size (up to 50-70 μm) and coherent element partitioning in minerals support approach to equilibrium. The transition in the fertile lherzolite occurs between 0.8-0.9 GPa at 1100°C, and between 0.7-0.8 GPa at 1000°C, whereas in the depleted peridotite is shifted towards lower P (about 0.1 GPa) indicating that the spinel-plagioclase reaction is moved at lower P at increasing bulk depletion (XCr). Plagioclase crystallizes as thin rim around seed relicts or as small anhedral crystals associated with olivine and pyroxenes; a Cr-rich spinel is stable within the plagioclase stability field up to low pressure (~0.3 GPa). The spinel-plagioclase reaction is therefore continuous within the plagioclase stability field, and is accompanied by systematic compositional variations in minerals as a function of pressure. Pyroxenes record a significant decrease in Al content (coupled to decrease in Na, in clinopyroxene) at decreasing pressure across the transition and progressively within the plagioclase stability field. Plagioclase records a marked An content increase within a rather narrow range of pressure, from 0.8 to 0.31 GPa, suggesting that plagioclase composition may be a potential geobarometer for the low-pressure recrystallization of mantle peridotites. In spinel, XCr and TiO2 increase at decreasing pressure up to relatively high values (TiO2 = 0.76 wt% at 0.5 GPa in the fertile lherzolite), similar to what documented in many impregnated plagioclase peridotites. Mass balance calculations indicate that at decreasing P, the increase in plagioclase modal amount is coupled to increase in modal olivine and overall decrease in modal pyroxenes reflecting the continuous reaction Al-rich sp + Al-rich px1 = plag + ol + Al-poor px2 + Cr-rich sp. Maximum plagioclase modal amounts produced by metamorphic recrystallization (8.97 and 4.89 wt.% respectively in fertile and depleted lherzolite) represents a modal constraint to discriminate the origin of plagioclase peridotites.

Session Type: *Oral Presentation*

MELT MIGRATION AND INTRUSION DURING EXTENSION-RELATED UPLIFT OF THE TALLANTE LITHOSPHERIC MANTLE (BETIC CORDILLERA, SE SPAIN) AS RECORDED BY PERIDOTITE XENOLITHS

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The Alboran Sea region has been affected since the late Oligocene by widespread magmatic activity involving eruption of tholeiitic to calc-alkaline magmas followed by Late Neogene alkaline basalts. These magmatic episodes are related to a complex geodynamic evolution leading to lithospheric extension beneath the Alboran domain. Neogene extension was related to lithosphere scale processes within the Alboran system, involving scenarios like delamination of gravitationally unstable lithosphere, slab roll-back and/or slab detachment. Each of these explanations involve large-scale mantle processes, which invite to study the structure and petrology of the pertinent upper mantle. Late Neogene alkaline lavas from the Cabezo Tallante volcanic center (SE Spain) contain upper mantle xenoliths that exceptionally preserve records of a multi-stage history of recrystallization, deformation, melt-rock interaction and melt intrusion tracking the progressive uplift of this lithospheric mantle sector. Xenoliths include porphyroclastic to equigranular spinel peridotites, impregnated plagioclase peridotites, and composite xenoliths made up of sp-, plag-peridotites intruded by amphibole-bearing pyroxenites. The earliest stages recorded in the Tallante xenoliths involved subsolidus reequilibration from garnet- to spinel-facies field, as suggested by rounded (opx+spinel±cpx±ol) clusters, the breakdown products of precursor garnet assemblage. Spinel-facies equilibration was accompanied by development of a porphyroclastic fabric accentuated in many xenoliths by spinel trails, presumably in response to shear deformation during an early stage of lithospheric mantle uprise. Porphyroclastic spinel peridotites subsequently underwent multiple episodes of reactive porous melt percolation and melt-rock interaction documented by crystallization of undeformed olivine replacing pyroxene porphyroclasts, and unstrained opx overgrowing undeformed olivine and pyroxene porphyroclasts. The porphyroclastic and melt-rock reaction textures are progressively obliterated by the development of an annealed granular structure (likely enhanced by heating during melt percolation) seen in equigranular spinel peridotite xenoliths. Cpx in equigranular peridotites have high Mg values (91.5-93.2), coupled to almost flat REE spectra (about 10 x C1) and strong Th, U enrichment, further indicating interaction with melts; computed equilibrium liquids have a tholeiitic-transitional affinity. Reactive porous flow was followed by an impregnation event, documented by crystallization of interstitial (plag±ol±opx) aggregates between mantle minerals in porphyroclastic and equigranular xenoliths, thus post-dating the annealing event. This indicates uplift of the mantle column to shallower lithospheric depths, where lower ambient temperatures favoured interstitial melt crystallization. The latest magmatic event recorded in the Tallante xenoliths is documented by the intrusion of cm-thick dikelets of hornblende pyroxenites. Geobarometric estimates and the observed crystallization order (ol-cpx-amph-plag) point to 7-10 kbar for pyroxenite intrusion. Cpx and amph in the pyroxenites display similar convex-upward LREE-MREE spectra; computed melts in equilibrium with clinopyroxene display alkaline affinity, similar to the host Tallante alkali basalts. Textural and geochemical features in xenoliths thus indicate that the progressive uplift of the Tallante lithospheric mantle was accompanied by interaction with melts of different sources, reflecting the magmatic evolution of the Alboran domain in response to lithosphere extension and thinning leading to the formation of the Betic-Rif arc.

Session Type: *Poster Presentation*

MELT MIGRATION AND INTRUSION IN THE ERRO-TOBBIO PERIDOTITES (LIGURIAN ALPS, ITALY): INSIGHTS ON MAGMATIC PROCESSES IN EXTENDING LITHOSPHERIC MANTLE

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The Alpine/Apennine ophiolites are largely thought to represent lithosphere sectors mostly formed at an ocean/continent transition and allow the direct observation of petrologic and geodynamic processes in extensional systems evolving from continental rifting to ultraslow spreading. Recent studies have revealed that the Alpine/Apennine peridotites experienced multiple melt/rock interaction and melt intrusion events occurred at different lithospheric depths, thus providing insights on mantle dynamics and lithosphere-asthenosphere interactions during progressive lithosphere extension. Here we present an overview of this multi-stage melt migration and intrusion history, as recorded in the Erro-Tobbio (ET) peridotites (Ligurian Alps, Italy). In the ET spinel peridotites, the oldest intrusion event is documented by the diffuse occurrence of cm-scale folded pyroxenite (mostly spinel websterite) bands. They often display isoclinal folds crosscut by mantle tectonite foliation, their primary intrusion relationships thus being transposed by old deformation events. Pyroxenites show variable bulk Al2O3 and CaO contents, and variably fractionated REE spectra, marked by LREE depletion (CeN/YbN = 0.034-0.15) and absent EuN anomaly. Unusual trace element signature (high Sc,V contents and low MREE/HREE ratios) in clinopyroxenes from one pyroxenite layer is witness of a precursor garnet-bearing magmatic assemblage. Spinel pyroxenites likely originated as high-P (> 15-20 kbar) intrusions that preceded the extension-related peridotite exhumation. In the spinel peridotites, field, textural and chemical evidence (e.g. olivine embayment replacing pyroxene porphyroclasts, increasing modal olivine, up to 85 wt%, at constant bulk Mg values), points that they experienced open-system melt migration by reactive porous flow, subsequent to pyroxenite intrusion and folding. Melt/rock interaction (causing olivine crystallization and pyroxene dissolution) occurred at high melt volumes at deep lithospheric levels. At shallower lithospheric depths, the ET peridotites were impregnated by melts, as documented by significant enrichment in interstitial plagioclase and crystallization of poikilitic orthopyroxene replacing mantle olivine and clinopyroxene. Reacted clinopyroxenes preserve strong LREE depletion, thus indicating that melt impregnation was related to porous flow migration of opx-saturated depleted MORB-type melts. After impregnation, peridotites underwent multiple gabbroic intrusion events. Structural and geochemical features of melt impregnation and melt intrusion products point to a progressive change in melt composition and dynamics. Peridotite impregnation was caused by diffuse migration of opx-saturated depleted melts, and is consistent with cooling and crystallization of migrating melts when the peridotites, due to lithosphere extension and thinning, became part of shallower and colder lithospheric environments. The subsequent intrusion events originated by MORB-type aggregated magmas that had not experienced significant compositional modifications during ascent. The transition from porous flow melt migration to emplacement of magmas in fractures reflects progressive change of the lithospheric mantle rheology, across the ductile to brittle transition, during extension-related uplift and cooling of the ET mantle.

Session Type: *Oral Presentation*

TRANSFORMATIVE REACTIONS BETWEEN "PRIMITIVE" SILICA-RICH MELTS AND MANTLE PERIDOTITE

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Silicate melts are important and highly efficient agents of mass transfer and chemical exchange across the crust-mantle "interface" (and in both directions). Physical processes of melt infiltration and transport will be occurring synchronously with chemical reactions between the invading melt and the original upper mantle (peridotitic) mineral aggregate ("rock"). Regardless of the predominant magma transport mechanism (i.e., fracture propagation versus reactive porous flow), the melt will attempt to equilibrate with the olivine-rich phase assemblage, with the transport mechanism merely controlling the relative surface area over which chemical reaction between the melt and the mantle will take place (i.e., the "melt:rock ratio"). Depending upon the magma's thermal and chemical inertia and this rather ambiguous parameter, the end result of reaction between "primitive" granitoid melts (~monzodiorites or high-Mg andesites) and peridotitic mantle will range from a cryptically to modally-metasomatized mantle, and a "hybrid" crustal melt with an overprinted mantle chemical signature.

We have studied reactions between hydrous, silica-rich melts ("adakites" derived from dehydration melting of garnet-bearing metabasalt), and both fertile and depleted mantle peridotite in a series of piston-cylinder and multi-anvil experiments conducted at ~1.5-4.0 GPa between ~1000-1300°C, using natural granitoid and peridotite starting materials. In addition to major-element analyses of the mantle-hybridized melt and crystalline reaction assemblage, we have measured a comprehensive range of trace elements by laser-ablation ICP-MS to obtain mineral-melt D's for clinopyroxene, orthopyroxene, garnet, olivine, amphibole, and (eventually) phlogopite in equilibrium with "primitive" Mg-rich granitoid melts. From our experimental results, it is clear that the dominant reaction is one which stabilizes high CaO and Al2O3 orthopyroxene at the expense of both olivine and the initial melt, with the formation of hydrous metasomatic minerals (amphibole at pressures < 2.0 GPa, and phlogopite at pressures > 2.0 GPa) favored by relatively low temperatures (<1200°C) and low "effective" melt:rockk ratios. Modal orthopyroxene can increase and modal olivine can decrease to the point at which the initial peridotitic assemblage has been converted to a pyroxenitic (websterite or garnet websterite) reaction assemblage. Reaction between crustal-derived, hydrous, SiO2-rich melts and olivine-rich peridotite therefore has the potential to have a geochemically and mineralogically transformative effect on fertile and depleted mantle assemblages, capable of converting olivine-rich peridotite to pyroxenite, and leaving a chemical signature linking it to crustal growth and the chemical evolution of continental (cratonic) lithosphere.

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THE NATURE OF HARZBURGITE-LHERZOLITE OUTCORPS; THE LHERZ MASSIF

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Studies of the ultramafic massifs of the eastern Pyrenees have made a significant contribution to our understanding of mantle composition and evolution. A number of competing petrogenetic models exist to explain the history of the Lherz body. In particular adjacent harzburgites and lherzolites have many contrasting interpretations which include; (1) melt depletion of an original lherzolite [1, 2] or, (2) refertilisation of a primary harzburgite by basaltic melt [5]. Two lherzolite-harzburgite contacts have been investigated in detail. Although both show a sharp boundary between the two lithologies, one has 2-5cm thick websterite banding adjacent and at distances of 1m+ from the contact, while the second includes amphibole+phlogopite-bearing veins in harzburgite and lherzolite samples within 1m of the contact. Lherzolites at both sites have a range of bulk compositions but trace and particularly REE contents of both whole rock and clinopyroxenes are relatively uniform. Harzburgites are relatively uniform in major element compositions and display a range of U-shaped (LREE enriched) trace element compositions in whole rocks and constituent pyroxene phases. Major element compositions of olivine and spinel phases in all samples are similar to the range of abyssal peridotites. The degree of melt extraction indicated by bulk compositions ranges from <1% in more fertile samples up to 25% melt extraction in harzburgites. This contrasts markedly with the degree of melt-extraction calculated from spinel compositions alone which ranges from <1% up to a maximum of 16%. This apparent inconsistency in the calculated extent of partial melting is similar to that shown by abyssal peridotites which have been interpreted as residues after melt extraction that have become enriched with excess olivine by subsequent melt percolation [6].

Whole Rock 187Os -188Os values define a broad positive correlation with 187Re-188Os and indices of melt depletion (Al2O3 and S). Re-Os isotope systematics alone define an errorchron corresponding to an age of ~1.7Ga, this is significantly younger than model reported in the literature [2, 7].

Taken together the results suggest that the peridotites of Lherz experienced an ancient melt extraction event which was followed by a magmatic episode associated with percolative porous flow. Refractory harzburgites and fertile lherzolites were later juxtaposed as a result of deformation processes coeval with the formation of a penetrative foliation and rotation of layered pyroxenites associated with tholeiitic magmatism. This was followed by emplacement of the peridotite body in to the lithospheric mantle and subsequent uplift during which time alkaline melts traversed the lithosphere crystallising amphibole bearing veins and modifying wall-rock peridotites during ascent. This new evidence obtained from adjacent harzburgites and lherzolites on the Lherz massif is largely in agreement with observations and interpretations given in previous studies [1-4, & 7]. Although it is tempting to speculate that harzburgite-lherzolite contacts on Lherz may preserve evidence of in-situ melt-rock reaction the evidence presented here suggests this is not the case.

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Session Type: *Oral Presentation*

CENOZOIC MAGMATISM AND ROCK UPLIFT OF THE COLORADO PLATEAU BY WARMING OF CHEMICALLY BUOYANT LITHOSPHERE

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The Colorado Plateau is a low-relief, high elevation region (average elevation ~1.9 km) within North America with an enigmatic relationship to Mesozoic-Cenozoic orogenic processes at the western plate margin. We propose that the chemically distinct lithosphere of the Colorado Plateau underwent conductive relaxation in the last 35-40 Ma, following removal of the Farallon plate from beneath North America in middle Tertiary time, while regions surrounding the plateau underwent variable extensional thinning during the same time interval. The centerpiece of this hypothesis, based on xenolith data, is that the Colorado Plateau is underlain by compositionally distinct mantle lithosphere that is depleted in basaltic components relative to the surrounding regions. We use 3D numerical models to show that conductive relaxation of the thermal perturbation due to removal of the Farallon plate can explain two key observations regarding the Cenozoic evolution of the Colorado Plateau. First, our models reproduce the observed encroachment of the onset of Cenozoic magmatism onto the plateau at rates of 3-6 km/my at margins adjacent to zones of extension. Additionally, Middle-Late Cenozoic thermal buoyancy modification, together with Laramide crustal thickening and isostatic responses to Cenozoic erosion, can explain the observed 2 km of net Cenozoic rock uplift of the Colorado Plateau. Our models represent a new approach to intra-plate rock uplift and highlight the importance of chemical heterogeneity in the evolution of continents.

Session Type: *Poster Presentation*

MODELS OF MANTLE DEFORMATION AND FABRIC BENEATH THE SAN ANDREAS FAULT: IMPLICATIONS FOR SEISMIC ANISOTROPY

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Seismic anisotropy from shear wave splitting observations has proven to be a powerful tool in observing and deciphering mantle deformation under continents. SKS waves are particularly useful because they have known incoming polarizations and their splitting parameters provide information on the integrated anisotropy in the mantle beneath the receiver, but lack depth resolution. The orientation of the fast directions of SKS splits are assumed to align with the direction of mantle anisotropy, which is thought to be a combination of anisotropy due to asthenospheric deformation of olivine by dislocation creep and active or 'frozen' fabrics within the lithosphere. This study bridges the gap between global-scale calculations of anisotropy based on LPO fabric and fault mechanical models of strain by modeling the development of fabric in an asthenospheric fluid beneath and idealized model of the San Andreas Fault plate boundary. Our calculations of anisotropy are based on the relationships between mantle flow, strain, and expected fabric development due to dynamic recrystallization under mantle conditions. We investigate the depth-dependence of anisotropy expected at a strike-slip plate boundary and how the patterns of anisotropy vary with rheologic structure and kinematic flow field.

Session Type: *Oral Presentation*

THE DENSITY OF MELT-DEPLETED LHERZOLITE, AND ITS IMPLICATIONS FOR CONVECTIVE DESTABILIZATION OF THE WYOMING CRATON

Derek L. Schutt, Charles Lesher, and Ken Dueker

The removal of melt from lherzolite decreases the density of the residue. This is thought to play a role in the stabilization of cratonic mantle. In particular, it is often thought that cold cratonic mantle is either neutrally buoyant with respect to fertile convecting asthenosphere (the isopycnic hypothesis), or even positively buoyant. Examination of the compositional effects of melt removal, and subsolidus effects such as the opening/closing of the pyroxene solvus, shows that cratonic mantle tends to be negatively buoyant. In particular, depending on the pressure at which melting occurred, mantle from the Moho to about 150 km depth is heavy with respect to fertile asthenosphere at ambient mantle potential temperature. We then examine compositional trends in Kaapvaal Craton garnet peridotite xenoliths and their effects on density. These show that the same ~150 km density cross-over point: above this depth, at a cratonic geotherm, xenoliths are heavy with respect to asthenosphere. These two studies suggest that cratonic mantle must be held in place through high viscosity, else it would convectively destabilize. If this is the case, a natural test of this hypothesis would be if the viscosity of cratonic mantle is decreased then it should drip away. We suggest that this has occurred in the Wyoming Craton, where Laramide-associated hydration has reduced viscosity. P-wave tomography shows a high velocity feature around 200 km depth under Pinedale, WY. This is likely cold peridotitic mantle dripping away. If this is the case, craton stability could be intimately tied to the Earth's deep water cycle.

Presentation Type: *Poster Presentation*

THREE STUDIES ON THE RELATIONSHIP BETWEEN TEMPERATURE AND COMPOSITION, AND VELOCITY AND DENSITY, IN THE UPPER MANTLE.

Derek L. Schutt, Charles E. Lesher, Ken Dueker, Huaiyu Yuan

Abstract: We present three complimentary studies that present the relationship between composition, temperature, velocity, and density, in the upper mantle. In the first study, we forward model the effects of temperature, grain size, and melting on the seismic velocity of the Yellowstone hotspot. Predicted fundamental mode Rayleigh wave phase velocities are compared to observations to show that the Yellowstone hotspot uppermost mantle has a slight excess temperature of about 55-200C, and thus is a weak mantle plume. In the second study, we use isobaric melting experiments to examine the compositional evolution of residue as increasing amounts of melt are removed. We find that the effects of melt depletion on density are significant, but are pressure dependent, and are less than previous studies had predicted. In addition, the effects of melt depletion on seismic velocity are small. The third study derives compositional trends in Kaapvaal Craton garnet peridotite xenoliths through principle component analysis. The effects of these trends on seismic velocity and density as a function of xenolith equilibration pressure are evaluated. We find melt depletion, as proxied by increasing Mg#, increases Vs slightly, and decreases density. Orthopyroxene enrichment increases density at certain pressures, and decreases Vp. These two trends explain about 50-90% of the compositionally-caused velocity variations among the xenoliths.

Session Type: *Poster Presentation*

THE ORIGIN OF MANTLE PYROXENITES IN THE PINDOS OPHIOLITE, NW GREECE

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The Jurassic Pindos ophiolite is one of the best-known ophiolite complexes in Greece. It consists of the two thrust-sheets, a lower one with clear supra-subduction zone characteristics and few mantle rocks (the Aspropotamos Complex), and an upper one (the Dramala Complex) consisting mainly of mantle peridotites and lower crustal cumulate rocks with a MOR (or back-arc) character. As in many other ophiolite massifs, the mantle rocks of the Dramala Complex are lithologically heterogeneous with abundant pyroxenites. In the literature, several possible origins for such mantle pyroxenites are discussed. These include pyroxenites which represent subducted and recycled oceanic material; magnetic segregations that crystallized from asthenospheric melts; and replacive/metasomatic pyroxenites that formed by melt-rock reaction from peridotites or older pyroxenites. In our research project we attempt to constrain the origin of the mantle pyroxenites in the Pindos ophiolite. Our petrographic and field data indicate that in Pindos two major types of distinctly different pyroxenites are present. The first type, 'early-stage' pyroxenites are 1-10 cm wide layers of orthopyroxenite (±ol ±sp ±cpx), occurring always parallel to high temperature mantle deformation fabrics in coarse-grained mantle tectonites, and parallel to 1-10 cm wide dunitic bands, defining a 'mantle layering'. The second type, 'late-stage' pyroxenites are coarse-grained, occur in layers as well as in meter-sized bodies of orthopyroxenite (±cpx ±amph, sp and ol being virtually absent), cross-cut the deformation fabrics of coarse- and fine-grained mantle tectonites but are in places deformed in mantle mylonite shear zones. Late-stage pyroxenites are characterized by a pronounced magmatic cumulate texture of coarse orthopyroxenes with interstitial clinopyroxenes and amphiboles. In early-stage pyroxenites, on the other hand, we have found metamorphic-metasomatic textures, consisting mainly of orthopyroxenes with multiple inclusions of clinopyroxene, olivine, or olivine+clinopyroxene, often defining orientation families. In several cases we observe inclusions in adjacent orthopyroxenes that belong to one orientation family. Such key textures are rare, however, and are only preserved in pyroxenites in coarse-grained tectonites. More commonly, early-stage pyroxenites show a strongly recrystallized texture as a result of subsequent sub-solidus deformation, In our opinion the 'early-stage' mantle pyroxenites in the Pindos ophiolite can be best interpreted as a product of a melt-rock reaction, in which the cpx and olivine inclusions are relics of older pyroxenites or clinopyroxene-rich peridotites. Such a melt-rock reaction requires a SiO2-rich melt, which could have been derived from the melting of older pyroxenites. In fact, these pyroxenites can be interpreted as equivalents of orthopyroxenite reaction zones often found at the margins of partially melted (gt-)clinopyroxenites in mantle xenoliths and lherzolite massifs. We therefore interpret the early-stage pyroxenites as relics of primary mantle heterogeneities possibly related to recycled material, and we intent to test this hypothesis by further trace element and isotope geochemical work. Late-stage, orthopyroxenites are clearly magmatic segregations and have a strongly boninitic character and represent a late imprint of magmatism that was coeval with emplacement of the ophiolite massif, possibly in a supra-subduction zone, proto-arc setting.

Session Type: *Oral Presentation*

GEOCHEMICAL FLUX IN THE MANTLE WEDGE: INSIGHTS FROM SUPRASUBDUCTION ZONE OPHIOLITES

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Understanding geochemical flux in the mantle wedge during subduction is critical to our understanding of the subduction factory process and arc volcanism. It forms an important aspect of the global geochemical flux and is one of the first order problems identified by the Geochemical Earth Reference Model (GERM) initiative. The MARGINS program attempts to understand these processes by studying active subduction zones (crustal inputs, eruption products, seismic tomography). An alternative approach is to examine outcrops of lithospheric mantle that underlie crust formed by supra-subduction zone (SSZ) magmatism.

We have analyzed major element mineral chemistry in 50 samples of mantle peridotite from six locations in the Coast Range ophiolite of California by EMPA, and over 100 grains of pyroxene for 13 REE (La, Ce, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu) and 14 other trace elements (Li, Be, Sc, Ti,V, Rb, Sr, Y, Zr, Nb, Ba, Hf, Pb, Th) by laser ablation ICP-MS analysis. Abyssal lherzolite is found in one block; all others are suprasubduction zone (SSZ) harzburgite and dunite, with associated pyroxenite, websterite, and chromitite [1-2]. The abyssal lherzolites can be modeled by <5% fractional melt extraction from a fertile MORB mantle source. Melting models for the SSZ peridotites imply 15-30% fractional melting under hydrous conditions [3]. All of the peridotites have fluid-mobile element concentrations that exceed model model refractory compositions by 2-3 orders of magnitude, consistent with fluid-phase enrichment during partial melting. In addition, some of the more refractory samples have LREE concentrations that indicate enrichment by an enriched melt phase. Modeling of whole rock ICP-MS data suggests that these more refractory samples may have begun to melt initially in the garnet field before inverting to spinel facies melting.

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Session Type: *Oral Presentation*

ULTRAMAFIC ALTERATION AND ORGANIC SYNTHESIS

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The disequilibrium between seawater and ultramafic rocks engenders conditions for organic synthesis. In some cases, the process is strictly abiotic, as demonstrated in experiments and inferred from the Lost City hydrothermal system on the seafloor. Overall, the reduction of inorganic carbon oxides to form organic compounds can be coupled to the oxidation of ferrous iron in the rock through reduction of H2O to hydrogen during the iron oxidation reactions. But, favorable conditions depend greatly on the temperature and pressure during alteration. In general, lower temperatures favor organic synthesis. Kinetic constraints will be better understood as aqueous organic reaction mechanisms are delineated. Microorganisms also take advantage of the organic synthesis potential to generate biomolecules, and it is plausible that the thermodynamic conditions generated during hydrothermal alteration of ultramafic rocks eliminate the energetic costs of some biochemical processes.

Thermodynamic modeling allows a framework for evaluating conditions at which organic synthesis becomes plausible. The extent to which such models are quantitatively useful depends on the availability of thermodynamic data for aqueous organic compounds and biomolecules at elevated temperatures and pressures. Estimated data of this type, based on the available experimental work and correlations algorithms, have been available for nearly two decades. Recent progress in theoretical geochemistry has led to data for a vastly expanded variety and quantity of aqueous organic compounds. New results indicate that at relatively low temperatures ultramafic alteration provides ample energy for biosynthetic pathways including lipid and amino acid synthesis. In addition, hydrolytic oxidation of olivine can provide sufficient hydrogen to reduce nicotineamide adenine dinucleotide (NAD) at attainable pH and silica activities. NAD reduction is a central step of biosynthesis. The capacity of the geochemical system to drive NAD reduction may correlate with the extent to which life can infiltrate ultramafic rocks.

Session Type: *Poster Presentation*

GRAIN SIZE DEPENDENCE OF THE MELT GEOMETRY IN PARTIALLY MOLTEN OLIVINE AGGREGATES

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The amount and geometry of the melt in the nominally melt-free areas in the Earth's mantle is still controversial. One of the important factors is to understand the melt distribution on the grain scale since it greatly impacts bulk-rock physical properties such as seismic properties and enhances electrical conductivity. It is particularly important to investigate whether the melt resides only in three-grain edge tubules or it exists along two-grain boundaries as well. To estimate the abundance of melt we use the grain boundary wetness, which can be calculated from the total length of solid-liquid and solid-solid boundaries (Takei, JGR, 1998). We have prepared synthetic polycrystalline olivine samples with mean grain sizes ranging from 8 micron to 30 micron with 4 wt% of basaltic melt. High resolution field emission SEM imaging of the coarse-grained sample shows frequent apparently wetted two-grain boundaries. Consistent with this observation the calculated wetness is 0.72, approximately 40% higher value than previously reported (Yoshino et al., JGR, 2005). This value corresponds to a smaller dihedral angle than the 35 deg. reported in the literature. In contrast to the values for the coarse-grained sample, the grain boundary wetness calculated for the fine-grained sample is 0.35 which fits well within the previously reported range. These preliminary results indicate that the grain boundary wetness increases with increasing mean grain size. However, this still leaves the question unresolved whether observed apparently wetted two-grain boundaries are only three grain junctions cut along the axis. To resolve this ambiguity we are performing consecutive serial sectioning (3 micron steps) and high resolution field emission SEM imaging in order to reconstruct the 3D melt geometry.

Session Type: *Oral Presentation*

MICROSTRUCTURAL AND RHEOLOGICAL EVOLUTION IN NATURALLY DEFORMED PERIDOTITE MYLONITES

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We have conducted a microstructural study of a highly deformed mantle shear zone from the Josephine Peridotite, Oregon, US. The goal of this study is to understand how microstructural evolution at large strains leads to transitions in rheological behavior. The particular shear zone we investigate here exhibits

a higher degree of localization than previously studied shear zones in the Josephine Peridotite. The margin of the shear zone is characterized by a single microstructural domain, which contains moderately strong olivine and orthopyroxene fabrics oriented obliquely to the shear zone. The highly deformed samples from the center of the shear zone contain two distinct microstructural domains—a coarser grained domain (~800 microns) that contains only olivine, and a finer grained domain (~200 microns) that contains both olivine and orthopyroxene. The coarser grained domain has a very strong and still highly oblique LPO. However, within the finer grained domain, the olivine has only a modest LPO and the orthopyroxene has no LPO at all, suggesting that a transition to grain-boundary sliding has occurred. Olivine fabric strength increases towards the center of shear zone, however unlike the results in Warren et al. (2008) the obliquity of the fabric is unchanged. We hypothesize that the existence and persistence of the oblique olivine fabric is due to multiple generations of deformation. The olivine fabric was generated during the first deformation phase. A second phase of deformation with moderately different kinematics was primarily accommodated by deformation in the newly recrystallized fine grained orthopyroxene rich domain, allowing the strong and oblique olivine fabric to remain unmodified. This suggests that the recrystallization of orthopyroxene, while rare, may significantly modify the rheological behavior of peridotite (cf Skemer and Karato 2008). These samples provide a crucial microstructural link between modestly deformed shear zones (Warren et al., 2008) and highly deformed ultramylonites (Warren and Hirth, 2006).

Session Type: *Oral Presentation*

WHAT DOES THE ARCTIC RIDGE SYSTEM TELL US ABOUT ALL MANTLE PERIDOTITES?

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The Earth Science community has evolved a number of unifying paradigms about the mantle, its composition, heterogeneity and evolution that we commonly take for granted even with the names we give mantle features: DMM and PRIMA and their brethren are good examples. Many of these are derived from observations on xenoliths, ophiolites and orogenic lherzolites, and not the least, basalts. A few hardy pioneers also study abyssal peridotites, but these have the inherent problems of being melting residues, associated with fracture zones, highly serpentinized, and very rare. The arctic ridge system gives us a unique perspective on the mantle relatively free from these problems, and is now relatively densely sampled, has almost no fracture zones.

Due to the slow spreading rate, which apparently severely limits the melt productivity, the thickest crust in the arctic ridge system is approximately “normal”. The most common crust is about half thickness and there are large expanses with no crust at all, in the sense of Hess, 1962, exposing mantle peridotite in the floor of extensive rift zones. Based on what we knew previously about the mantle, it is possible to make quite a few predictions about the nature of the arctic mantle, many of which it doesn’t live up to:

1. The Arctic ridge mantle is too depleted. The extraction of the Arctic Ridge crust cannot account for the average depletion of observed arctic ridge mantle.

2. The Arctic ridge mantle is too old. Extreme mantle depletions occur along the arctic ridge that are unmatched by crustal production off-axis. Also, Os isotopes record direct evidence of past melting events that shouldn’t survive convective mixing.

3. The Arctic ridge mantle is too heterogeneous. Local variations of melting degree indicators are far in excess of any possible thermal gradient. This requires melt channeling in the asthenosphere and stagnation in the lithosphere. But how much of this heterogeneity is ancient instead?

4. The Arctic Ridge mantle isn't heterogeneous enough (in the way we thought). What is not found is much evidence of the type of mantle vein that could be a melting source for the different alkaline endmembers of Arctic ridge MORB. Where are they?

The result is that the sub-Arctic oceanic mantle begins to look increasingly like the sub-continental lithospheric mantle. Perhaps they are indeed more or less the same reservoir. This implies that formation of heterogeneities (at mid-ocean ridges and subduction zones) and destruction of heterogeneities via convective stirring occur in much the same way for both subcontininetal and suboceanic mantle. Only the sub-cratonic lithosphere forms a truly chemically distinct entity among the observable parts of the mantle.

Session Type: *Oral Presentation*

CRUSTAL RECYCLING AND OSMIUM ISOTOPES LINKED

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Formation, subduction, and incomplete mixing of oceanic crust produces chemical and isotopic heterogeneity in Earth's mantle (1). Recently, osmium isotopes have proved to be an important tracer for old recycled crust because the decay of long-lived radioactive 187Re to stable 187Os generates increased 187Os/188Os ratios in such rocks (2). Elevated 187Os/188Os values have been recently found in Icelandic basalts, where they are correlated with the relative abundances of other isotopes (3,4). These data support the notion that the mantle source of Icelandic basalts contains oceanic crust which has been recycled by subduction and mantle convection (5). However, it has been difficult to assess this model because independent estimates of the proportions of components and their Os isotopic compositions were lacking. Sobolev et al. (6,7) recently proposed that the abundances of Mn and Ni in early-formed olivine crystals in oceanic basalts such as Hawaii and Iceland can provide these estimates. The method makes use of fundamental differences in chemical composition, mineralogy, and melting behavior between recycled (oceanic) crust and mantle (6,7). We combine data for averaged compositions of olivine phenocrysts for olivine-rich lavas and bulk rock 187Os/188Os ratios from Quaternary rocks of Iceland to obtain the proportion of pyroxenite derived melt by both Ni excesses and Mn deficits in olivine (8). These parameters indeed show strong linear correlations, and this permits quantitative assessment of the end-member isotope ratios - peridotitic mantle (Xpx=0) and pyroxenite from recycled crust (Xpx=1). The best correlation based on Ni yields a (peridotitic) intercept of 187Os/188Os = 0.126±0.002 (2σ), similar to estimates of present-day oceanic mantle 187Os/188Os = 0.125. The calculated isotopic composition of pyroxenite is 187Os/188Os = 0.140-0.155. The analogous correlation based on Mn is consistent with this result, although the scatter is slightly greater. These values can be modeled as 1.1-1.8 billion-year-old oceanic crust reacted with present- day oceanic peridotite shortly before final melting. The obtained isotopic compositions of the peridotitic and pyroxenitic components for Iceland also support independently "olivine based" estimates of source proportions (7), as well as the qualitative idea of the presence of ancient recycled materials in Icelandic mantle sources (3-5).

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Session Type: *Oral Presentation*

Multi-Continuum ReactionTransport Modeling of Low-Temperature Alteration and Mechano-Chemical Processes in Fractured Rock

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Most tectonic processes in the crust and shallow upper mantle involve strong coupling of thermal, chemical, and mechanical processes in rocks that are heterogeneous at a wide range of spatial scales. One of the most pervasive processes in the Earth’s crust is that of fluids (i.e., water, brines, CO2, etc.) flowing through fractured heated rock under stress. Although we can sometimes analyze the rocks and the fluids for their physical and chemical properties, it is very difficult to create quantitative numerical models based on fundamental physics and chemistry that can capture the dynamic changes that have or will take place. The initial conditions and the history are only known roughly at best, and the boundary conditions have likely varied over time as well. Multicomponent chemical and thermal diffusion, multiphase flow, advection, and thermal expansion/ contraction are taking place simultaneously in rocks that are structurally and chemically complex (a heterogeneous assemblages of mineral grains, pores, and fractures). For example, in rock where flow is focused through fractures with apertures of only microns there is slow cross-flow and diffusion with fluid in the rock matrix, but the large scale flow system can be dominated by the small-scale sealing, overpressuring, and potentially cycles of rupture. Assessing the rates of such processes requires consideration of transport in discrete fractures or by using multiple continuum methods that capture the sub-grid scale transport processes occurring through many small features within the rock mass. At the scale of fracture asperities and grain contacts the deformation may be controllled by the grain-scale stresses, the dissolution rates at the grain contacts, transport through fluid films and the extent of transport through the system. In this talk, reaction-transport simulations coupling thermal, hydrological, chemical, and mechanical processes will explore the relative rates of alteration under low-temperature metamorphic conditions for representative stresses, temperatures, and mineral assemblages.

Session Type: *Poster Presentation*

DEFORMATION AND FLUID-ROCK INTERACTIONS IN PERIDOTITE XENOLITHS FROM THE AVACHA CALC-ALKALINE VOLCANO, SOUTH KAMCHATKA SUBDUCTION ZONE

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A large part of our knowledge on the mantle composition and structure in subduction zones is derived from geochemical and geophysical data. However, the interpretation of these observations is usually not unique. Variations in temperature and in composition may induce similar seismic velocity and gravimetric anomalies. Trench-parallel polarization of fast shear waves may result for instance from deformation of hydrated olivine or from trench-parallel flow in the mantle wedge. Analysis of peridotites xenoliths from subduction zone allows to constrain the actual nature and structure of the mantle in the wedge and overlying lithosphere, providing essential keys to interpret geophysical data.

Peridotites xenoliths entrained by andesites from the Avacha volcano (S Kamchatka) are refractory spinel harzburgites with <1% cpx. Their coarse-grained microstructures, widely-spaced subgrain boundaries and sinuous grain boundaries in olivine are consistent with deformation under low deviatoric stresses, with significant contribution of diffusional processes. Some samples are partially recrystallized into irregularly shaped aggregates composed by polygonal, strain-free olivine and orthopyroxene crystals. This recrystallization is generally associated with development of fibrous orthopyroxenes aggregates that have been previously interpreted as resulting from the reaction with Si-rich fluids (Arai et al. 2003), suggesting that it is favoured by fluid percolation. Mm-scale opx-rich veins that evolve at the cm-scale from well-developed to cryptic structures cut the ductile deformation structures, suggesting a transition from porous to fracture-controlled for the late, post-kinematic fluid flow. Infrared analyses show that olivine contains 5.4 to 8.6 ppm by wt of water. These values are similar to those observed in spinel peridotites from other subduction zones (Peslier et al. 2006). In contrast, water contents in opx (~35 ppm by wt) are surprisingly low. Olivine and orthopyroxene have strong crystal preferred orientations (CPO) coherent with the activation of (010) 100 and (001) 100 slip systems in olivine and (100)[001] in opx. Recrystallization is accompanied by dispersion of the CPO. Considering the measured equilibrium temperatures (950°-1000°C) and thermal models for cold, Kamchatka-like subduction zones, we propose that these xenoliths were extracted from the base of the overlying plate lithosphere. However, their high depletion and strong deformation suggest that they may have recorded partial melting and deformation in the mantle wedge previous to their accretion to the overlying plate.

Session Type: *Oral Presentation*

DEFORMATION AND REACTIVE MELT TRANSPORT IN THE MANTLE LITHOSPHERE ABOVE A LARGE-SCALE PARTIAL MELTING DOMAIN: THE RONDA PERIDOTITE MASSIF, S SPAIN

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The Ronda peridotite massif in southern Spain is composed by a lithospheric domain and an "asthenospherized" domain that records large-scale heating and partial melting during the Miocene. The two domains are separated by a recrystallization front. Based on a detailed petrostructural and geochemical study of this fossil lithosphere-asthenosphere boundary in the southern part of the Ronda massif, we show that the lithosphere above the recrystallization (and partial melting) front was also affected by the thermal event. It was deformed under an unusually strong transient thermal gradient. Heterogeneous reactive percolation by melts produced in the underlying asthenospherized domain lead to refertilization of refractory lithospheric peridotites up to 1.5 km from the melting front, producing metric-scale intercalations of fertile and refractory mantle rocks ahead of the melting front. It also lead locally to strong REE enrichment in clinopyroxenes, previously unreported in the Ronda massif. Up to 800 meters from the front, pre-existing garnet pyroxenite layers were partially molten and the resulting melts probably contributed to the refertilization process. Parallelism between the recrystallization front, compositional boundaries, and deformation structures, as well as variations in the deformation intensity of pyroxenes and spinels, suggests syn- to late-tectonic melt transport controlled by both the deformation and the thermal gradient. Variations in the strength of olivine crystal preferred orientations as a function of the modal and chemical composition of the spinel tectonites point to a higher contribution of diffusion to deformation in the most fertile rocks, corroborating the hypothesis that deformation occurred in presence of melt. These observations show that the Ronda spinel tectonites record deformation and melt percolation under a strong thermal gradient in a narrow zone at the base of the subcontinental lithosphere, just above a large-scale partial melting domain formed in response to transient heating due to upwelling of hot asthenospheric mantle during the late stages of a lithospheric thinning episode.

Session Type: *Oral Presentation*

THE IMPORTANCE OF MELT EXTRACTION FOR INFERRING MANTLE COMPOSITION

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Partial melting of the Earth’s mantle is a near-fractional process. Detailed studies of mantle-derived melts and melt inclusions have shown that erupted melts consist of incomplete mixtures of small degree partial melts produced at variable depths in the melting regime. Owing to the large chemical variability of instantaneous fractional melts, melting of homogeneous sources suffices to explain the chemical variability observed in mantle-derived melts, but the isotopic variability commonly observed in oceanic basalts clearly proves that their mantle sources are compositionally heterogeneous. It is less apparent, however, whether this compositional heterogeneity also manifests itself mineralogically. Mineralogical heterogeneity in the Earth‘s mantle is most often related to melting of recycled oceanic crust in the form of pyroxenite or eclogite components enclosed in the ambient peridotitic mantle although the isotopic evidence remains ambiguous. The trace element systematics are a more promising tracer because, in addition to compositional differences, the higher modal abundance and different composition of garnet and clinopyroxene in pyroxenite compared to peridotite can lead to distinctive signatures in the partitioning behavior. Recent partitioning experiments show that these are most pronounced for Ba, La, and Sr, but that in general, the partitioning behavior of the lithophile trace elements in pyroxenite and peridotite-melt systems is broadly similar. Thus, for distinguishing between pyroxenite and peridotite melts, there is a trade-off between the partitioning behavior and source composition. Preserving distinct signatures is most likely if differences in source composition are amplified by opposing partitioning behavior. The most prominent case is for La/Nb and it is shown that the combination of $La/Nb \ll 1$ with enriched isotope and deep melting signatures should be a unique fingerprint of pyroxenite-derived melts. Comparison of the modeled and observed trace element - isotope systematics in selected MORB and OIB suites (e.g. from the East Pacific Rise, Iceland, Tristan da Cunha, Gough and St.Helena) further shows that factors such as the relative abundance of different source components, their difference in solidus temperature, and the extent and depth range of melt aggregation shape the isotope -trace element relationships of the erupted melts from pyroxenite-bearing peridotites. Moreover, the range and the absolute values of key trace element ratios (e.g. Ba/Th, La/Nb, Sr/Nd, La/Sm, Sm/Yb) and their relation to the isotopic variation provides constraints on the origin of the different source components. In addition to identifying source or partitioning-related differences, inferring the origin and distribution of heterogeneous components in the Earth's mantle requires detailed knowledge about the mechanisms of melting and melt mixing during the melt extraction process. These mechanisms determine how and to what extent the chemical and isotopic heterogeneity of mantle sources is reflected in the erupted melts. Thus the paradigm that the isotopic range observed in partial melts directly reflects that of their source rocks is obsolete as it is strictly true only for isotopically homogeneous sources.

Session Type: *Poster Presentation*

CARBONATION AND SERPENTINIZATION OF PERIDOTITE IN THE SAMAIL OPHIOLITE

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In situ mineral carbonation of peridotite may provide a useful sink for carbon sequestration. In the Samail Ophiolite of Oman, this process is occurring naturally as low temperature alteration of tectonically-exposed mantle peridotite produces carbonate veins and travertine terraces associated with on-going serpentinization and carbonation. Through XRD, XRF, and electron microprobe analyses, I am determining the mineral composition of these carbonates as well as the serpentinized peridotites that host them. Based on this mineral analysis, I will use Geochemist's Workbench to model the reactions that produce these assemblages.

Session Type: *Poster Presentation*

HOW TO BUILD A PLUTON: INSIGHTS FROM MAPPING GABBRO-BODIES IN THE TRINITY OPHIOLITE.

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The Trinity Ophiolite exposes Silurian to Devonian gabbroic bodies hosted by mantle rocks. It is a good on-land analogue of M. Cannat's (1993) heterogeneous crustal model for slow spreading environments. We remapped part or all of the China Mountain, Toad Lake and Bonanza King plutons in order to infer what processes were involved in their construction. We identify three intrusive series in the studied plutons. Their relative ages have been determined by the occurrence of fragments of older series in the younger series. The early Series 1 is best exposed in the Toad Lake pluton. It consists of three subunits: rocks of the mantle-crust transition zone (MTZ), overlain by a pyroxenite and a gabbroic subunit. Series 2 also consists of three subunits: slightly evolved, varytextured gabbronorite, grading upward into amphibole gabbro with no primary opx, typically overlain and locally crosscut by diabase dikes forming also local dike swarms. Most structural elements are steep. The complete succession of Series 2 is only exposed in the Bonanza King pluton. In the other bodies only the varytextured gabbronorite was identified. Most importantly, emplacement of Series 2 led to an almost complete disruption of Series 1 in the China Mtn. and Toad Lake plutons. Thus, fragments of Series 1 pyroxenite and more rarely MTZ rocks occur as exotic blocks within the Series 2 varytextured gabbronorite. Contacts of Series 2 to the host mantle are marked by peridotite fragments and (rooted?) screens of peridotite in gabbro, suggesting a lithospheric setting. The late Series 3 is only found in the China Mtn. and Toad Lake bodies. It consists of banded, mostly fine to medium grained, typically magmatically foliated gabbronorite. It is mineral-chemically evolved and is correlated with the "laminated gabbronorite" of the Toad Lake area described by Cannat and Lecuyer (1991). Emplacement of this series caused no major disruption of series 2. While the tectonic significance of the three series is not clear at this stage, we can infer a hotter, more asthenospheric setting for Series 1 and a colder, lithospheric, but still spreading-related environment for Series 2. The volumetrically minor Series 3 shows little affinity to spreading but may easily be mistaken as representing the early"layered gabbro" member within a typical ophiolite pseudostratigraphy. The uniqueness of each of the Trinity gabbro plutons is in our view the result of the different proportions in which each Series is represented and the extent to which the early Series 1 has been disintegrated by the later Series 2 and 3.

Cannat, M., and C. Lecuyer, 1991: Tectonophysics, v. 186, p. 313-328.
Cannat, M, 1993: J. Geophys. Res., v. 98, p. 4163-4172.

Session Type: *Oral Presentation*

STACKED GABBRO UNITS AND INTERVENING MANTLE: A DETAILED LOOK AT A SECTION OF IODP LEG 305, HOLE 1309D

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Hole U1309D (IODP Legs 304/305) penetrated 1415 m into the seafloor of the Atlantis Massif, an oceanic core complex at 30°N, Mid-Atlantic Ridge. More than 96% of all recovered rocks are gabbroic. Based on a mineral chemical overview, we suggest that between ≤800 and 1115 mbsf, a magmatic unit occurs, ranging from olivine gabbro and troctolite in the lower part to gabbronorite and oxide gabbro in the upper part. Below 1235 mbsf, massive gabbronorites/oxide gabbros were drilled and they may represent the roof of an underlying magmatic unit. The focus here is on the zone where both units interact and the screens of a microstructurally distinct, olivine-rich troctolite occur. We argue that the olivine-rich troctolite is a former mantle unit which was converted to olivine-rich troctolite as the deeper intrusion was emplaced against it. A similar origin had been attributed to troctolitic rocks from Site 1275, ODP Leg 209. Our main arguments against a possible cumulate nature of the olivine-rich troctolites is the lack of any systematic down-hole trend in compatible elements within the olivine-rich troctolite, their distinctly fine-grained microstructure, their high Cr in cpx, and the fact that they form a distinct group in a NiO vs Mg/(Mg+Fe)olivine space. The inferred order of transformation of the former mantle rocks tracks the evolution of residual melt in the underlying magma body, i.e. from more primitive to more evolved. A recurring theme in this and other olivine-bearing rocks from Hole U1309D is the inferred dissolution of olivine, presumably caused by the percolation of evolved melts. Evidence for the percolation of such melts through the olivine-rich troctolites are chemically evolved, interstitial pyroxenes, highly evolved amphiboles and orthopyroxenes as inclusions in Cr-spinel and mm-scale noritic veins. The percolation by evolved melts would also be the major difference to otherwise conceptually similar rocks from the ophiolithic crust-mantle transition zone. By arguing that the olivine in the olivine-rich troctolites is residual, the conundrum of the fate of truly primitive cumulates remains. We speculate that any once more primitive cumulate has reacted with its residual melt via equilibrium crystallisation to an olivine gabbro stage. Such equilibrium crystallization in turn might have been favored by the inefficiency of melt segration in intrusions encased in a lithospheric environment with low magmatic strain.

Session Type: *Poster Presentation*

TRACE ELEMENTS IN PERIDOTITES FROM HOLE 1274A, ODP LEG 209 AND THEIR RELATION TO MAGMATISM AND ALTERATION.

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Peridotites recovered from Hole 1274A, OPD Leg 209 (20°N, Mid-Atlantic Ridge) are 65 to 100% serpentinized harzburgites and dunites. Trace element patterns of selected cpx grains in harzburgites determined via SIMS are consistent with high degrees of melting requiring a component of garnet field melting (Seyler et al., 2007; Suhr et al., 2008) due to steeply sloping middle and heavy REE patterns. Whole rock trace element patterns from the same Hole (Godard et al., 2007) can be recalculated to their cpx-equilibrium concentration by using the bulk distribution coefficient of each sample. In such a cpx-reference frame, the average HREE contents of the cpx in the harzburgites as derived from the whole rock data is virtually identical to the directly measured cpx concentrations via ion probe. However, the middle REEs, light REEs and Sr of cpx is lower in the directly measured cpx by a factor of 4, 10, and 100, respectively, compared to the recalculated whole rock patterns. While the samples in this comparison are not identical, the similar heavy REE content of both sets suggests that the non-cpx matrix contains a high, light to middle REE and Sr component not present in the cpx grains selected for SIMS analyses. A comparison of a fresh and altered opx grain by SIMS analysis also shows a ten-fold enrichment in La, Ce, Sr of the serpentinized opx over the fresh opx. The combined evidence suggests that the enrichment is due to low-T alteration. This conclusion is supported by Laser ICP-MS data from cpx and opx grains in the 1274A peridotites. While their heavy REEs show negligible inter-grain variation, light and middle REE patterns and Zr show strong fanning for different grains within a single sample. Opx also shows higher absolute concentrations in LREE than cpx, in contrast to what would be expected on the basis of mineral/melt distribution coefficients. It thus seems that the more incompatible elements in serpentine, opx, and dusty cpx are affected by low T alteration, in contrast to what has been derived in recent studies for this Hole (Godard et al., 2008; Paulick et al., 2006). Another factor in 1274A peridotites is probably the local infiltration of a highly evolved melt: a harzburgite from Core 27R studied via SIMS shows an extremely strong grain to grain variation. One cpx grain shows a 50x C1 concentration in Ce and Nd. Very low Sr, Eu, Ti and Zr in this analysis suggest here an influence from a highly evolved (gabbro-derived?) melt which has seen prior plagioclase, Fe-oxide and zircon fraction.

Godard et al., 2007, EPSL 267, 410-425
Paulick et al., 2006, Chem. Geol. 234, 179-210
Seyler et al., 2007, CMP 153, 303-319
Suhr et al.., 2008, G-cubed 9, issue 3

Session Type: *Poster Presentation*

EVIDENCE FOR PROGRADE METAMORPHISM IN A DUNITE BODY FROM THE TRINITY OPHIOLITE (CABIN MEADOW LAKE)

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The Trinitiy Ophiolite is known for its gabbroic intrusions into a peridotite environment. Peridotites in the area of Cabin Meadow Lake (to the south of the South China Mtn. gabbro body) are remarkably unaltered. Meter-sized dunites from this area locally contain relict opx-grains due to incomplete reaction with a percolating melt. They also have minor primary cpx and pargasitic amphibole which occur in interstitial positions or as rims on spinel and fresh opx. While the olivine grains in the dunite (Mg# of 91.8) are unaltered with just a few late serpentine veins, some of the relict opx grains are completely altered to serpentine. Only these serpentines (Mg# 98) after opx display a secondary, coronitic olivine. Fresh opx in the same slide does not show this feature. The coronitic olivines range from 10 µm thick to replacing nearly the entire serpentinized opx grain. They have Mg# 95, i.e. they are extremely forsteritic. Around some serpentinized opx grains, a second, outer olivine-corona is developed between the original olivine and the highly forsteritic one. It is always thin (max. a few tens of µm) and more Fe-rich (Mg# 87) than the host olivines. At least in one case, the Fe-rich olivines exists as the only corona. The Fe-rich olivine is marked by significant concentrations of TiO_2 (up to 0.2 wt. %) and Cr_2O_3 (~0.07%). Finally, there is also a secondary diopsidic cpx. An olivine corona is not observed on rare, altered orthoamphibole (?). At this preliminary stage of the study, I suggest that the coronitic olivines develop as a result of prograde metamorphism of serpentinized opx grains, the estimated temperature being 400-450°C (Evans and Trommsdorf, 1976). The highly forsteritic nature presumably derives from the Fe-poor nature of the precursor serpentine. Ti-Cr-rich olivines associated with more Fe-rich olivine coronas are not well understood. Perhaps they derive from formerly present primary amphibole rims on the orthopyroxenes. The regional significance of the described occurrence is not clear at all. In any case, it is tempting to relate the inferred heating to the emplacement of the numerous gabbro bodies in the Trinity Massif. Perhaps more importantly, an implication would be that the host to the gabbros was partly serpentinized at the time of the pluton emplacement.

Evans and Trommsdorf, 1976, SMPM 50. 481-492

Session Type: *Poster Presentation*

DIFFUSION CREEP OF HARZBURGITE

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Experimental deformation experiments have been conducted on fine-grained, two-phase aggregates of olivine and orthopyroxene to investigate the role of grain- and phase-boundary sliding on rheology and fabric development. A suite of large-strain ($\gamma \geq 1$) general shear experiments conducted at T=1200˚C and P=1.6 GPa on aggregates ranging from 35-100 vol% olivine, to characterize the evolution of fabric, were complemented by small-strain axial compression experiments at T=1200˚C and P=0.3 GPa, to better constrain the rheology. Microstructural and rheological data suggest that deformation of these two-phase aggregates in the diffusion creep regime occurs via interface-reaction-controlled diffusion creep that is accompanied by extensive migration of olivine-orthopyroxene phase boundaries. The resulting rheologies suggest that olivine + orthopyroxene composites are weaker than the olivine end-member at the conditions tested. Physically, this behavior arises because long-range, i.e., grain-scale, diffusion of Si4+ is unnecessary in these pseudobinary two-phase aggregates. We further demonstrate that interface-controlled diffusion creep leads to strong crystallographic preferred orientations (CPO) of the component minerals, which develops in the near-absence of dislocation activity. The CPO formed in these anhydrous, low-stress experiments has the olivine a-axis aligned perpendicular to the flow direction --"Type B" fabric --argued by some to be the unique result of deformation under conditions of high differential stress and high water fugacity. Phase boundary dynamics, thus, are argued as a significant factor in the accumulation of strain in polyphase aggregates.

Session Type: *Oral Presentation*

GENERAL GEOCHEMICAL AND RHEOLOGICAL FEATURES OF THE LITHOSPHERIC MANTLE BENEATH THE CARPATHIAN-PANNONIAN REGION

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Our knowledge of the lithosphere beneath the Carpathian - Pannonian Region (CPR) has been greatly improved through petrologic, geochemical, isotopic studies and orientation analyses of upper mantle xenoliths hosted by Neogene -Quaternary alkali basalts. These basalts occur at the edge of the Carpathian-Pannonian Region (Styrian Basin, Nógrád-Gömör and Eastern Transylvanian Basin) and its central portion (Little Hungarian Plain, Bakony-Balaton Highland). The xenoliths are mostly spinel lherzolites, accompanied by subordinate pyroxenites, websterites, wehrlites, harzburgites and dunites. The peridotites represent residual mantle material showing textural and geochemical evidence for a complex history of melting and recrystallization, irrespective of location within the region. The lithospheric mantle is more deformed in the center of the studied area than towards the edges. The deformation may be attributed to a combination of extension and asthenospheric upwelling in the late Tertiary, which strongly affected the central part of CPR subcontinental lithosphere. There is also a systematic variance in olivine orientation patterns in deformed peridotite xenoliths with their equilibrium temperatures and the depth of their origin beneath the central part of the CPR. Olivines in xenoliths derived from the deep lithospheric mantle, displaying the most primitive compositions and texture, always display decisive symmetric fabrics indicating that deformation was coaxial in a constant stress field. Those samples derived from shallower depths always reflect the activation of multiple slip systems. The peridotite xenoliths studied show bulk compositions in the following range: 35 - 48 wt% MgO, 0.5 - 4.0 wt% CaO and 0.2 - 4.5 wt% Al_2O_3 with no significant differences with regard to their geographical location. Mineral compositions, particularly of clinopyroxene, vary according to xenolith texture. Clinopyroxenes in more deformed xenoliths are relatively enriched in strongly incompatible trace elements such as light rare earth elements (LREE). Modal metasomatic products occur as both hydrous phases, including pargasitic and kaersutitic amphiboles and minor phlogopitic micas, and anhydrous phases - mostly clinopyroxene and orthopyroxene. Vein material is dominated by the two latter phases but may also include amphibole. Amphibole mostly occurs as interstitial phases and is more common than phlogopite. Most metasomatized peridotites show chemical and (sometimes) textural evidence for re-equilibration between metasomatic and non-metasomatic phases. However, amphiboles in pyroxenites are sometimes enriched in K, Fe and LREE. The presence of partially crystallized melt pockets (related to amphiboles and clinopyroxenes) in both peridotites and pyroxenites is an indication of decompression melting and, rarely, incipient partial melting triggered by migrating hydrous melts or fluids. Metasomatic contaminants may be ascribed to contemporaneous subduction beneath the Carpathian - Pannonian Region between the Eocene and Miocene.

Session Type: *Oral Presentation*

GEOCHEMICAL VARIABILITY OF THE FIZH MANTLE SECTION, OMAN OPHIOLITE WITH RELEVANCE TO PALEO-RIDGE SEGMENT STRUCTURE

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Spatial variation of mineral and whole rock compositions of harzburgites and dunites were investigated in the mantle section of the Fizh block, the northern Oman ophiolite to investigate their relationship to segmentation of paleo-ridge system. Recently Miyashita and Adachi (2003), Le Mée et al. (2004) and Monnier et al. (2006) reported an inferred center and an end of a paleo ridge segment system in the Fizh block. Fo content of olivines from harzburgites ranges from 90 to 92 while Cr# [=100 x Cr/(Cr+Al)] ratio of spinel widely ranges from 24.2 to 77.6. Spinels with Cr# more than 60 indicates that these peridotites have experienced greater degree of melt extraction than abyssal peridotites. Spinel Cr# mapping in the Fizh block shows that the harzburgites with spinel Cr# >70 linearly distribute in the western side of NW-SE oriented shear zone. We call it as “a highly-refractory zone”. It is also confirmed that abundances of whole rock HREE are lowest in this zone.

From the south toward the north in the Fizh block the maximum and minimum Cr# of spinel increases and decrease, respectively, with expanding the range of Cr#. In the south spinel Cr# is limited in a range from 55.6 to 63.2 while, in the Rajmi area in the northern Fizh block, spinels Cr# ranges from 24.2 to 77.6. These results indicate that the range of spinel Cr# increases from the south where a segment center of a paleo ridge was located, toward the north, i.e., the segment end. The south of Fizh block that corresponds to the central part of segment mainly consists of relatively homogeneous refractory peridotites while, in the north Fizh block where the segment end locates, the less depleted peridotites coexist with highly-refractory peridotites.

We consider that the degree of partial melting was initially much less in the segment end relative to the segment center due to much efficient conductive cooling through fracture zone. However, during the oceanic detachment a fluid flux focused the segment end interacted with residual peridotites and formed highly-refractory peridotites.

Whole rock MREE [Nd, Sm, Eu]-Yb plots show secular trends corresponding to the range of spinel Cr#. The first trend seems a residual trend by melting at mid-ocean ridge while the other trend formed by remelting of the residual peridotites. On the other hand, peridotites near the basal thrust are most strongly enriched in LREE and the enrichment gradually decreases toward the Moho. It indicates that a LREE-enriched fluid may have derived from the basal thrust and flew into the mantle section. The peridotites near Moho and inside of shear zone are characterized by linear REE patterns with positive Eu anomaly indicating refertilization by addition of melt components.

Session Type: *Poster Presentation*

GEOCHEMISTRY OF RESIDUAL PERIDOTITES FROM THE ATLANTIS MASSIF, MAR 30°N: INTER- AND INTRA-GRAIN VARIATIONS OF CLINOPYROXENE TRACE-ELEMENT COMPOSITIONS

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The Atlantis Massif is a 1.5-2 Myr old oceanic core complex forming on the inside-corner high at the intersection of the Atlantis Fracture Zone and Mid-Atlantic Ridge (MAR) 30°N (Blackman et al., 2006). The domal, corrugated surface of the massif is interpreted as a long-lived, low-angle normal or detachment fault exposed at the seafloor. High density mantle rocks invoked to explain observed gravity anomalies and high seismic velocities inferred from seismic analysis were expected to occur less than 1 km below the seafloor (e.g., Cann et al., 1997). Integrated Ocean Drilling Program Expeditions 304/305 successfully recovered long mafic-ultramafic rock sections from two holes, Holes U1309B and U1309D, at and below the detachment fault (Site 304/305-U1309). Hole U1309B was deepened to 101.8 mbsf with an average recovery rate of 46%. The Hole U1309D was deepened to 1415.5 mbsf with an average recovery rate of 74.8%. Cores from both holes dominantly consist of gabbroic rocks, such as 49% for Hole U1309B and >85% for Hole U1309D. Peridotite, a prospective main target of these cruses, was rarely but successfully recovered from both Holes U1309B (3%) and U1309D (0.3%) (Blackman et al., 2006). We present petrological and geochemical features of the peridotites from the Atlantis Massif, and discuss their origin.

Recovered peridotites are fragmented and limited short intervals surrounded by a huge gabbro body. A single interval composed of spinel harzburgite was collected at 58 mbsf in Hole U1309B. The harzburgite (Hole B harzburgite) exhibits protogranular texture with deformed olivine and orthopyroxene. The interval is in direct contact with the coarse-grained gabbro interval above, but the lower boundary was not recovered. Based on the modal composition and mineral chemistry, the harzburgite probably correspond to a restite of upper mantle origin. However, REE compositions of clinopyroxene, which are systematically changed within the harzburgite interval, suggest that original features of the residual harzburgite were modified by late-stage events. In the harzburgite section far from the contact with the gabbro, clinopyroxenes have a low MREE/HREE ratio with low HREE abundances and slight enrichment of LREE (e.g., $(Gd/Yb)_N$ = 0.14, $(Ce/Yb)_N$ = 0.45, Yb_N = 2). This feature indicates that the Hole B harzburgite is originally depleted mantle residue formed by partial melting under polybaric conditions, such as garnet lherzolite and spinel lherzolite stability conditions. The LREE/HREE ratio of clinopyroxene increases toward the contact, and the REE abundances are higher near the contact (e.g., Yb_N = 5, Ce_N = 1.6). These compositional variations of clinopyroxene can be explained by a reaction with the melt related to surrounding gabbro formation. Several short peridotite intervals surrounded by gabbros occur at different depths of a limited zone (61 - 224 mbsf) in Hole U1309D. The intervals consist of lherzolite, wehrlite and dunite (Hole D peridotites). The peridotites contain various amounts of interstitial plagioclase indicating melt impregnation. Trace-element compositions of clinopyroxene in the Hole D peridotites are relatively constant despite the various lithologies, and are comparable to those in the Hole B harzburgite section adjacent to gabbro.

References: Blackman et al. (2006) IODP304/305 Exp. Rep.; Cann et al. (1997) Nature 385, 329

Session Type: *Oral Presentation*

THE EFFECT OF WATER ON THE PARTIAL MELTING OF PERIDOTITE AT 3 GPA.

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We have investigated the influence of water on partial melting of fertile garnet peridotite by performing experiments with a hydrated synthetic peridotite at 3 GPa. The starting material consists of a synthetic KLB-1 peridotite analog mixed in varying ratios with a synthetic hydrous olivine composition (Mg# of 83 + 10% H2O) to produce starting materials with 1, 1.5, and 2.5 wt% H2O. Experiments were performed in a Walker-style multianvil apparatus in AuPd capsules at temperatures ranging from 1250 to 1475 ° C. Resulting charges consist of liquid+ol+opx±cpx±gt and all phase compositions were measured by electron microprobe. Liquids are preserved as 20×20 to 100×300 micron pools of heterogeneous quench crystals and extensive analysis is required to reconstruct partial melt compositions. We therefore perform ~150 individual microprobe analyses on the quench for each experiment and accept only those analyses (typically 10 to 40 analyses) that yield olivine-liquid Fe-Mg KD values between 0.30 and 0.35. Inferred equilibrium liquid compositions range from basaltic at high temperature to nephelinitic at low temperature. Melt fractions, F, are calculated by mass balance and range from 0.12 to 0.31. As an index of the influence of H2O on melting, we calculate ΔT, which is the difference between the temperature of the experiment and the temperature required to generate that melt fraction under dry conditions, which are inferred from the experiments of Walter (1998) and from those of Davis and Hirschmann (in prep). Small corrections for iron loss are also required. Calculated values of delta T are a simple function of the H2O concentration in the melt, which we infer by mass balance, and this trend shows excellent agreement with previous determinations at lower pressure. This simple relation allows calculation of the influence of flux melting in arc and back-arc settings, and, when extrapolated to low bulk H2O contents, to the influence of H2O on partial melting in the source regions of oceanic islands and mid-ocean ridge basalts.

Session Type: *Oral Presentation*

FIELD-BASED CONSTRAINTS ON RHEOLOGY OF THE LITHOSPHERIC MANTLE, TWIN SISTERS, WASHINGTON

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We present direct finite strain and rheological estimates of naturally deformed mantle materials using field observations in the Twin Sisters ultramafic body of Washington State. The rocks are largely unaltered, containing virtually no serpentine except in fault zones. We mapped in detail a ~15000 m2 area. The outcrop consists of m-scale banded dunite and harzburgite, with both deformed orthopyroxenite dikes and undeformed clinopyroxene dikes. Folded and elongated (boudinaged or ductilely thinned) orthopyroxenite dikes within the host dunite provide strain markers that allow us to characterize the finite strain over Using dynamic instability analysis on the folded orthopyroxenite dikes, orthopyroxene is calculated to have ~31 times the effective viscosity of olivine-rich host rocks (based on a power law exponent of 3.0 for this dislocation creep process). Detailed mapping also indicates that inclusion of up to 15% orthopyroxene in the olivine-rich host rocks does not affect the relative viscosity, constraining the rheological behavior of two-phase, mantle material.

Session Type: *Oral Presentation*

H2O-SATURATED PERIDOTITE MELTING BEHAVIOR FROM 3-5+ GPA

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We present new experimental data on the melting behavior of hydrous undepleted peridotite to improve our understanding of the conditions required for melting the mantle wedge at subduction zones. Piston cylinder and multi-anvil experiments from 3.2 to 5+ GPa on the primitive mantle composition of Hart & Zindler (1986) reveal the H_2O-saturated solidus remains approximately isothermal at 810°C between 3 - 5 GPa. Chlorite is stable on the solidus from 2 to 3.6 GPa and likely transports H_2O to P-T conditions suitable for hydrous melting in the mantle wedge. Initial findings on the composition of 25 - 35% partial melts of H_2O-saturated peridotite at 3.2 GPa reveal they are low-alkali olivine tholeiites with ~47-49 wt% SiO_2, 10-12 wt% Al_2O_3 and 16-20 wt% MgO. These melts are in equilibrium with a harzburgite residue, consistent with intermediate-to-high degree melting of a mantle peridotite. The change in melt fraction with temperature is equivalent or greater than that measured for anhydrous peridotite at these conditions, unlike previously suggested (Gaetani & Grove, 1998). Our ongoing work aims to expand melt composition data over a wider range of temperatures and pressures.

Session Type: *Oral Presentation*

STRUCTURAL REACTIVATION DURING CONTINENTAL DEFORMATION DUE TO ANISOTROPY IN THE MANTLE LITHOSPHERE

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Structural reactivation is a major feature of continental deformation at all scales, from continental breakup along ancient collisional belts to localized intraplate seismicity. To understand the effect of inherited lithospheric structures on the rifting process, we have developed a multi-scale model that explicitly takes into account an evolutive anisotropic viscosity due to the preferred orientation of olivine crystals in the mantle by coupling a viscoplastic self-consistent (VPSC) simulation of the deformation at the polycrystalline aggregate scale to a 3D Finite Element code. Models with a homogeneous initial olivine LPO show a highly anisotropic mechanical behavior, characterized by (i) variation in strength as a function of the direction of solicitation relative to the initial LPO and (ii) development of shearing parallel to the preexisting LPO. To analyse the extensional deformation of a continental plate containing pre-existing lithospheric scale shear zones, we use a multi-domain meshing tool to define planar zones, which display an initial olivine LPO that differs from the one in the surrounding plate. These multi-domain models show that the reactivation of pre-existing lithospheric scale shear zones depends on their orientation relatively to the imposed stress field. Strong strain localization in the inherited structures is observed when the pre-existing faults are oblique to the imposed extension. Deformation within the inherited shear zones is characterized by shearing parallel to the fault trend, extension normal to it and vertical thinning, i.e., transtension. However, faster evolution of olivine LPO within the pre-existing shear zone results in progressive hardening within the inherited domain. It may lead to re-homogeneization of the strain distribution if thermal or magmatic processes are not activated in the thinned lithospheric domain.

Session Type: *Poster Presentation*

EVOLUTION OF A HIGH-TEMPERATURE, HARZBURGITE-HOSTED SHEAR ZONE, TWIN SISTERS MASSIF, NW WASHINGTON.

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The Twin Sisters peridotite massif, NW Washington, composed primarily of harzburgites and dunites, contains folded orthopyroxenite dikes and planar cross-cutting websterite and clinopyroxenite dikes. An ultramylonitic shear zone in harzburgite offsets an orthopyroxenite dike by ~35 cm, and a clinopyroxenite dike with similar orientation by <2 cm. The dikes are near orthogonal to the shear zone. The shear zone is <5 mm thick and <1.5 m long, apparently terminating at both ends at a similar distance from the offset orthopyroxene dike. The clinopyroxenite dike is located near one end of the shear zone. Pyroxene grains from both dikes are strung out in the shear zone. Shear strain in the shear zone postdates formation of the orthopyroxenite dike and must exceed 70, assuming simple shear deformation. The smaller offset along the clinopyroxenite dike suggests that much of the strain may have been accomplished before the dike formed, although it is also possible that the smaller offset represents decreased slip near the edge of the shear zone. The shear zone likely nucleated on the orthopyroxenite dike, which presented a rheological heterogeneity during bulk straining at high temperature.

Harzburgite outside the shear zone has a dynamic porphyroclastic microstructure with olivine and orthopyroxene grain sizes ranging from 1-10 mm. The shear zone has irregular, intertounging margins with the host. There are three zones of progressively smaller recrystallised olivine and orthopyroxene grains towards the shear zone centre. Grain size immediately inside the shear zone margins averages 60-70 mm. The smaller estimate is from grains that are slightly elongated with rare undulose extinction and weakly interlobate grain boundaries; most grains have a more polygonal microstructure with little optical evidence of intracrystalline dislocations. Towards the shear zone centre there is first a 0.35-0.7 mm thick zone of grains averaging 25 mm; then a 0.12 mm thick zone of ~10 mm grains. These very-fine-grained zones have comparatively straight margins with the surrounding material. There are porphyroclastic orthopyroxene (some with clinopyroxene lamellae) <5 mm long within the shear zone that originated as part of the orthopyroxenite dike. The orthopyroxene:olivine ratio is highest in the finest-grained material.

These microstructural observations suggest progressive strain localization into the finer-grained material. We hypothesise that the ratio of orthopyroxene:olivine neoblasts increased during progressive shearing, as the orthopyroxene porphyroclasts were progressively recrystallised. We will present textural data from sheared material as an indicator of dominant deformation mechanisms during progressive shearing, and the influence of the changing orthopyroxene:olivine ratio during deformation.

Session Type: *Poster Presentation*

TRACE ELEMENT AND ND-HF-O ISOTOPE COMPOSITIONS OF GARNET CLINOPYROXENITE LAYERS FROM THE EXTERNAL LIGURIDE MANTLE PERIDOTITES (NORTHERN APENNINE OPHIOLITES, ITALY): INSIGHTS INTO GARNET FACIES MANTLE PROCESSES

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The mantle sequences from the External Liguride units (Northern Apennines, Italy) consist mostly of fertile amphibole-bearing spinel-plagioclase lherzolites with sporadic pyroxenite layers, which retain a subcontinental lithospheric origin (Rampone et al. 1995; Piccardo et al. 2004). Some of the pyroxenite layers are made of garnet and Al2O3- and Na2O-rich clinopyroxene, with rutile, graphite and sulphides as accessory phases (Montanini et al. 2006). These garnet clinopyroxenites have SiO2 contents of 43-45 wt% and molar Mg# values ranging from 66 to 71. Relative to enclosing lherzolites, they show high contents of Al2O3, CaO, Na2O and TiO2, and low concentrations of Cr and Ni. Their C1-normalised REE pattern is characterised by extreme LREE depletion. Some of the garnet clinopyroxenites display a barely appreciable positive Eu anomaly and nearly flat MREE and HREE. Another set of samples lacks the positive Eu anomaly and exhibits HREE enrichment over MREE; these samples have also relatively high amounts of Y, Sc and V. Trace element compositions of garnets parallel the whole-rock variations. Coexisting clinopyroxenes have low concentrations of REE, with a pattern characterised by depletion in LREE and HREE. Garnet and clinopyroxene separates from the garnet clinopyroxenites provided a narrow range of oxygen isotope values, which are close to typical mantle compositions. The initial Nd and Hf isotope compositions of the garnet clinopyroxenites cannot be determined accurately, because the age of their formation is unconstrained. In addition, Sm-Nd and Lu-Hf fractionations may have changed in response to: (i) a garnet facies partial melting event, and (ii) chemical exchange processes under spinel- to plagioclase-facies conditions, resulting from migration of melts and/or interaction with the enclosing lherzolites. As a whole, the geochemical data allow us to envisage two different petrogenetic scenarios for the origin of the External Liguride garnet clinopyroxenites. The samples with flat HREE and positive Eu anomaly may represent recycled plagioclase-rich mafic cumulates, which underwent an event of partial melting in the garnet stability field. On the other hand, a high-pressure cumulus process may be inferred for the origin of garnet clinopyroxenites with enriched HREE and no positive Eu anomaly.

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Session Type: *Poster Presentation*

MYLONITIZED ULTRAMAFIC PSEUDOTACHYLYTE AND ASSOCIATED DEFORMATION TEXTURES, BALMUCCIA PERIDOTITE MASSIF, IVREA ZONE, ITALY

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Ultramafic pseudotachylyte is important because it is the only material for studying actual seismogenic processes in the mantle. The Balmuccia peridotite massif contains many varieties of fault-related pseudotachylytes that were generated at various depths from the upper mantle to the shallow crustal levels. We focus in this presentation on mylonitized pseudotachylytes associated with mylonitic peridotite walls. High-grade mineral assemblage (i.e., spinel-peridotite facies) of recrystallized pseudotachylyte and its wall rocks indicates that the whole process took place in the depths in lithospheric mantle. We described an occurrence of mylonitized pseudotachylyte and discussed a probable triggering process of pseudotachylyte formation in terms of compositional evolution of metamorphic fluids accompanied with plastic deformation (Ueda et al., 2008). This scheme was partly based on the idea that, relying on the observation of limited samples, plastic deformation gradually intensifying towards the fault (Jin et al, 1998). However, our observation of additional samples from the same area indicates that there are many more varieties with more complex textures that do not fit in the scheme of a single straightforward shear localization (leading to a seismic rupturing and melting) presented by Ueda et al, 2008. Some samples clearly record cyclic fault movements. It is probable that other samples with more complex textures also have resulted from repetitive deformation. There is also a spatial variation of mode and extent of mylonitization along faults judging from discrete samples. The deformation textures in this area, therefore, needs to be studied with more care combining observation of various scales (e.g., from field to microstructures). We present preliminary observations of some representative samples of such complex-textured mylonitized ultramafic pseudotachylyte and host peridotite from the Balmuccia massif.

Session Type: *Poster Presentation*

CONTROLS ON REACTION PROCESSES BETWEEN THOLEIITIC MELT AND RESIDUAL PERIDOTITE IN THE UPPERMOST MANTLE: AN EXPERIMENTAL STUDY AT 0.8 GPA

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Melt-rock reaction in the upper mantle is known from a variety of ultramafic rocks and is an important process in modifying melt composition on its way from the source to the surface. Evidence for depletion or enrichment by melt percolation is found in ophiolites, mantle xenoliths, and mantle sections exposed along MOR's. It includes disequilibrium textures, changes in major-to-trace element compositions and isotopic ratios.

Here, we present partial results from an experimental study that targets to evaluate the compositional evolution of ascending magma over a range of temperatures and pressures as a function of initial melt and peridotite compositions. In order to simulate melt-peridotite reaction processes, we perform nominally dry piston cylinder experiments with a 3-layered setup: a bottom layer composed of vitreous carbon spheres (serving as a melt trap) overlain by a peridotite layer and on top a "melt layer" corresponding to a primitive MORB composition. The peridotite layer is mixed from pure separates of orthopyroxene, clinopyroxene and spinel (Balmuccia peridotite), and San Carlos olivine. Two tholeiitic melt compositions were used, respectively with compositions in equilibrium with lherzolitic (ol, opx, cpx) and harzburgitic (ol, opx) residues after partial melting of KLB-1 at 1,5GPa (cf. Runs 19 and 20 of Hirose & Kushire, 1993). Melt from the melt layer is forced to move through the peridotite layer into the melt trap.

Experiments have been conducted at 0.8 GPa with peridotite of variable grain sizes, in the temperature range 1200 to 1320°C and for run durations of 10min to 92h. In this P-T range, representing conditions encountered in the thermal boundary layer beneath MOR's, melt is subjected to fractionation, whereas the peridotite is partially melting (Ts ~1260°C). Results show a strong dependence between phase relations in the melt layer and changes in the modal composition of the peridotite layer, both as a function of temperature and melt composition. Textural and compositional evidence demonstrate that reaction between percolating melt and peridotite occurs by a combination of dissolution-reprecipitation and solid-state diffusion. Dissolution, with or without reprecipitation, takes place for a certain phase when it is out of equilibrium with the melt relating to its major-element composition. Diffusional equilbration on the other hand is active whenever a phase is out of equilibrium with respect to its minor components, and is a much slower process. Generally. Dissolution-reprecipitation leads to well-equilibrated phases whereas diffusional equilibration introduces zoning at experimental timescales.

Session Type: *Poster Presentation*

HOW OLIVINE [010]-FIBER CPO DID RECONCILE CONFLICTING SURFACE WAVE AND BODY WAVE ANISOTROPY OBSERVATIONS IN THE KERGUELEN ISLANDS AREA

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Plastic deformation in the mantle rocks results in a variety of olivine crystallographic preferred orientations (e.g., Ben Ismaïl and Mainprice, 1998). The variety in olivine CPO reflects the activation of different slip systems (+ diffusion?) under different P-T conditions, changes in strain regime (Tommasi et al. 2000), and possibly also in water content (Jung and Karato, 2001). The physical properties of mantle rocks are dependent on the fabric intensity and symmetry (e.g., Tommasi et al., 1999). There is, in particular, a strong link between olivine crystallographic fabric and the seismic anisotropy retrieved from the analyis of shear wave splitting and P-wave azimuthal anisotropy.

Recently several studies have highlighted the importance of a specific type of olivine fabric, the [010]-fiber CPO (following material sciences terminology, Bunge 1982), which is characterized by a strong point maximum of [010] and a dispersion of [100] and [001] in the foliation. This CPO was already described in Ben Ismail and Mainprice (1998), but was regarded as rather rare compared to the traditional orthorhombic or [100]-fiber CPO. In xenoliths from Tanzania (Vauchez et al., 2005), Kerguelen Island (Bascou et al., 2008) and Siberia (Tommasi et al., 2008), [010]-fiber CPO represents the dominant crystallographic fabric. A peculiarity of this CPO-type is that it results in a minimum of anisotropy normal to the foliation (flow plane) rather than parallel to the lineation (flow direction), as it is the case for orthorhombic or [100]-fiber CPO. Thus development of [010]-fiber CPO in the mantle may result in "atypical" seismic anisotropy observations, where absence of shear wave splitting is associated with strong surface wave anisotropy.

We illustrate this situation with the results obtained for Kerguelen islands xenoliths. We have studied the microstructures and olivine CPO, and calculated the resulting seismic anisotropy for a suite of 16 ultra-mafic samples affected by different degrees of partial melting and magma-rock interaction. In this suite, protogranular harzburgites are the least metasomatised samples and dunites record the ultimate stage of metasomatism. Harzburgites consistently display a [100]-fiber olivine CPO and dunites an orthorhombic CPO. Consequently, harzburgites display the maximum of anisotropy within the foliation plane and the minimum perpendicular to the foliation plane, whereas the lowest anisotropy is parallel to the lineation for dunites. Assuming that the lithospheric mantle is primarily harzburgitic and displays a horizontal foliation, the seismic properties calculated for the Kerguelen xenoliths allow to reconcile the rather high anisotropy evidenced by horizontally-propagating surface waves and the apparent isotropy revealed by the absence of splitting of vertically-propagating teleseismic SKS-waves recorded by the GEOSCOPE Kerguelen station.

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Session Type: *Oral Presentation*

ON PLAGIOCLASE PERIDOTITES AND SILICA ACTIVITY

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Plagioclase peridotites are widespread on the ocean floor along slow-spreading ridges and in the mantle section of ophiolites. They are usually characterized by a) LREE depleted plagioclase, with variable but low Sr-concentrations and high anorthite contents (~70-95), b) LREE depleted and MREE-HREE enriched cpx rims relative to their cores, c) very variable spinel compositions on grain and thin section scale, d) textures indicating cpx+ol dissolution and concomitant opx+plag crystallization.

Their origin has usually been attributed to subsolidus breakdown, melt entrapment and/or fractional crystallization from a transient melt. However, existing models cannot account for all observed features combined, and seem to suggest extensive melt-rock reaction at high melt-rock ratios prior to the formation of plagioclase peridotites.

Gakkel Ridge plagioclase peridotites originate from the “Sparsely Magmatic Zone”, a magma-starved environment where only mantle rocks have been recovered. The exceptional freshness of these samples allowed a very detailed, texturally controlled study on the major and trace element mineral compositions. The studied samples share all the aforementioned characteristics. Furthermore, complex zoning has been preserved in all minerals (probably because of the early onset of rapid cooling at the ultraslow spreading Gakkel Ridge) that record various stages of reaction progress.

We show that all salient features of these plagioclase peridotites are best explained by partial equilibration with infiltrating melt(s) characterized by relatively high aSiO2 (inherited from relatively fertile peridotite) into a more depleted peridotite (or harzburgite) with lower silica activity. Depending on the reactivity of the system, this may continue to complete consumption of the melt (leading to reactive melt stagnation), or until equilibrium is reached. This process can operate at minimal melt-rock ratios and will occur at all pressures. It can be applied to other environments as well, with potentially wider applications to mantle petrology.

Session Type: *Poster Presentation*

SPINEL IN PLAGIOCLASE PERIDOTITES AS PETROGENETIC INDICATOR

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Spinels are ubiquitous in mantle peridotites and a known valuable petrogenetic indicator, their composition capable to reflect melting and melt-rock reaction processes as well as changes in oxygen fugacity. In contrast to spinels from residual peridotites, spinels in plagioclase peridotites are characterized by their wide range in composition both on grain scale and sample scale. Further, their higher relative Ti content sets them apart from residual spinel compositions. Plagioclase peridotites, representing about 30% of recovered abyssal peridotites at mid-ocean ridges, are thought to be either formed by melt-rock interaction or closed-system phase transformation from spinel-to-plagioclases facies conditions. There is no systematic study to the authors’ knowledge that investigates spinel compositions in plagioclase peridotites.

We investigated spinel compositions in 16 thin sections from a set of spinel and plagioclase peridotites. The samples were dredged from the Sparsely Magmatic Zone at the ultraslow-spreading Gakkel Ridge and show no or only traces of alteration; plagioclase contents range from nil to 13%. Spinel peridotites are very homogeneous on sample scale and low in titanium ($TiO_2 < 0.1$ wt%). Plagioclase peridotites cover a large range in composition with Cr-numbers (molar Cr/(Cr+Al)) between 0.1 and 0.55, sometimes within a single grain, and TiO_2 concentration as high as 0.5 wt%. In general, spinel Cr-number and Ti-content are well correlated but the slope of the correlation varies for each sample. The compositional variation often follows a spatial gradient in average spinel composition on sample scale, however, on grain scale, zoning in spinel (as seen in EPMA element maps) is unsystematic and cannot be tied to either mineralogy or deformation. Besides Ti-concentrations, trivalent iron is also elevated and application of oxygen barometers suggests increasing oxygen fugacities with increasing plagioclase content.

By investigating a larger number of samples, it is possible to distinguish between different factors like melt volume and composition as well as residual rock composition that are all reflected in the final spinel composition. It will be shown that changes in a_{SiO2} of the system affect spinel stability and hence composition and that oxygen fugacity, through its relation with silica activity, is an important factor as well. Furthermore, the effect of melt-rock reaction versus metamorphic phase transitions can be separated as well. This model can explain the variation seen in plagioclase peridotites.

Session Type: *Poster Presentation*

A NEW POTENTIAL GEOSPEEDOMETER FOR ULTRAMAFIC ROCKS

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Cooling rates of ocean floor mantle rocks from mid-ocean ridges can potentially provide important information about ridge dynamics, emplacement mechanisms and mantle uplift. There are a growing number of geospeedometric methods to retrieve such cooling rates in various settings. However, few exist for typical four-phase mantle peridotites and they only cover temperatures below 800°C. The down-temperature lithophile trace element exchange between clinopyroxene (cpx) and orthopyroxene (opx) can provide such a high-temperature spinel peridotite geospeedometer.

Orthopyroxenes studied by SIMS from two fresh Gakkel Ridge peridotites are zoned in all trace elements while clinopyroxenes are homogeneous. This allows the calculation of equilibrium temperatures [1]. Several profiles in opx cover a range of 1250°C (opx core) to 800°C (opx rim) and are in agreement with straightforward diffusion and closure temperature models.

The data allow us to estimate diffusion systematics of 16 elements (REE and TE) and their cation distributions in orthopyroxene. The data set is internally coherent as all elements were subjected to the same extrinsic parameters and it can be concluded that:

1. Decreasing ionic radius increases REE diffusion in opx (as it does in cpx).

2. M2-site diffusion is controlled more by ionic radius than by cationic charge.

3. M1-site diffusion is controlled by both ionic radius and cationic charge.

4. M1-site diffusion is generally slower than M2-site diffusion for isovalent cations, most likely because of higher M1- site energies compared to M2-site.

The advantages of this geospeedometer should be its relatively good precision, use of standard analytical methods and its coverage of the important range between solidus temperatures and 800°C. In combination with other geospeedometers it will be possible to retrieve the continuous cooling history of a mantle rock from its solidus down to low temperatures.

[1] G. Witt-Eickschen & H. O'Neil (2005): Chemical Geology, 65 – 101.

Session Type: *Poster Presentation*

MANTLE REFERTILIZATION: THE PERSPECTIVE FROM ABYSSAL PERIDOTITE COMPOSITIONS

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Orogenic lherzolites have provided evidence for much of what we know about fertile mantle composition. However, re-analysis of orogenic lherzolites in recent years has led to the question of whether they represent primitive, unmelted mantle or if they represent portions of depleted mantle that have been refertilized. In contrast, studies of abyssal peridotites from mid-ocean ridges have focused on the depleted nature of the oceanic upper mantle. We present a global compilation of abyssal peridotite data that demonstrates much larger variations in peridotite composition than commonly assumed. We suggest that many abyssal peridotites represent portions of refertilized, previously depleted mantle. Consequently, the ridge processes reflected in abyssal peridotite composition – particularly those from ultra-slow spreading ridges – may be very similar to the processes that created some orogenic lherzolites. Abyssal peridotites are typically assumed to be the residues of near-fractional melting of an initially uniform source composition. Using a global compilation of abyssal peridotite modal, major and trace element compositions, consisting of ~300 samples from all mid-ocean ridge systems, we assess the extent to which this assumption is true. After filtering the dataset for veined samples, we observe considerable variation among nominally residual peridotites. In addition, as a function of spreading rate, peridotites at slow and ultra-slow spreading rates extend to more depleted and more enriched compositions than predicted by a simple mantle melting model. For example, concentrations of light rare earth elements in peridotite Cpx vary by 4 orders of magnitude, at length-scales ranging from the grain-scale to the ridge segment-scale. Similarly, spinel Cr# and modal Cpx extend over large ranges at small length-scales. Small-scale variations in peridotite composition do not reflect variations in degree of melting, as mantle thermal structure is unlikely to vary at the sub-kilometer scale. Instead, we find that peridotite compositions re•ect two effects in addition to decompression melting: (i) melt-rock reaction processes during melt extraction and (ii) initial source heterogeneity. To constrain the role of source heterogeneity, we assess the isotopic range of abyssal peridotite Cpx. Using a compilation of all published data (70 samples), we find that the average Nd isotopic composition of peridotite Cpx (0.513167) is similar to average MORB (0.51313), but that peridotites extend to more depleted compositions than MORB. While the isotopic composition of peridotites clearly indicate source heterogeneity, the lack of a correlation between concentration and isotopic composition indicates the role of recent melt-rock interaction in modifying peridotite composition. On this basis, we suggest that many relatively undepleted peridotites have undergone melt re-fertilization of initially depleted mantle.

Session Type: *Oral Presentation*

OBSERVATIONS OF STRAIN LOCALIZATION AND OLIVINE LATTICE PREFERRED ORIENTATION IN JOSEPHINE PERIDOTITE SHEAR ZONES

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The Josephine Peridotite contains a unique series of shear zones that can be used to understand shear deformation in the upper mantle. We use outcrop-scale observations to place constraints on (i) the origin of strain localization and (ii) the evolution of olivine lattice preferred orientation (LPO) as a function of shear strain. The latter constraint is key for quantifying the relationship between the kinematics of deformation and the direction and magnitude of seismic anisotropy. Deformation in the oceanic lithosphere is largely confined to plate boundaries, indicating the importance of strain localization for plate tectonics. In the Josephine shear zones, strain localization is associated with the presence of melt. In one shear zone, strain gradients indicate a > 100-fold variation in effective viscosity over a distance of 25 meters. We suggest that focused melt transport in the form of a syn-deformational dunite promoted strain localization. Grain size variation across the shear zone is minor and cannot explain the viscosity variation. Based on experimental constraints for the effect of melt fraction on effective viscosity, we speculate that about 10% melt was present in the shear zone during deformation. Analysis of the olivine LPO variation across the shear zone indicates that the harzburgite LPO re-orients from a pre-existing LPO outside the shear zone to a shear-aligned LPO between 168% and 258% shear strain. Our observations broadly agree with experimental observations but indicate that a pre-existing fabric influences the amount of strain necessary for LPO re-alignment. In addition, our micro-structural observations suggest that the evolution of fabric strength and pattern differs from experimental observations. These differences suggest that the basis for theoretical models of LPO evolution, used to predict and understand patterns of seismic anisotropy (and thus mantle flow), require adjustment to more accurately reflect the response of olivine to shear deformation at conditions relevant to the upper mantle.

Session Type: *Oral Presentation*

THE TRACE ELEMENT SIGNATURE OF RECYCLED OCEANIC CRUST IN THE MANTLE

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Melting at mid-ocean ridges produces an incompatible element enriched crust and an incompatible element depleted lithosphere. Virtually all of this returns to the mantle via subduction. Over geologic time, a very substantial fraction of mantle would have been processed in this way. What effect has this had on mantle composition? How do we identify recycled components in the mantle, or in melting products of the mantle? Several factors complicate the answers to these questions. First, oceanic crust acquires a veneer of sediment that, for the most part, is also subducted. Second, its composition is affected by reaction with seawater, the net effect of which is still only partly understood. Third, some material from the subducting slab is lost to the overlying mantle wedge and eventually finds it way into island arc magmas. We have used a straightforward mass balance approach to assess these combined effects and calculate the composition of material that is returned to the deep mantle. Combining available data on the composition of subducting sediments, altered oceanic crust, and island arc magmas with convergence rates and crustal accretion rates and several simplifying assumptions, the deep mantle flux may be calculated as:

Deep Mantle Flux = Trench Flux – Arc Flux

To assess global variability in the deep mantle subduction flux, we carried out this calculation for 7 different subduction zones.

The effect of the addition of continental-derived sediment is to produce a subduction package (the trench flux) that is strongly enriched in the most incompatible elements (Rb, K, Ba, Th, U, and Pb) with a distinctly continental trace element signature (e.g., Pb/Ce ~ 0.12, Nb/U ~ 22, Rb/Sr ~0.04). However, the subduction package has, on average a nearly chondritic rare earth pattern (La/SmN ~ 1.1). The subduction zone filter has only a secondary effect on the composition of material subducted into the mantle, such that the mantle flux, as defined above, is compositionally similar to the trench flux. The elements experiencing the most severe lost in subduction processing are principally those most enriched in the sediment, namely K, Rb, Sr, Ba, Th, U and Pb; yet, on average, 78% to 86% percent of these elements survive into the deep mantle. Ninety percent or more of the rare earths survive into the deep mantle, and 98% of Nb and Ta survive transit through the subduction zone into the deep mantle. Consequently, the essential trace element characteristics of the subduction package do not change significantly. Both Pb/Ce and Nb/U ratios, which are on average 0.108 and 29.6, respectively, are distinctly 'continental' in character. The Rb/Sr ratio remains high (0.036), Sm/Nd is slightly super-chondritic, while the 238U/204Pb ratio, ~8, is similar to that of primitive mantle. Over time, this ratios should lead to isotopic compositions that depart significantly from the mantle array in the direction of high 87Sr/86Sr, i.e., in the direction of EMII.

Session Type: *Poster Presentation*

CONTRASTING MOHO TEMPERATURES INFERRED FROM ULTRAMAFIC XENOLITHS AT KHARCHINSKY & SHIVELUCH VOLCANOES, KAMCHATKA ARC

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Contrasting features in ultramafic xenoliths imply different upper mantle conditions beneath Kharchinsky and Shiveluch volcanoes, Kamchatka. The xenoliths at Shiveluch are primarily metasomatized dunites, with uniformly Mg-rich olivine (FO88-92) and Cr-rich spinel. Fibrous, low-Al opx along olivine grain boundaries, and mm-scale veins of opx, amphibole, and phlogopite, appear to have formed by deuteric/autometasomatic processes during the final stages of cooling following dunite formation by replacive processes. The absence of textural equilibrium between the olivine and fibrous opx, indicated by jagged and interpenetrating grain boundaries, indicate that the metasomatism occurred at shallow mantle depths, shortly prior to the eruption that carried the xenoliths to the surface. This implies that metasomatism was not by slab-derived fluids/melts at great depths within the subduction zones. The oxidized nature of the xenoliths (deltaFMQ = +1.4 to 2.6) is interpreted to have been inherited from the oxidized basaltic melts that were involved in dunite formation be replacement / melt-rock reaction processes. Two-pyroxene thermometry indicates that the dunites equilibrated at 800-900°C, indicating relatively low temperatures at MOHO depths beneath Shiveluch Volcano. Abundant ultramafic xenoliths from Kharchinsky Volcano are mostly peridotites and olivine pyroxenites. The peridotites are primarily harzburgites containing uniformly Mg-rich olivine and pyroxene and Cr-rich spinel, consistent with an origin in the depleted upper mantle. The pyroxenites, which are less coarse and less intensely deformed than the peridotites, contain relatively Fe-rich olivine and cpx (Mg#75-88), and show mm-scale layering in some samples, are interpreted to have formed by cumulate processes, probably during basalt evolution in the deep crust or upper mantle. Two-pyroxene thermometry indicates that the Kharchinsky peridotites equilibrated at temperatures that were 200-250°C hotter (1000-1050°C) than the pyroxenites (800-900°C). Thermometry results from these xenolith suites indicate that moho temperatures at Kharchinsky, a small and inactive Pleistocene-age basaltic volcano, may be significantly hotter than at nearby Shiveluch, a large and active andesite-dacite volcano. These differences may indicate that temperatures in the upper mantle beneath arc volcanoes are highly transient, and perhaps related to different primitive melt genesis and evolution processes at different volcanoes.

Session Type: *Poster Presentation*

EVIDENCE FOR DIFFERENT STYLES OF ALKALINE METASOMATISM DURING COMPRESSIVE CONTINENTAL RIFTING AS RECORDED BY MANTLE XENOLITHS FROM MID ATLAS (MOROCCO)

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Insights into the multistage metasomatic evolution of the subcontinental mantle beneath the Mid Atlas have been provided by the petrochemical characterization of mantle xenoliths hosted in alkaline basalts from the Azrou-Timahdite volcanic district. Since Eocene, this area has been subjected to alkaline volcanism along fault systems developed in response to the collision between European and African plates. The lithospheric mantle established after the Pan-African orogenic cycle was mainly formed by porphyroclastic to protogranular spinel-lherzolites associated with spinel-websterites, and by porphyroclastic to coarse granular anhydrous-harzburgites. Websterites rarely contain secondary garnet, produced by subsolidus reaction at P of 2.5 GPa. Lherzolite and websterite minerals show major, trace and isotopic compositions strictly consistent with those estimated for DM reservoir, showing only limited LILE metasomatic enrichments. Cryptic metasomatic imprint is stronger in the anhydrous harzbugites, according to a higher permeability towards small melt volumes. The widespread development of alkaline metasomatism is better recorded by the occurrence of several types of amphibole-bearing ultramafics. The early metasomatic event was related to the pervasive porous-flow migration of alkaline liquids ubiquitously characterized by strong enrichments (i.e. larger than in the host alkali basalts) in highly-incompatible elements such as LREE, U and Th, but with distinct LILE/HFSE fractionation. In particular, melts producing porphyroblastic (amphibole-rich) to coarse-granular (amphibole-poor) lherzolites were originally also enriched in Nb, Ta, Zr and Hf, but with negative Ti anomaly. Differently, melts producing porphyroblastic (amphibole- rich) harzburgites were dramatically impoverished in HFSE. Notwithstanding such differences, these LILE-enriched melts share the same Nd and Sr isotopic composition of the host alkali basalts, indicating a derivation from a common reservoir. A second style of alkaline metasomatism is characterized by the production of Fe-rich and Mg-rich wehrlites. Fe-rich wehrlites developed for the late crystallization of clinopyroxene+spinel+amphibole in mantle sectors formerly strongly impoverished in modal pyroxenes by interaction with porous-flow migrating melts. Fe-wehrlites sometimes show trace-element heterogeneity testifying for an early percolation of strongly LREE-enriched melts with large negative HFSE anomaly, followed by melts progressively more similar to the host alkali basalts. The geochemical variation of the metasomatic melts recorded by the Mid Atlas mantle is broadly consistent with the regional change of the alkaline volcanics, highlighting a progressive evolution of the melting process in the plumbing source region.

ADDENDUM

2008 AGU Chapman Conference on Shallow Mantle Composition and Dynamics Fifth International Orogenic Lherzolite Conference
22-26 September 2008
Mount Shasta, CA

This Addendum reflects any changes made after publication of the program book and/or reported to AGU between 9 September and 17 September 2008.

Monday, 22 September
Poster Session R-06 • Piccardo, Giovanni *Seismogenetic shear zones in the mantle lithosphere: ultramafic pseudo-tachylytes in the Lanzo peridotite (Western Alps, NW Italy).* Change to **R-07**

Tuesday 23 September
Phipps Morgan, Jason *Modelling mantle flow and deformation beneath mid-ocean ridges* (withdrawn)

Wednesday 24 September
Rapp, Bob *Transformative reactions between "primitive" silica-rich melts and mantle peridotite* (withdrawn)

Friday 26 September
Kaszuba, John *Experimental Investigations of the Potential to Sequester CO2 in Oceanic Crust* (withdrawn)