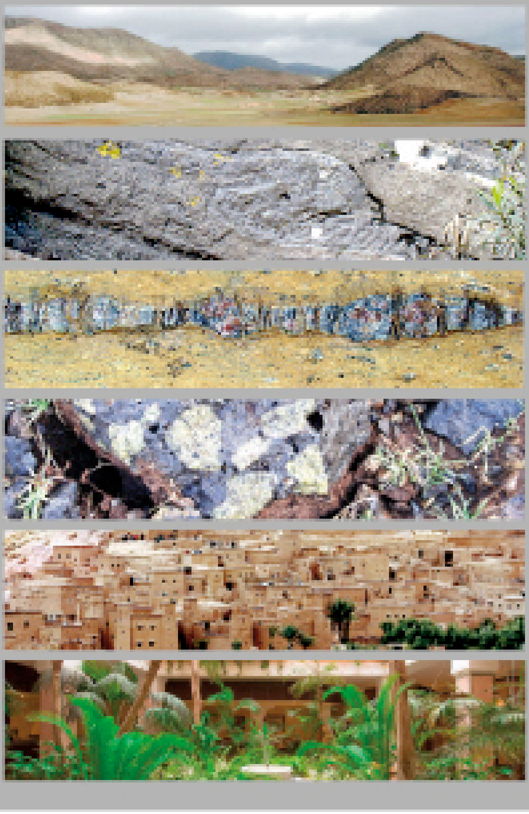
from 4 to 15 may 2014
OROGENIC LHERZOLITE CONFERENCE

6th LHERZOLITE

Marrakech
MOROCCO

ABSTRACTS VOLUME



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4-7 May _ Pre-conference field trip to the Beni Bousera Orogenic Peridotite

8-11 May _ Conference Meeting in Marrakech (Hôtel Le Semiramis)

12-14 May _ Post-conference field trip to the Middle Atlas Volcanics and Mantle Xenoliths

12-15 May _ Post-conference field trip to the Anti-Atlas Pan-African Ophioites

Organizing committee

Conference : Jean-Louis Bodinier and Andréa Tommasi (Géosciences Montpellier, France), Amina Wafik (University Cadi Ayyad, Marrakech, Morocco), Kamal Targuisti (University Abdelmalek Essaâdi, Tetouan, Morocco), Carlos J. Garrido (IACT, Granada, Spain), Martin Menzies (Royal Holloway, Egham, U.K.), Henry Dick (WHOI, Woods Hole, U.S.A), Kazuhito Ozawa (University of Tokyo, Japan), Yigang Xu (Chinese Academy of Sciences, Guangzhou, China).

Beni Bousera field trip : Andréa Tommasi, Carlos J. Garrido, Kamal Targuisti, Jean-Louis Bodinier, Isma Amri (University Abdelmalek Essaâdi, Tetouan, Morocco).

Middle Atlas field trip : Houssa Ouali, Hicham El Messbahi (University Moulay Ismaïl, Meknes, Morocco), Jean-Marie Dautria (Géosciences Montpellier, France), Jean-Louis Bodinier, Kamal Targuisti.

Anti-Atlas field trip : Amina Wafik, Hassan Admou (University Cadi Ayyad, Marrakech, Morocco), Antoine Triantafyllou, (Mons University, Belgium), Julien Berger (Géosciences Environment Toulouse, France).

6th Orogenic Lherzolite Conference
Scientific Program

8 may

Subcontinental mantle lithosphere / melt-rock reactions - 1 Chair: C. Garrido

9h-9h10	Bodinier / Menzies	Opening
9h10-9h30	O'Reilly	Updating metasomatism concepts: stealth, densification, and geophysical consequences
9h30-9h50	Rampone	The trace element chemistry of olivine as proxy of melt-rock reaction in the oceanic lithosphere
9h50-10h10	Takazawa	Update on the spatial distribution of highly refractory peridotites in the northern Oman mantle section as proxy for fluid infiltration and flux melting
10h20-10h50	**Break**	

Subcontinental mantle lithosphere / melt-rock reactions - 2 Chair: K. Ozawa

10h50-11h10	Borghini	Pyroxenite emplacement in Northern Apennine ophiolitic peridotites (Italy): insights on the origin of small-scale chemical and isotopic heterogeneity in the upper mantle
11h10-11h30	Lambart	PX-MELT: a predictive model for the melting of pyroxenites in the mantle
11h30-11h50	Montanini	Garnet pyroxenites from the External Ligurian mantle sequence (Italy): Evidence for crustal recycling and melt/peridotite interaction
11h50-12h10	Katzir	Garnet pyroxenites as markers of recurring extension and magmatism at the margins of the Arabian plate
12h30-14h	**Lunch**	

Subcontinental mantle lithosphere / melt-rock reactions - 3 Chair: S. O'Reilly

14h-14h20	Sossi	Origin of the Balmuccia peridotite massif
14h20-14h40	Rooks	Textures and geothermobarometry of off-craton spinel & garnet-bearing peridotites from South Patagonia
14h40-15h	Ntaflos	Petrological, geochemical and isotopic evidence for lithospheric delamination underneath Far East Russia
15h-15h20	Puziewicz	Lithology of Central European Lithospheric Mantle
15h20-15h40	Zanetti	Sources, migration mechanisms and geodynamic environment of K-LILE-Mg-enriched melts: evidence from the Finero Complex (Southern Alps)
16h10-16h50	**Break**	

Subduction-related massifs and UHP peridotites Chair: M. Menzies

16h50-17h10	Griffin	Transition-Zone mineral assemblages in peridotite massifs, Tibet: Implications for collision-zone dynamics and orogenic peridotites
17h10-17h30	Yang	Diamonds and highly reduced minerals from chromitite of the Ray-Iz ophiolite of the Polar Urals: deep origin of podiform chromitites and ophiolitic diamonds
17h30-17h50	Robinson	The fate of crustal materials subducted into the mantle: Evidence from ophiolites
17h50-18h10	Dilek	Subduction Initiation Record (SIR) in Suprasubduction Zone Ophiolites

9 may

Volatiles, fluids and melts in the mantle - 1 Chair: W. Griffin

9h-9h20	Gaillard	Electrical Petrology of mantle melting: a methodology to reconcile the petrological and the geophysical asthenosphere
9h20-9h40	Golovin	Pristine melts from lithosphere-asthenosphere boundary preserved within sheared peridotite xenoliths from kimberlites
9h40-10h	Pokhilenko	Petrological and geochemical features of secondary enrichment of the craton mantle peridotites of the diamond stability field
10h-10h20	Demouchy	Distribution of Hydrogen in the Mantle Lithosphere
10h20-10h50	**Break**	

Volatiles, fluids and melts in the mantle - 2 Chair: F. Gaillard

10h50-11h10	Guild	Determination of the boron concentration and isotopic composition of the subcontinental lithospheric mantle by secondary ion mass spectrometry
11h10-11h30	Denis	Water content and hydrogen behaviour during metasomatism in the uppermost mantle beneath Ray Pic volcano (Massif Central, France)
11h30-11h50	Debret	The redox state of iron in serpentine from Western Alps ophiolites
11h50-12h10	**Lunch**	

9 may

(continuation)

Geodynamics

Chair: T. Morishita

14h-14h20	Dick	The SW Indian Ridge - remelting the Gondwanan mantle
14h20-14h40	Morishita	Petrological evidence for arc-metasomatized peridotites beneath the mid-ocean ridges
14h40-15h	Jean	The Coast Range Ophiolite: Evaluating ophiolite genesis at subduction zones, melt extraction history, enrichment processes, and capturing the MOR-SSZ transition
15h-15h20	Ionov	The Role of the Mantle Lithosphere in the History and Dynamics of Central Mongolia
15h20-15h40	Menzies	Cracking cratons & the China Syndrome
15h40-16h	**Short Poster Presentations**	
16h-18h30	**Poster session with Moroccan pastries**	

10 may

Deformation in the mantle lithosphere -1

Chair: A. Tommasi

9h-9h20	Hansen	The interplay between deformation and microstructure in olivine-rich rocks
9h20-9h40	Hidas	Ductile strain localization in the shallow subcontinental lithospheric mantle during the final exhumation of the Ronda massif (Betic Cordillera, S-Spain)
9h40-10h	Krukenberg	Correlations between strain geometry, shape fabric, and crystallographic preferred orientation revealed by microtomography and textural analyses: heterogeneous deformation of mantle xenoliths from Marie Byrd Land, Antarctica
10h-10h20	Jung	Petrofabrics of olivine and chlorite in chlorite peridotites and implications for seismic anisotropy in subduction zone
10h20-10h50	**Break**	

Deformation in the mantle lithosphere -2

Chair: L. Hansen

10h50-11h10	Chatzaras	Rheological properties of the upper mantle section of San Andreas Fault system: Evidence from spinel peridotite xenoliths
11h10-11h30	Baptiste	Deformation, seismic properties and water contents of the lithospheric mantle beneath the East African Rift, North Tanzania
11h30-11h50	Czertowicz	Ultra-depleted, ultra-deformed peridotite emplaced onto the New Zealand Gondwana margin
11h50-12h10	Liptai	Understanding the complex physico-chemical features of the upper mantle beneath the Nógrád-Gömör Volcanic Field (Northern Pannonian Basin) - A study on peridotite xenoliths

12h30-14h	**Lunch**	

14h-14h20	Short Poster Presentations	
14h20-16h	Poster	session
15h40-16h	**Coffee/tea at Poster session**	

Mantle petrology

Chair: F. Parat

16h00-16h20	Youbi	Cr-spinels crystal chemistry in Morocco and Libya mantle xenoliths
16h20-16h40	Klemme	The garnet-spinel transition in Lherzolite and Harzburgite
16h40-17h	Dygert	A possible difference in cooling rates recorded in REE in coexisting pyroxenes in peridotites from ophiolites and mid-ocean ridges
17h-17h20	Korsakov	Diamond and graphite-bearing eclogite xenoliths from Udachnaya East kimberlite pipe
17h20-17h50	Ozawa	Contrasting P-T histories recorded in exhumed mantle peridotites and its implication in lithosphere-asthenosphere interaction
17h50-18h10	Downes	Textures of sub-continental mantle peridotite rocks revisited

11 may

Sulfides & PGE -1

Chair: O. Alard

9h-9h20	Aubach	Metasomatic processes in the mantle wedge: New insights from Eastern Alpine peridotites
9h20-9h40	Bragagni	Re-Os in single sulfides vs. whole rock: mantle melting, metasomatism and kimberlitic overprinting in Somerset (Rae Craton, Canada)
9h40-10h	Szabo	History of the subcontinental lithospheric mantle beneath the Carpathian-Pannonian region
10h-10h20	Mundl	Os and Hf isotopes in mantle xenoliths from Southern Patagonia: Evidence for Proterozoic SCLM fragments
10h20-10h50	**Break**	

Sulfides & PGE -2

Chair: C. Szabo

10h50-11h10	Senda	Os isotope ratios and PGE abundances of troctolites from Pacific oceanic lithosphere
11h10-11h30	Kochergina	Rhenium-osmium isotopic composition of mantle xenoliths from the Bohemian Massif
11h30-11h50	Wainwright	Unravelling metasomatic effects on Re-Os ages: A case study from Letlhakane (Botswana)
11h50-12h10	Coggon	190Pt-186Os versus 187Re-187Os: A single-grain to whole-rock scale study of >3.8 Ga peridotites and chromitites from Earth's oldest layered intrusion
12h30-14h	**Lunch**	

Sulfides & PGE -3

Chair: S. Aulbach

14h-14h20	Alard	Sulfur isotopic composition of the Sub-Continental Lithosphere Mantle (SCLM)
14h20-14h40	Ishikawa	Osmium isotope heterogeneity in the Pacific uppermost mantle
14h40-15h	Liu	Relic of Paleoproterozoic mantle lithosphere beneath southeastern (SE) China: constraints from the Sr-Nd-Hf-Os isotopes of Mingxi mantle xenoliths
15h-15h20	Williams	Iron isotope tracing of mantle mineralogical heterogeneity
15h20-15h40	**Break**	

Moroccan peridotites

Chair: J.L. Bodinier

15h40-16h	Tommasi	The Beni Bousera peridotite: an oblique-slip shear zone thinning the lithospheric mantle
16h-16h20	Hajjar	The Sulfide and Graphite Mineralization of the Ultramafic Massif of Beni Bousera (Internal Rif, Morocco)
16h20-16h40	Triantafyllou	New interpretation of the tectonic & metamorphic evolution of the Iriri-Tachakoucht arc complex (Sirwa inlier, Moroccan Anti-Atlas)
16h40-17h	Bhilisse	Mantle serpentinization in the Neoproterozoic ophiolite of Bou Azzer El Graara (Bou Azzer mining district, Central Anti-Atlas, Morocco)

Poster presentations - 9 May

Chair: J.L. Bodinier

Subcontinental mantle lithosphere / melt-rock reactions

Abe	Petrology of the peridotite xenoliths from lower oceanic lithosphere
Afanasyev	On two genetic types of diamonds
Akizawa	Diversity of melt migration processes in the mantle along a mid-ocean ridge axis: implications from the northern Oman ophiolite
Arnoux	Nature and evolution of the upper mantle of the Middle Atlas (Morocco) constrained by a petrological study of mantle xenoliths
Baziotis	Phosphorus zoning as a recorder of crystal growth kinetics:implications from secondary olivine and pyroxene in mantle xenoliths from Cima Volcanic Field
Borghini	Near-solidus phase assemblages and partial melting behavior of a natural pyroxenite: an experimental study at 1-1.5 GPa
Chanouan	Petrological Characteristics of Mantle Xenoliths from the Quaternary Basaltic District of Azrou-Timahdit, Middle Atlas, Morocco
Chetouani	Diversity of mafic layers in the Beni Bousera massif and its relation with the peridotite structure and evolution
Dygert	Decoupling among trace elements and Ni during melt percolation and melt-rock reaction in the mantle: An example from a dunite-harzburgite-lherzolite sequence from Trinity Ophiolite
El Messbahi	Regional variability of lithospheric mantle beneath the Middle Atlas (Morocco)
Garrido	Channeling of reactive porous flow in the subcontinental lithospheric mantle: lherzolite-harzburgite-dunite layered peridotite bodies of the Ronda massif (Betic Cordillera, S-Spain)
Kourim	Nature and Evolution of the lithospheric mantle beneath the Hoggar swell (Algeria): a record from mantle xenoliths
Kukula	Peridotitic xenoliths from the Feldstein basalt (Thuringia, Germany): preliminary data
Matusiak-Malek	Peridotite-melt reaction as a cause of upper mantle heterogeneity beneath eastern part of cenozoic Central European Volcanic Province
Mikhailenko	Origin of the lherzolite – megacrystalline orthopyroxenite contact xenoliths from Udachnaya kimberlite pipe
Montanini	Record of subcontinental mantle refertilization: the lherzolite-websterite-hornblendite association from St. Lucia (Corsica)
Montanini	Mantle xenoliths from Sardinia (Italy): evidence for reaction between refractory peridotites and carbonatite melts
Nikolenko	Mantle mineralization of the “Chompolo field” kimberlites (South Yakutia)
Patko	Silicate melt inclusion study in wehrlite xenoliths from the Nógrád-Gömör Volcanic Field (Northern Pannonian basin, Hungary)
Piccardo	Tectonic and magmatic processes during passive rifting of the Ligurian Tethys: the study case of Erro-Tobbio peridotite (NW Italy)
Pokhilenko	Mantle metasomatism of megacrystalline peridotites: chromspinelide and phlogopite from the xenoliths of Udachnaya kimberlite pipe (Yakutia)
Shelestov	Mineralogy and origin of picroilmenite rich vein in coarse-grained garnet lherzolite from Udachnaya East kimberlite pipe
Zanetti	Evidence for refertilisation of a strongly depleted mantle column in the extra-Andean backarc (Paso de Indios, Argentina)
Tabit	The ultrabasic massif of Beni Bousera (Internal Rif, Morocco). Mineralogical, geochemical and model study

Volatiles and fluids in the mantle

Butjosa- Molines	Abyssal, mantle wedge and subducted hydrated ultramafic rocks in the Villa Clara serpentinitic mélange, Central Cuba
Maurice	Experimental study of serpentine dehydration
Murata	Ultra-fine textures along grain boundaries in nominally fresh mantle xenoliths

Poster presentations - 10 May

Chair: A. Tommasi

Subduction-related massifs and UHP peridotites

Guo	Petrogenetic significance of anorthite as inclusions in spinel of the Purang ophiolite (southwestern Tibetan plateau)
Li	Structure and Mineralogy of Peridotite from Baer ophiolite, Yalung Zangbo Suture Zone, Tibet: Records of Two Stage Evolution from Mid-ocean Ridge to SSZ
Liu	Dongbo and Purang Ultramafic Massifs in the Western Yarlung Zangbo Suture Zone, Tibet, as the Remnants of an Ocean-Continent Transition (OCT)
Xiong	Multi-stage melting processes of Ophiolitic Chromitites from Dongbo Peridotite, the Western Yarlung-Zangbo Suture Zone, Tibet

Mantle deformation and seismic properties

Arnoux	Observations of anomalous subcrustal reflections along the East Pacific Rise: Possible detection of a permeability barrier
Baptiste	Petrophysical constraints on the seismic properties of the Kaapvaal craton mantle root
Hidas	Analysis of strain localization in the subcontinental lithospheric mantle under retrograde conditions on the example of the southern Lanzo shear zone (Alps, northern Italy)
Ishikawa	Microstructures, composition and seismic properties of the Ontong Java Plateau mantle root
Klebesz	Petrophysical and seismological model of the lithospheric mantle beneath the Nógrád-Gömör Volcanic Field (Northern Pannonian Basin)
Michels	Thermorheological constraints on the timing of olivine petrofabric development and the significance of measured mantle anisotropy beneath the European Cenozoic Rift System
Satsukawa	Fluid-induced deformation in chromite during metamorphism
Stewart	Linked kinematic and compositional evolution of the Red Hills ultramafic massif, New Zealand: A glimpse at the mantle section of an obliquely spreading forearc center
VanderBeek	Seismic Structure of the Shallow Mantle Beneath the Endeavor Segment of the Juan de Fuca Ridge

Geodynamics

El Bahariya	Tectonic evolution of Neoproterozoic ophiolites of the Central Eastern Desert of Egypt form MORB to SSZ tectonic setting
Gao	A combined basalt and peridotite perspective on multi-stage melt extraction at the 53° E amagmatic segment of the Southwest Indian Ridge
Kassem	Structural evolution for Jabal Tays ophiolite in Eastern Arabian Shield: Implication for evidence of active ocean floor magmatism
Salem	Exploration of new gold occurrences in the alteration zones at the Barramiya District, Central Eastern Desert of Egypt using ASTER data and geological studies
Secchiari	Multi-stage evolution of peridotites from New Caledonia: preliminary results
Varas Reus	Subduction initiation and recycling of Alboran domain derived crustal components prior to the intra-crustal emplacement of mantle peridotites in the Westernmost Mediterranean: isotopic evidence from the Ronda peridotite
Wojtulek	Reconstruction of the formation setting of the chromitites from the Central-Sudetic Ophiolite (SW Poland)

Mantle petrology

Downes	Petrology and Geochemistry of Spinel Pyroxene Clusters in Mantle Peridotite Xenoliths from the Massif Central, France and Lanzarote, Canary Islands
Moine	Zoisite-grossular exsolutions in omphacite of corundum-bearing eclogite from Siberian craton

Sulfides & PGE

Aradi	Major and trace element geochemistry, origin and timing of sulfide formation in ultramafic xenoliths from the Nógrád-Gömör Volcanic Field (northern Hungary – southern Slovakia)
van Acken	Highly siderophile elements and Os isotopes in single sulfides in peridotite xenoliths from the Kangerlussuaq area, S.W. Greenland

Petrology of the peridotite xenoliths from lower oceanic lithosphere

Natsue Abe

IFREE, JAMSTEC, 2-15 Natsushima-cho, Yokosuka 237-0061, Japan

Petitspot is a cluster of small volcanic knolls on the oceanic lithosphere [1]. It is a kind of intraplate volcanism, similar to monogenetic volcanoes of alkaline basalts in continental plate, although there is no mantle upwelling beneath the eruption fields. Therefore, it is not related any OIB activities. The source region of the petitspot magma is expected not at very deep, but just around the boundary between the lithosphere and asthenosphere [2]. It is thought to be erupted through the small fracture on the oceanic lithosphere [1]. Petitspot volcanoes often include ultramafic xenoliths and xenocrysts that provide us many information about the chemical and physical properties of the lower oceanic lithosphere between 40 to 70 km deep without any affection of OIB [3-5]. Therefore, study on the petitspot volcanism and its ejecta is one of the most suitable research on the actual state of the oceanic plate [6, 7]. The multidisciplinary research including rock and sediment samplings, and surface and sub-seafloor geophysical surveys on the petitspot and the plain old oceanic plate around have been conducted since 2005 to reveal mechanism of the petitspot volcanism and background physics of the oceanic lithosphere and asthenosphere beneath the northwestern Pacific [6, 8-10]. However, the petitspot volcanism and its global activities are still unclear due to few rock and data samplings from the petitspot fields and the scarcity of the global detail bathymetry data.

Here we present the petrology of the ultramafic xenoliths, which shows less deformed, and the fertality and variation of the melt extraction, and the feature of the petistspot volcanism with geophysical and morphological features in the eruption fields found up to now. Then, we would like to propose the next step of the oceanic lithosphere.

On two genetic types of diamonds

V. Afanasyev
Sobolev Institute of Geology and Mineralogy, Russia

Two groups of diamonds may be distinguished on the basis of their carbon isotope compositions and other related genetic features. They are mantle-type and subduction-type diamonds, which both crystallize in the mantle but the source carbon comes from a mantle reservoir in the former and from crustal slabs sinking into the mantle (fractionated carbon) in the latter. Synthesis of data in terms of this hypothesis has revealed a set of features typical of "mantle" and "subduction" diamonds.

Mantle-type diamonds mostly have a narrow $\delta^{13}C$ range from -2‰ to -9‰; the parageneses are peridotitic; the crystals are mostly of high quality, with few defects and layer-by-layer growth; the grains of diamonds are macrocrysts (mostly > 0.25 mm); the diamond content is mostly low (most often sporadic grains); diamond morphology is quite simple: laminar crystals of the series "octahedron - transitional habit - rhombic dodecahedron"; Ni impurity is present in different forms (S2, S3, 523 nm, etc.); the age is mostly Archean; diamonds exist in kimberlite and lamproite; the tectonic setting of primary diamond deposits follow mostly Clifford's rule.

Subduction-type diamonds differ from mantle-type ones in their carbon isotope composition, with a wide range of $\delta^{13}C$ from +2.5‰ to -39‰; the parageneses are mostly eclogitic or pyroxenitic; crystals have a lot of structure defects, fibrous and radiated growth, cryptocrystalline or fine-grained aggregates, but some crystals may be of high quality; microcrysts (<0.25 mm) typically coexist with macrocrysts; diamond crystals are sometimes as abundant as to be a rock-forming phase; diamond morphology is highly diverse: a full range of all known habits (laminar octahedron - transitional - rhombic dodecahedron crystals; cuboids; mixed cube-octahedron-rhombic dodecahedron; cryptocrystalline octahedron and dodecahedron; exotic varieties like ballas, carbonado, or low-quality bort crystals); Ni impurity has not been encountered; the age of diamonds is Archean or Proterozoic; diamonds exist mostly in kimberlite, lamproite, various mafic and ultramafic igneous rocks, and in metamorphics; primary diamond deposits have various settings, including Proterozoic and Phanerozoic orogens.

Thus, the two types of diamonds differ in many aspects, and can be discriminated even visually. The features of difference, associated with their different growth conditions, are probabilistic but allow discriminating between the mantle- and subduction-type diamonds in the first approximation. Synthesis of data on the properties of the two diamond types can provide new insights into their genesis and growth.

Diversity of melt migration processes in the mantle along a mid-ocean ridge axis: implications from the northern Oman ophiolite

Norikatsu Akizawa[1], Shoji Arai[1], Akihiro Tamura[1], Kazuhito Ozawa[2] & Katsuyoshi Michibayashi[3]

[1]Department of Earth Sciences, Kanazawa University, Kanazawa 920-1192, JAPAN ; [2]Department of Earth and Planetary Science, Tokyo University, Tokyo 113-0033, JAPAN ; [3]Institute of Geosciences, Shizuoka University, Shizuoka 422-8529, JAPAN

Dunite bands and dikes in the ophiolitic mantle peridotite are interpreted as fossil melt channels within the suboceanic mantle. In particular, concordant dunite bands are of possible importance as the melt channels through which parental melts of MORB (mid-ocean ridge basalt) were transported to shallower mantle beneath the paleoridge axis. However, no comprehensive petrological data of concordant dunite bands and ambient peridotites along a ridge segment have been published. I conducted sampling and chemical analysis of concordant dunite bands and their ambient peridotites from various “stratigraphic levels” in the mantle section along a paleoridge segment at the northern Oman ophiolite.

Most of the concordant dunite bands overlap in major-element compositions with their ambient peridotites, however some of them show rather lower Cr/(Cr + Al) atomic ratio of chromian spinels (< 0.50), and higher Al2O3 (up to 4.0 wt%) and Cr2O3 (up to 1.3 wt%) of clinopyroxenes at the uppermost mantle section than in the lower mantle section. In the ambient peridotites, trace-element (rare earth elements: REE with Sr, Zr, Ti and Y) patterns of clinopyroxene incline from heavy-REE (HREE) to light-REE (LREE) abruptly, whereas they show various shapes in concordant dunite bands, depending on the stratigraphic levels along the paleoridge segment: gentle to steep slope from HREE to LREE, except for spoon-shaped pattern at the lower mantle section of the segment center.

I also conducted numerical modeling [1-D steady state modeling, Ozawa (2001)], which duplicates simple fractional melting and influx melting processes, to clarify a variety of the melt migration processes in the mantle section by using trace-element compositions of clinopyroxene. The results indicate that the LREE-enriched melt generated at higher pressure conditions flowed through a melt channel until shallower mantle section (less than 10 km to the MTZ), where such LREE-enriched melt were mingled with highly depleted melts generated at lower pressure conditions, and N-MORB-like melts were generated as a consequence. Another numerical modeling [plate model, Vernières et al. (1997)] suggests fracture-related melt transport with chromatographic melt percolation into the wall peridotite at the uppermost mantle section in the paleoridge segment end. These variations in the melt migration process resulted from a difference in mantle geotherm along the paleoridge segment related to the active mantle upwelling, i.e., higher at the segment center and lower at the segment end at a given stratigraphic level.

Sulfur isotopic composition of the Sub-Continental Lithosphere Mantle (SCLM)

Olivier Alard[1]

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The S-isotopic composition of the Earth's mantle ($\delta^{34}S=0\pm2‰$) has been found to be chondritic [1-4]. Such composition satisfies the paradigm that chemical composition of the whole Earth should be 'chondritic' and provide support to the 'late veneer' hypothesis which is otherwise supported by a broadly chondritic abundances of the highly siderophile (HSE: Os, Ir, Ru, Rh, Pt, Pd, Au, Re and therefore chondritic $^{187}Os/^{188}Os$) and the chalcogenides elements (S, Se, Te; [5]). However in details, mantle data show large variability ($-7\leq \delta^{34}S <10‰$) and a strong dichotomy between in one hand peridotite xenolith showing mostly $\delta^{34}S>0$ [6] and on the other hand sulfide from orogenic massifs showing $\delta^{34}S<0‰$ [3, 7]. These differences could be related to: (*i*) sampling processes (magmatic vs. tectonic); (*ii*) sulfide weathering; (*iii*) the strong contrast between sulfide mineralogy (mss vs. pn); (*iv*) mantle heterogeneities; or (*v*) analytical techniques.

More recently, various workers have reported $\delta^{34}S$ for mantle lavas not compatible with chondritic composition ($\delta^{34}S \approx -2‰$; [8, 9]). However magma formation, sulfur partitioning between sulfide and silicate melt and/or sulfide extraction from the mantle and later on fractional crystallisation may significantly affect the sulfur isotopic ratios of magma-derived rocks. Indeed, insufficient experimental data are available on sulfur-isotope partitioning between sulfide and silicate melts to definitely rule out this possibility.

In order to shed some new lights on this issue more than 200 sulfide grains from ≥30 mantle samples including peridotite xenoliths hosted in alkali basalts and in kimberlites and orogenic peridototite from the Pyreneans massifs have been investigated. Coupling EMP, SIMS, LA-ICPMS and LA-MC-ICPMS, major elements, $\delta^{34}S$, siderophile and chalcophile trace elements, and Os isotopes have been obtained in-situ on the same sulfide grain.

Almost all sulfides from xenoliths or orogenic massifs have $\delta^{34}S<0$ ($-7\leq d^{34}S < 0.5‰$). These results are in agreement with recent data [8-10], do not support a contrasted composition between massif and xenoliths, but still indicate a significant level of heterogeneity within the SCLM. Preliminary results unfold broad correlations between HSE and/or chalcogenides abundances and/or $^{187}Os/^{188}Os$ and $\delta^{34}S$, which suggest that during melt depletion sulfur isotope become heavier. In contrast, metasomatic and pyroxenites sulfides are characterised by significantly lighter composition values ($-7\leq \delta^{34}S<-4$ ‰). Thus, as for Os isotopes and HSE abundances [11,12], $\delta^{34}S$ is fractionated during mantle processes. Using the same approach, fertile mantle composition may be estimated at best about -1±1‰ which is within error of the "canonical" [1-3] and recent estimates [8].

***References**: [1] M. Chaussidon, F. Albarede, S.M.F. Sheppard, Nature 330 (1987) 242-244. [2] M. Chaussidon, F. Albarede, S.M.F. Sheppard, Earth Planet. Sci. Lett. 92 (1989) 144-156. [3] M. Chaussidon, J.P. Lorand, Geochim. Cosmochim. Acta 54 (1990) 1-12. [4] H. Sakai et al., Geochim. Cosmochim. Acta 48 (1984) 2433-2441. [5] Z. Wang, H. Becker, Nature 499 (2013) 328-332. [6] D.A. Ionov, J. Hoefs, K.H. Wedepohl, U., Earth Planet. Sci. Lett. 111 (1992) 269-286. [7] M.R. Wilson, T.K. Kyser, R. Fagan, Geochim. Cosmochim. Acta 60 (1996) 1933-1942. [8] J. Labidi, P. Cartigny, M. Moreira, , Nature 501 (2013) 208-211. [9] R.A. Cabral, et al., Nature 496 (2013) 490-493. [10] J. Farquhar et al., Science 298 (2002) 2369-2372. [11] Alard et al., Nature 407 (2000) 891-894. [12] Alard et al. Earth Planet. Sci. Lett. 203 (2002) 651-663.*

Major and trace element geochemistry, origin and timing of sulfide formation in ultramafic xenoliths from the Nógrád-Gömör Volcanic Field (northern Hungary – southern Slovakia)

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Neogene to Quaternary alkaline basalts containing lower crust- and mantle-derived xenoliths in the Nógrád-Gömör Volcanic Field (NGVF, northern Hungary – southern Slovakia) are providing a unique opportunity to characterize the deeper parts of the lithosphere beneath the Carpathian-Pannonian region. Three types of ultramafic xenoliths were found in this region: Type-I peridotites (lherzolites and harzburgites), heavily metasomatized Type-I Fe-wehrlites, and Type-II (lower crustal cumulate) xenoliths, all of them containing sulfide minerals as inclusions or interstitial grains.

Sulfide mineralogy of the three xenolith suites are different; sulfides of the Fe-wehrlite and Type-II xenoliths are dominated by pyrrhotite and Ni-poor monosulfide solid solution (MSS), whereas Type-I peridotites contain more pentlandite, Ni-rich MSS and chalcopyrite. This difference between Type-I and II sulfides is also confirmed by their Fe content (53-59 wt % and 40-47 wt %, respectively), whereas the sulfides of the Fe-wehrlites have intermediate Fe contents (47-52 wt %). Based on their texture, sulfide and silicate major element compositions, Type-I wehrlites are formed by a reaction between peridotite and mantle-derived melts, which can be connected to the Type-II cumulates. Another remarkable feature of the Type-I lherzolitic sulfides is their unusually high Co concentrations, which can be as high as 1.75 wt %.

In-situ LA-MC-ICP-MS Platinum-group element (PGE) + Au analyzes were carried out on sulfide grains from the Type-I peridotite suite. Total concentrations of PGEs range from 5 to 250 ppm; Au concentrations are below 1 ppm. Ir-type PGEs (Os, Ir and Ru) and Rh are correlating with each other ($r^2>0.8$) as expected, i.e. these elements reside in the same phase (MSS). All of the sulfides have a negative Pt-anomaly, and Pt is not correlated with all the trace and major elements due to its nugget behavior, meaning it resides mainly in Pt-rich phases.

Two thirds of the samples have subchondritic (relative to the Enstatitic Chondritic Reservoir) $^{187}Os/^{188}Os$ (0.1127–0.1275) and $^{187}Re/^{188}Os$ (0.0149-0.3821) ratios, suggesting their isotopic ratios were not affected by infiltrating asthenospheric melts. Re-depletion ages (T_{RD}) range between 0.23±0.02 and 1.99±0.1 Ga, with main peaks at 0.7, 1.1 and 1.5 Ga. These ages can be related to melting events and metasomatism during the break-up and amalgamation of Rodinia and Columbia supercontinents, respectively. However, the oldest rocks known in the region are Paleozoic or younger, and age data on the lower crust of this region is scarce, hence they cannot be linked directly to the age of the subcontinental lithospheric mantle.

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Observations of anomalous subcrustal reflections along the East Pacific Rise: Possible detection of a permeability barrier

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Crustal accretion along mid-ocean ridges primarily occurs within the narrow neovolcanic zone at the spreading axis and requires melt focusing from a broad, partially molten zone at depth. Numerous mechanisms have been proposed to facilitate the process of magmatic focusing at mid-ocean ridges, although one of the predominant explanations is channelized flow through high-porosity decompaction channels beneath a melt-impermeable boundary, or permeability barrier, at the base of the sloping thermal lithosphere. Numerical simulations, as well as structural and petrological observations from the Oman ophiolite, suggest the existence of permeability barriers and associated high-porosity channels. However, direct seismic images of permeability barriers have been elusive. A recent analysis of seismic data from the East Pacific Rise (EPR) between the Siqueiros and Clipperton transform faults (8°15'N-10°20'N) reveals anomalous subcrustal reflections ~20 km east of the rise axis and ~20-50 km south of the Clipperton transform fault. While the reflections possess energy at all frequencies, they are most easily visible in the 20-30 Hz range. They possess a non-inverted, complex waveform and are characterized by large P and small S wave amplitudes. Reflection coefficient analyses reveal that the reflections originate from a solid interface that is dunitic in composition. The approximate depth, slope, and geographical extent of the reflector are estimated by back projecting the onset times of the anomalous reflections into a predefined velocity model. This method reveals that the reflector dips both away from the ridge axis and northward toward the Clipperton transform fault with a minimum depth below seafloor of ~7.2 km (0.7 km below the Moho) nearest to the ridge. Further off-axis and roughly 20 km to the north, closest to the Clipperton transform fault, the depth of the reflector increases to ~10.6 km (4 km below the Moho). The slope of the observed reflector thus conforms to the base of the thermal boundary layer (i.e. the 1200-1300° C isotherms) in thermal models adjacent to oceanic transform faults (Roland et al., 2010). The 1240° isotherm is thought to represent the temperature of plagioclase crystallization in basaltic melts, which creates a sharp depth interval of crystallization that generates permeability barriers. In addition, the anomalous reflections are present near a network of off-axis crustal magma bodies that have previously been proposed to originate from melt percolation through structural or compositional heterogeneities within a permeability barrier. We therefore infer the anomalous subcrustal reflections originate from a melt-impermeable boundary at the base of the thermal lithosphere. Our seismic results are the first possible detection of a permeability barrier beneath a spreading center and thus support previous models that invoke such features as a mechanism for subcrustal melt accumulation, off-axis volcanism, and magmatic focusing at mid-ocean ridges.

Nature and evolution of the upper mantle of the Middle Atlas (Morocco) constrained by a petrological study of mantle xenoliths

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It is largely established that the petrological study of mantle xenoliths allows to better constrain the evolution of the lithospheric sub-continental mantle. The Atlas Mountains fold-belts located in the north-west of the African continent is one of the places where mantle xenoliths occur. More specifically the Middle Atlas area corresponds to a mountain chain lacking a crustal root a characteristic related to lithospheric and asthenospheric processes occurring during the compressive phase. The xenoliths found in the Middle Atlas were brought to the surface by Neogene – Quaternary alkaline lavas emplaced during the crustal thinning phase that took place before the compressive phase.

In order to better constrain the nature and evolution of the lithospheric sub-continental mantle beneath Middle Atlas, we have conducted a petrological and geochemical study on 15 selected representative xenolith samples from the Tafraout area. The study of primary mineral phases of those mantle xenoliths evidences that the lithospheric sub-continental mantle is heterogeneous consisting mostly of lherzolites with minor harzburgites and pyroxenites including a garnet-bearing websterite. All the peridotites are spinel bearing rocks coming from the spinel peridotitic mantle stability field corresponding to a pressure ranging from 7 to 22 kbar, i.e. a depth ranging from 25 to 100 km. Finally the garnet-bearing websterite also originates from the same lithospheric mantle zone as evidenced by its temperature and pressure of equilibration, ranging from 700 to 900°C and close to 1.2 GPa, respectively.

Three main petrogenetic processes explain the upper mantle heterogeneity evidenced by our study: (1) A partial melting event evidenced for example by the high #Mg (100Mg/Mg+Fetotal) of primary silicates (CPX, OPX, OL) commonly >90, (2) A mantle metasomatic event related to the circulation of mafic silicated alkaline melts more or less enriched in CO2. This event is evidenced by the LREE enrichment of peridotitic CPX and by the crystallization of new mineral phases such as amphibole and secondary CPX, finally (3) A magmatic event leading to the crystallization within the upper mantle of mafic silicated alkaline melts highlighted by the formation of pyroxenites and in particular of garnet-bearing websterites.

Metasomatic processes in the mantle wedge: New insights from Eastern Alpine peridotites

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Mantle lithologies exhumed from orogenic terrains provide the opportunity to study deep Earth processes from the outcrop- to the micro-scale. Among such occurrences, the upper Austroalpine Ulten zone in Eastern Italy has been studied in great detail. There, very fresh garnet peridotites and associated pyroxenites occur as lenses in lower crustal gneisses and migmatites of the Central European Variscan Belt. Spinel peridotites from the depleted mantle wedge that initially resided at ~1200º C and 1.3-1.6 GPa [1,2] were dragged to greater depth via corner flow and captured by the cold slab during the Variscan orogeny. This led to cooling, a small pressure increase (850 - 900º C; < 1.9 GPa) and garnet growth ca 330-340 Ma ago, and was followed by rapid exhumation in buoyant continental crust and a mild, retrogressive overprint at ~1.5-1.7 GPa, 730°C [1-6]. Reaction of peridotites with three types of fluids has been postulated: (1) Intrusion of hot (1430-1470º C), alkaline melts from an inner, subduction-modified wedge led to formation of initially garnet-free pyroxenite layers and to cryptic LILE, LREE, Li, Pb and U enrichment of spinel lherzolites residing in the overlying, cooler portion of the mantle wedge; (2) Reaction of peridotite with siliceous crustal melts, related to migmatisation of subducted continental crust, generated reactive pyroxenite and may be documented by orthopyroxene porphyroclasts in highly deformed peridotite; (3) After consumption of the melt, residual hydrous, oxidising (FMQ to FMQ+2), CO2-bearing fluids led to crystallisation of abundant amphibole and minor apatite and dolomite, LILE enrichment and high LILE/HFSE during peak metamorphism and also during subsequent retrogression [3-8].

We are currently acquiring new whole-rock major-element, S, PGE and Re-Os isotope compositions, combined with trace-element systematics of abundant associated sulphides, from a variety of peridotite and pyroxenite samples from the Ulten Zone to constrain the nature and effects of subduction-related fluids and melts on the deep mantle wedge. The new data will be integrated with earlier results, which show that the peridotites have chondritic relative PGE abundances that are higher than estimates for the primitive upper mantle [9]. Constraining the highly siderophile element concentrations (HSE) of the sulphides, together with bulk-rock S contents, will help to determine where in the Ulten zone peridotites and pyroxenites the HSE reside and how they were mobilised. The results will further be compared with those for orogenic peridotites and pyroxenites from diverse tectonic settings (ocean floor, ocean-continent transition, continental) as well as with xenoliths from supra-subduction zones that typically sample shallower regions of the mantle wedge. Identifying the similarities and differences of the different processes acting upon lithospheric mantle in these settings will ultimately not only increase our understanding of the mass transfer into subduction zone mantle, but also the effects of its recycling, via delamination or deep subduction, on the convecting mantle source of oceanic basalts.

[1] Nimis and Morten (2000) J Geodyn 30: 93-115; [2] Rampone and Morten (2001) J Petrol 42: 207-219; [3] Tumiati et al. (2003) Earth Planet Sci Lett 210: 509-526; [4] Braga and Sapienza (2007) Geoacta 6: 37-45; [5] Sapienza et al. (2009) Contrib Mineral Petrol 158: 401-420; [6] Tumiati et al. (2013) JPet 54: 453-479; [7] Scambelluri et al. (2006) Contrib Mineral Petrol 151: 372-394; [8] Malaspina et al. (2009) J Petrol 50: 1533-1552; [9] Braga et al. (2005) Ofioliti 30: 179-180

Deformation, seismic properties and water contents of the lithospheric mantle beneath the East African Rift, North Tanzania

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We have analyzed the microstructures, the crystal preferred orientations (CPO), and calculated the seismic properties of 53 mantle xenoliths from four localities within the East African rift (North Tanzania), two within the rift axis, and two within the North Tanzanian Divergence. OH concentrations in olivine were measured in 15 of these xenoliths. Most samples have harzburgitic to dunitic compositions, and high olivine Mg#, suggesting early, extensive partial melting.

Within the rift axis, peridotites display mylonitic, porphyroclastic, to granular microstructures, which record deformation by dislocation creep under high stress, followed by variable, yet weak degrees of annealing. Highly sheared orthopyroxene crystals in mylonite indicate that the deformation was initiated at low temperature. However, the crystallisation of olivine from orthopyroxene observed in most samples suggests that the deformation continued at near solidus temperatures. Extensive exsolutions formation in orthorpyroxene indicates that this deformation was followed by rapid cooling. Late percolation events are evidenced by the occurrence of veins crosscutting the microstructure, as well as the presence of pervasive interstitial clinopyroxene and phlogopite. Axial-[100] olivine CPO predominates, suggesting the activation of the high temperature, low pressure [100] (0kl) slip system, coherent with a transtensional deformation.

Off-axis, within the Tanzanian Divergence, peridotite xenoliths from Lashaine display very coarse-granular textures, indicating a deformation by dislocation creep under low deviatoric stress conditions followed by annealing. The orthorhombic to axial-[010] olivine CPOs are consistent with the simultaneous activation of [100](010) and [001](010) slip systems, coherent with a transpressional deformation. Peridotite xenoliths from Olmani display microstructures and CPOs intermediate between those from Lashaine and rift-axis samples.

No systematic variations of olivine OH concentrations between in- and off-axis samples are observed. Hydrogen concentrations in olivine vary between 2 and 12 ppm wt. H_2O. The lowest concentrations were measured in mylonites from rift-axis localities and the highest in a coarse-granular peridotite from Lashaine.

Maximum P-wave azimuthal anisotropy (AVp) ranges between 3.3 and 18.4% and the maximum S-wave polarization anisotropy (AVs), between 2.3 and 13.2%. The change in olivine CPO symmetry, from dominantly axial-[100] peridotites from the rift-axis to orthorhombic in xenoliths from Olmani and axial-[010] in peridotites from Lashaine, results in a variation in the seismic anisotropy patterns. In all cases the fast S-waves are polarized parallel to the flow direction, but while in the rift-axis S-waves propagating parallel to the lineation will sample no anisotropy, off-axis the apparent isotropy direction will be sampled by S-waves propagating normal to the foliation.

Petrophysical constraints on the seismic properties of the Kaapvaal craton mantle root

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We calculated the seismic properties of 47 mantle xenoliths from 9 kimberlitic pipes in the Kaapvaal craton based on their modal composition, the crystal-preferred orientations (CPO) of olivine, ortho- and clinopyroxene, and garnet, the Fe content of olivine, and the pressures and temperatures at which the rocks were equilibrated. These data allow constraining the variation of seismic anisotropy and velocities within the cratonic mantle. The fastest P and S2 wave propagation directions and the polarization of fast split shear waves (S1) are always subparallel to olivine [100] axes of maximum concentration, which marks the lineation (fossil flow direction). Seismic anisotropy is higher for high olivine contents and stronger CPO. Maximum P wave azimuthal anisotropy (AVp) ranges between 2.5 and 10.2% and the maximum S wave polarization anisotropy (AVs), between 2.7 and 8%. Changes in olivine CPO symmetry result in minor variations in the seismic anisotropy patterns, mainly in the apparent isotropy directions for shear wave splitting. Seismic properties averaged over 20 km-thick depth sections are, therefore, very homogeneous. Based on these data, we predict the anisotropy that would be measured by SKS, Rayleigh (SV) and Love (SH) waves for five endmember orientations of the foliation and lineation. Comparison to seismic anisotropy data from the Kaapvaal shows that the coherent fast directions, but low delay times imaged by SKS studies, and the low azimuthal anisotropy with with the horizontally polarized S waves (SH) faster than the vertically polarized S wave (SV) measured using surface waves are best explained by homogeneously dipping (45°) foliations and lineations in the cratonic mantle lithosphere. Laterally or vertically varying foliation and lineation orientations with a dominantly NW–SE trend might also explain the low measured anisotropies, but this model should also result in backazimuthal variability of the SKS splitting data, not reported in the seismological data. The strong compositional heterogeneity of the Kaapvaal peridotite xenoliths results in up to 3% variation in density and in up to 2.3% variation of Vp, Vs, and Vp / Vs ratio. Fe depletion by melt extraction increases Vp and Vs, but decreases the Vp / Vs ratio and density. Orthopyroxene enrichment due to metasomatism decreases the density and Vp, strongly reducing the Vp / Vs ratio. Garnet enrichment, which was also attributed to metasomatism, increases the density, and in a lesser extent Vp and the Vp / Vs ratio. Comparison of density and seismic velocity profiles calculated using the xenoliths' compositions and equilibration conditions to seismological data in the Kaapvaal highlights that (i) the thickness of the craton is underestimated in some seismic studies and reaches at least 180 km, (ii) the deep sheared peridotites represent very local modifications caused and oversampled by kimberlites, and (iii) seismological models probably underestimate the compositional heterogeneity in the Kaapvaal mantle root, which occurs at a scale much smaller than the one that may be sampled seismologically.

Phosphorus zoning as a recorder of crystal growth kinetics:implications from secondary olivine and pyroxene in mantle xenoliths from Cima Volcanic Field

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Phosphorus(P)-rich zones in olivine may reflect incorporation of P in excess of equilibrium partitioning during rapid growth and zoning patterns may record growth rate variations (Milman-Barris et al. 2008; Stolper et al. 2009). We report data on two mantle xenoliths from Cima Volcanic Field (CA, USA) with second-generation P-rich olivines (in Ci-1-196) and pyroxenes (in Ci-1-105). Ci-1-196 contains multiple lherzolite, websterite and dunite layers, whereas lherzolite and clinopyroxenite layers alternate in Ci-1-105. The host rock, not analyzed here, is thought to be an alkaline basalt similar to hawaiite (Wilshire et al. 1988).

In Ci-1-196, a thin (~200 µm wide), dark layer at the contact between lherzolite and websterite is interpreted as a rapidly crystallized melt, it consists of Ol+Gl+Pl+Spl+Cpx+Ap+Ilm. Olivines in the layer have 0.03-0.62 wt% P_2O_5; P-rich olivines (P_2O_5>0.1 wt%) are Fo85-89.3. Apatite inclusions occur in the rim of P-rich Ol (Fo85) and in Pl (An54). Glass is widespread (~15 vol%) and variable in composition with P_2O_5 ≤1.2 wt%. Plagioclase occurs as prismatic, flow-oriented crystals parallel to the plane of the layer or interstitial to Ol and Cpx. Cpx crystallized from the melt layer and formed by reaction between melt and matrix Ol. Spinel occurs as inclusions in the Ol or in association with Pl and glass, showing euhedral to anhedral shapes with chromite cores zoned to Ti-chromite rims and an outer rim rich in ulvöspinel. Ilmenite occurs as idiomorphic crystals or as thin rims (<2-3 µm) on Pl. In Ci-1-105, an irregularly-shaped (average ~2 mm width) dark pocket between matrix Ol and Cpx contains Ol+Gl+Pl+Spl+Cpx+Ap and is interpreted as rapidly crystallized melt. Euhedral to anhedral Cpx in the pocket are Al, Ti-rich, have P_2O_5 0.115-0.682 wt%, and project into the ternary from Wo49En38Fs13 to Wo52En32Fs16. The melt pocket contains Ol (Fo88.5-88.6) with P_2O_5 ~0.084 wt%, richer in P than matrix Ol (P_2O_5 from 0.016-0.064 wt% and Fo84.2-89.0). Apatite occurs both as large (~100 µm) crystals near the pocket rim and as tiny crystals. Glass (5-10 vol%) in the pocket is K_2O-rich (7.01-7.86 wt%) with P_2O_5 ≤1.23 wt%. Pl (An64-53Ab33-42Or3-5) occurs as prismatic, un-oriented crystals. Euhedral to anhedral spinel (uniform Al# = 0.82, Cr#= 0.14) occurs as inclusions in Ol or in association with Pl and glass. Two mapped sub-areas with minimum P in Ol from Ci-1-196 are surrounded by P-rich planes parallel to crystal edges. The P-rich zones are 3-7 µm wide. P_2O_5 in Ol is negatively correlated with Si and Mg+Fe+Ca, suggesting a substitution $Mg_2SiO_4 + \frac{1}{2}P_2O_5 \rightarrow Mg_{1.5}Vac_{0.5}PO_4 + \frac{1}{2}MgO + SiO_2$. A slight correlation between P and Al implies either diffusive relaxation of Al gradients or, judging by the dynamic experiments of Grant & Kohn (2013), cooling rates >10 °C/h that generate disequilibrium solute trapping of P but near-equilibrium incorporation of Al. High P_2O_5 in Cpx is reported in only 6 other occurrences worldwide (GEOROC database), in nephelinite, basanite, and pyroxenite hosts from both convergent margin and intraplate tectonic settings. P-rich pyroxenes in Ci-1-105 are similar (in SiO_2, Al_2O_3, and TiO_2) to those in groundmass of a basanite (Yurtmen 2000). There is no zonation of Cpx P content in two mapped crystals. Experiments on development or relaxation of P-zoning in Cpx are needed but relaxation of growth zoning in P seems unlikely. Uniform enrichment then probably suggests slow enough crystallization to avoid boundary enrichment and growth from a large enough reservoir to avoid progressive P enrichment (unlikely in an isolated melt pocket) or growth of pyroxene after melt P_2O_5 became buffered by apatite saturation.

Petrology and Geochemistry of Spinel Pyroxene Clusters in Mantle Peridotite Xenoliths from the Massif Central, France and Lanzarote, Canary Islands.

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This study investigates spinel pyroxene clusters in mantle peridotite xenoliths from two localities in different tectonic settings: (1) the Massif Central, France, an uplifted plateau associated with Tertiary-Quaternary volcanic activity on relatively young continental lithosphere; (2) Lanzarote in the Canary Islands, an oceanic intraplate volcanic island chain built on old (Jurassic) oceanic lithosphere. Spinel pyroxene clusters are considered to be metamorphic products of garnet breakdown. The phase transition from the garnet stability field to the spinel stability field is represented by the equation olivine + garnet = orthopyroxene + spinel. Garnet is rarely associated with oceanic lithosphere and thus the presence of garnet and its conversion to spinel requires investigation. The spinel pyroxene clusters were analysed using standard electron probe and SEM techniques using both EDS and WDS analysis. The samples from Lanzarote have also been cored and scanned using X-Ray CT tomography, rendering a 3D image of the clusters in the rock. Tailored probe sections have been created from the 3D data for microprobe analysis and element maps have been made for several examples of the clusters in the Lanzarote samples. Microprobe results show that Mg#s for olivine, orthopyroxene and clinopyroxene for the two localities are broadly similar and range from 89-92, whereas the spinel Cr#s exhibit higher values in the Lanzarote samples (38-44) than in the samples from the Massif Central (14-22). Microprobe data are being used to reconstruct original garnet composition to test the hypothesis that the spinel pyroxene clusters are the result of garnet breakdown. Analysis of the area scans of the clusters reveals a garnet (pyrope) signature. Some clusters from Lanzarote show evidence of metasomatism in the form of silicate glass reacting with spinel. The lowest Mg#s values in silicate minerals in the Lanzarote samples are associated with this metasomatism.

Mantle serpentinization in the Neoproterozoic ophiolite of Bou Azzer El Graara (Bou Azzer mining district, Central Anti-Atlas, Morocco)

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The neoproterozoic Bou Azzer inler central Anti Atlas Mountains, southern Morocco represents a geological window into the Precambrian basement. It's surrounded by a discordant Phanerozoic cover. It is interpreted as the boundary between the northern margin of West African Craton (WAC) and dismembered parts of the Anti-Atlas Pan-African orogenic belt commonly known as Bou Azzer ophilite. This comprises a tectonic contact juxtaposing a tectonic block dominated by mafic-ultramafic plutonic bodies commonly called a dismembered ophiolite by several authors (Leblanc,1981; Saquaque et al., 1989; Hefferan et al., 2002). In Bou Azzer inlier within the Anti-Atlas orogenic belt of Morocco, serpentinization has affected all ultramafic rocks. Two main phases of serpentinization at Bou Azzer was pointed out (Wafik, 2001) : i) an oceanic syn-rifting pseudomorphic serpentinisation stage with antigorite and two continental tectonic serpentinzation stages during tectonic setting of ophiolite with ii) syn-collision extensional stage lizardite and iii) post-collision extensional stage chrysotile filling veins and faults. After this author, Serpentinite is initial reserve of Ni-Co mineralization in Bou Azzer, where is reconcentrated by tectono-magmatic events that took place later. Our recent study on tectonite and serpentinization process and The Bou Azzer, focused on five selected areas from West to East : Bouffrokh, Mechoui (mokhazni), Bou Azzer center, Ambed, Ait Abdallah and Ait Ahmane. In this work we mapped some serpentine massifs in order to determine any lateral or vertical variation to Bou Azzer inliers' scale. The field study has pointed out a gradient both horizontally and vertically. Therefore, the ultrabasic rocks of the western part of the buttonhole particularly at the level sector of Bou Offroh are completely serpentinized while the process of serpentinization is partial at Ambed and almost absent in some eastern areas as Ait Ahmane and Ait Abdellah. The new mineralogical and geochemical datas we have obtained agree with Wafik's (2001) observations, and have allowed us to clarify the serpentinization's repartition and process. Two major serpentinization stages the Bou Azzer Pan-African orogen are observed: (1) Pseudomorphic Precoce stage: materialized by the isotropic serpophite preserving the primary form of olivine crystals, often with needles antigorite. Brucite is fairly frequent, as micrometric inclusions in other serpentine minerals as antigorite and serpophite. (2)Tectonic Late stage: materialized by framework or parallel veins and fractures filled by chrysotile a and g. These minerals are often crosscutting the antigorite, serpophite and brucite crystals. They are accompanied by opaques minerals. These opaque assemblages are associated with serpentinization process. Macroscopically and microscopically interstitial spaces and schistosity plans are underlined by thick laminas and veins of magnetite. Some sulfides as pyrite and chalcopyrite are also filling this fractures. These results lead us to assume that the precoce syn-rifting serpentinization of has affected homogeneously ultramafic rocks of Bou Azzer ophiolites and late tectonic serpentinization has affected heterogeneously ultramafic rocks of Bou Azzer ophiolites. This resulted in serpentinization's vertical and lateral gradients, related to deformation gradients during panafrican ophiolite's subduction and obduction from East to West. It was accentuated by different erosion levels. In areas with high hydrothermal alteration as Mechoui sector, serpentines have been transformed to listwenites. They have variable compositions of the metamorphic grade, with a full combination carbonate, breunnerite, quartz, magnetite and fuschite with relics of antigorite and chromospinelles. In contact with gabbros granitoids dykes, serpentinites become chloritic with of asbestos with banded textures corresponding to advancing metasomatism's front. The intrusive rocks also exhibit metasomatic transformations contacts with serpentinite. They are materialized by centimetric rims of rodingite to vesuvianite and garnet. Some veins and dykes are fully transformed into giobertite and magnesite by supergene alteration of serpentinite like Ambed and Ait Ahmane massifs.

Pyroxenite emplacement in Northern Apennine ophiolitic peridotites (Italy): insights on the origin of small-scale chemical and isotopic heterogeneity in the upper mantle

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Deep melt intrusion and melt-peridotite interaction are considered the most efficient processes in creating small-scale heterogeneity in the upper mantle (e.g. Lambart et al., 2012; Mallik and Dasgupta, 2012). Pyroxenite-peridotite mantle sequences outcropping in the Western External Liguride ophiolitic Units of the Northern Apennines (Italy) experienced a cold decompressional tectonic evolution (Borghini et al., 2011) and preserve petrochemical records of deep-seated events. They thus represent an excellent study case to investigate the origin of pyroxenites and how their emplacement modifies the chemical and isotopic composition of the upper mantle. Pyroxenites range from spinel-bearing websterite to clinopyroxenite; they occur as cm-thick bands (up to 40 cm) parallel to the spinel-facies tectonite foliation in the host peridotites and often show orthopyroxene-rich rims along the boundary with the host peridotite. In spite of partial subsolidus low-P re-equilibration (spinel- to plagioclase-facies), most of the pyroxenites record chemical features inherited from a precursor garnet-bearing assemblage. Mass balance calculations provide up to about 40% of garnet in the original mineralogy, thus supporting that pyroxenites originated from melt segregation in mantle peridotites at rather high pressures ($P > 1.6$ GPa). Tholeiitic affinity and rather low XMg (estimated range 58-62) of the pyroxenite parental melts suggest that these layers were produced by partial melting of a heterogeneous pyroxenite-bearing mantle. Interaction between pyroxenite melts and host mantle is indicated by modal and chemical modification of peridotite wall-rocks, namely i) orthopyroxene enrichment at the expense of olivine, ii) higher Al, Ca, Si contents and slightly lower Mg# of bulk rocks, iii) Al-richer spinel and lower-Mg# pyroxenes, compared to pyroxenite-free country peridotites. In the modified peridotites, clinopyroxene porphyroclasts record a trace element gradient resulting from percolative reactive flow of pyroxenite melt up to about 20 cm from the pyroxenite-peridotite boundary. Farer, clinopyroxene composition is affected by a more efficient chemical buffering of the host peridotite through ion exchange chromatographic-type processes. Sr and Nd isotopic compositions in peridotites and pyroxenites define a large range (87Sr/86Sr = 0.701750-0.702877; 143Nd/144Nd = 0.512799-0.513544). 143Nd/144Nd ratios on few meters scale cover almost the entire Nd isotopic variability documented in abyssal peridotites (Borghini et al., 2013). Pyroxenite intrusion modified the host peridotites, lowering their 143Nd/144Nd as a combined effect of the systematic LREE enrichment (i.e. Sm/Nd decrease) and radioactive decay. Sm/Nd errorchrons defined by pyroxenites and modified peridotites yield a small range of ages between 424-452 Ma (errors < ±50 Ma). This constrains the timing of pyroxenite emplacement that predates the low-P evolution related to rifting and opening of the Jurassic Ligurian Tethys, as indicated by plagioclase - clinopyroxene - whole rock Sm-Nd internal isochrones (178 ±25 Ma). Recently, Hf isotope analyses have been performed on separated clinopyroxenes from the same set of samples. Preliminary results indicate that 176Hf/177Hf ratio of pyroxenites and peridotites well correlates with the 143Nd/144Nd ratio and confirm a large isotopic variability at the massif scale.

Borghini et al. (2011): Lithos 126, 42-53; Borghini et al. (2013): Geology 41, 1055-1058; Lambart et al. (2012): Journal of Petrology 53, 451-476; Mallik and Dasgupta (2012): EPSL 329-330, 97-108.

Near-solidus phase assemblages and partial melting behavior of a natural pyroxenite: an experimental study at 1-1.5 GPa.

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Mafic layers embedded in mantle peridotites represent a diffuse lithological heterogeneity in the upper mantle and they are often invoked as a minor but important component in the mantle source of oceanic basalts, responsible for their chemical and isotopic variability (e.g. Kogiso et al., 2004; Lambart et al., 2013). Recent studies have proposed that such heterogeneities can mostly consist of second generation ("stage 2") pyroxenites originated by deep intrusion and melt-peridotite reaction processes triggered by partial melting of deeper low-MgO mafic components (e.g. Lambart et al., 2012; Mallik and Dasgupta, 2012). Indeed, these hybrid rocks would be able to produce high-MgO low-reactive magmas and preserve the pyroxenite signature of the original melt (Lambart et al., 2013). Pyroxenite layers in ophiolitic mantle sequences of the Northern Apennines (Italy) have been recently interpreted as the result of deep infiltration of low-MgO melts in the peridotites (see Borghini et al., this meeting). Their emplacement led to significant chemical modification of host peridotites introducing a very large isotopic variability (Borghini et al., 2013). They therefore represent a natural portrait of stage 2 pyroxenite, a potential enriched component in the basalt mantle sources. This study aims to define i) the near-solidus phase assemblage, ii) melt productivity and iii) composition of partial melts of a stage2-type pyroxenite, by high pressure and temperature synthesis of a natural pyroxenitic bulk composition. Experiments were carried out at P from 1 to 1.5 GPa and T from 1100 to 1330°C, using both single-stage and end-loaded piston cylinders. As starting material we use a glass obtained by complete melting of rock powder sample in a furnace at 1500°C (at FMQ fO_2 conditions) and rapid quench in dry ice. Resulting glass has X_{Mg}=0.83, CaO=14.4 wt%, Al_2O_3=10.1 wt% and Na_2O=0.3 wt% similar to bulk compositions of several worldwide pyroxenites. To promote the nucleation of the minor phases in subsolidus experiments, gel is seeded with 1% of a mixture of synthetic pure spinel (50%) and Dora-Maira pyrope (50%). A layer of carbon vitreous spheres (d< 125 μm) is used to favor the melt trapping. Textures of run products show largely variable grain size depending on temperature, up to about 70-80 μm at 1330°C and around 5-10 μm in subsolidus run at 1100°C. Coherent element partitioning (e.g. X_{Mg} in olivine and pyroxenes) and first mass balance calculation support approach to equilibrium. Preliminary results show that at 1 GPa a subsolidus assemblage made by clinopyroxene, orthopyroxene, spinel and olivine is stable at 1100 and 1150°C. At 1 GPa, glass compares at 1200°C and is in equilibrium with clinopyroxene, orthopyroxene, spinel and olivine, whereas orthopyroxene disappears at 1250°C with increasing melting degree. Experiments performed at 1.5 GPa are characterized by garnet, spinel, clinopyroxene, ortopyroxene (±ol) subsolidus assemblage stable at 1150° and 1200°C. Preliminary results indicate that for relatively high melting degrees (>30 %), a stage2-type pyroxenite produces melts with Mg# similar to that of near-solidus partial melts from fertile lherzolite (Falloon et al., 2008).

Borghini et al., this conference. Borghini et al. (2013): Geology 41, 1055-1058.
Falloon et al., (2008): Journal of Petrology 49, 591-613.
Lambart et al. (2012): Journal of Petrology 53, 451-476.
Kogiso et al. (2004): Journal of Petrology 45, 2407-2422.
Lambart et al. (2013): Lithos 160-161, 14-36.
Mallik and Dasgupta (2012): EPSL 329-330, 97-108.

Re-Os in single sulfides vs. whole rock: mantle melting, metasomatism and kimberlitic overprinting in Somerset (Rae Craton, Canada)

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Mantle xenoliths from Somerset Island are characterized by variable HSE (highly siderophile elements) signature and Os ages with TRD ranging between 1.3 and 2.7 Ga [1]. In a classical 187Re/188Os vs. 187Os/188Os diagram, eight whole rocks define an isochron with an age of 100 Ma. This age matches the kimberlitite eruption, suggesting a variable overprint related to the emplacement of the hosting body. Furthermore those samples point towards the lowest 187Os/188Os measured in the whole suite of samples indicating that before the kimberlite eruption they possibly belonged to a similar portion of the mantle characterized by the lowest 187Os/188Os signature recorded in the local SCLM (TRD=2.7 Ga). Mineral investigations show no striking differences between samples belonging to the isochron and the rest of the suite. We measured Re-Os in sulfides from four mantle xenoliths with variable HSE signature and Os ages. Individual sulfide grains were micro-sampled from thick sections, with Os extracted via µ-distillation and analyzed by N-TIMS. Sulfides from one xenolith lying on the 100 Ma isochron show an oldest Os age of 2.7 Ga. This suggests that sulfides are able to fully preserve ages that resemble geological events even when the mineral and bulk compositions have been completely overprinted by syn-eruptive processes. Sulfides extracted from other samples (not lying on the 100 Ma isochron) show similarly oldest age of 2.7 Ga. We interpret these ages as an evidence of large SCLM formation at 2.7 Ga, likely related to a synchronous event of Greenstone belt formation in a rift setting. The SCLM was later heterogeneously affected by metasomatic processes and overprinting during the kimberlite eruption.

[1] Irvine et al. (2003) Lithos 71, 461-488.

Abyssal, mantle wedge and subducted hydrated ultramafic rocks in the Villa Clara serpentinitic mélange, Central Cuba

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The Villa Clara serpentinite-matrix mélange (VCSM, Central Cuba) encompasses bodies of an ophiolite suite, bodies formed at depth in a subduction channel (high-P blocks of eclogite, garnet amphibolite, amphibolitite, blueschist, greenschist, quartzite, metapelite and antigoritite), and bodies of related volcanic-arc sequences and unrelated platform-derived sediments. The ophiolitic bodies are composed mostly of hydrated ultramafic rocks though fragments of layered and isotropic gabbros, diabase, basalt and pelagic sediments are also found. Available data indicate that formation of rock bodies and of the melange itself is a long lasting process that started in the late Jurassic and early Cretaceous (ca. 130 Ma), respectively, and finished during the late Eocene. On the basis of field relations, whole-rock composition, mineral assemblages, textures, and mineral chemistry, three principal groups of (meta) ultramafic rock are distinguished:

i) Group 1 (abyssal) ultramafic rocks are mainly composed of lherzolite and clinopyroxene-rich harzburgite, which have porphyroclastic texture with strongly deformed orthopyroxene porphyroclasts. Serpentine minerals mainly consist of mixtures of lizardite and chrysotile. Accessory Cr-spinel grains are anhedral and rimmed by Cr-magnetite and chlorite. The composition of olivine (Mg#~91), Opx (Mg#=93-95,Al_2O_3=3.38-4.36wt.%),Cpx (Mg#=91-92,Al_2O_3=4.11-7.50 wt.%,Na_2O=0.64-1.20 wt.%) and Cr-spinel compositions (Cr#<0.2, Mg#>70; TiO_2<0.05 wt.%) indicate fertile abyssal compositions. These ultramafic rocks can be interpreted as abyssal peridotites (Proto-Caribbean lithosphere) which started to form in the late Jurassic and was incorporated into serpentinitic mélange during arc-continent collision or, alternatively, before collision as blocks of downgoing oceanic lithosphere that did not subduct and were trapped in the subduction channel.

ii) Group 2 (mantle wedge) serpentinized peridotites, are extensively serpentinized and display pseudomorphic textures. Textural differences between mesh-texture lizardite and bastite indicate that most serpentinized peridotites were predominantly harzburgite. Serpentinites also contain minor chrysotile, chlorite and magnetite.Antigorite was not observed in this group. These serpentinized peridotites contain relicts of primary Cr-rich spinel partially oxidized to ferrian chromite and magnetite. Primary compositions are preserved in unaltered crystal cores, that have Cr#=0.41-0.64, Mg#=0.5-0.63 Fe^{3+}#=0.02-0.07, TiO_2 =0.05-0.26wt.%. We interpret these compositions as relicts of depleted mantle peridotites formed in a suprasubduction zone (probably in fore-arc/arc environment) during early Cretaceous-latest Cretaceous times.

iii) Group 3 (subducted) serpentinites are antigoritites. Samples consist mainly of antigorite(>90%), with minor magnesite-dolomite, Cr-spinel grains completely altered to magnetite. Also, some samples contain tremolite. Complete transformation of Cr-spinel indicates significant mobility of Cr related to the fluid/rock interaction during serpentinization in subduction zone. Fluid-rock interaction is denoted by veins made of coarse grained tremolite and chloritite blackwalls around tectonic blocks of HP metabasite within antigoritite. These metaultramafic rocks constitute deep fragments of the serpentinitic subduction channel that have undergone HP metamorphism. They can be interpreted as either subducted abyssal peridotites (Proto-Caribbean lithosphere) incorporated into the subduction channel developed in the Caribbean-Proto-Caribbean plate interface and finally exhumed in the melange or as deep hydrated fore-arc peridotites (Caribbean lithosphere).

Petrological Characteristics of Mantle Xenoliths from the Quaternary Basaltic District of Azrou- Timahdit, Middle Atlas, Morocco

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Quaternary alkali basalts of Azrou-Timahdite area contain a wide variety of ultramafic xenoliths: lherzolites, wehrlites, pyroxenites and occasionally amphibolites. A comprehensive mineral chemistry studies, done mainly by Electron probe microanalysis (EPMA) and Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS), allow proposing a petrogenetic history of these ultramafic xenoliths.

The studied xenoliths contain spinel, attesting their generation at depths from 30 to 70 Km, the intermediate zone of the lithospheric upper mantle. The olivine forsterite contents (Fo) are higher in lherzolites than in wehrlite, Fo88–91 and Fo80-83, respectively. Orthopyroxenes are enstatites with high Mg#s (88–91). Clinopyroxenes display higher Mg# than olivines and orthopyroxenes, indicating equilibrium between the coexisting phases. Progressive impoverishment in clinopyroxene of lherzolites and generation of rocks with different amounts of clinopyroxene evidence partial melting processes. LREE enrichment in clinopyroxene combined with high Na and Ti contents indicate mantle metasomatic processes. The metasomatism resulted in refertilization of peridotites evidenced by recrystallization of clinopyroxene and LREE enrichment. The wehrlite lithologies may be the end product of the latter process.

Given the above scenario, we believe that the mineralogical variations in the upper mantle beneath this part of the Middle Atlas Mountains can be attributed to a combination of two mantle processes: partial melting and metasomatism.

Rheological properties of the upper mantle section of San Andreas Fault system: Evidence from spinel peridotite xenoliths

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The viscosity of upper mantle in zones of strain localization remains a major question in geodynamics. Putting quantitative constraints in the rheological contrast between the viscous lower crust and upper mantle can inform on strain accumulation in the seismogenic upper crust sections of active lithospheric scale fault zones. Lithospheric strike-slip faults appear to evolve into wide shear zones in the upper mantle. This observation has been taken as indication for strong mechanical coupling between the various lithospheric layers, suggesting that crustal deformation in fault zones may depend more on the viscous flow in the upper mantle than the local strength heterogeneities in the crust.

To understand better the role of mantle rheology in active seismogenic faults, we study a suite of spinel peridotite xenoliths that have been entrained in the Coyote Lake basalt, located at the intersection of Hayward and Calaveras faults of the San Andreas Fault (SAF) system in central California. Previous studies show that the xenoliths equilibrated at 970-1100 oC, corresponding to depths of 38-43 km and therefore sample the upper mantle section of the SAF system (Titus et al., 2007). This study also shows that the xenoliths are characterized by strong olivine crystallographic preferred orientations and high shear wave anisotropies of approximately 6%, suggesting the existence of a mantle shear zone below SAF to a depth of at least 40 km. This is also suggested by the occurrence of a 130 km wide zone in the lithospheric mantle, where shear wave splitting directions become parallel to the SAF (e.g., Hartog and Schwartz, 2001). The strength of the upper mantle in the shear zone below this creeping segment of the SAF is unknown.

Microstructural observations combined with water content analysis and differential stress measurements using olivine paleopiezometry allow us to determine active deformation mechanisms and calculate the viscosity of the upper mantle shear zone. Our dataset informs on lithospheric mantle strain rates in the deep root of the SAF system. We compare the upper mantle viscosity estimates below SAF with those reported from other regions in western US (e.g., Dixon et al. 2004; Palasse et al., 2012) and with modeled viscosities for lower crust, to provide constraints for the top- or bottom-driven nature of lithospheric deformation.

Dixon, J.E., Dixon, T.H., Bell, D.R., Malservisi, R., 2004. Lateral variations in upper mantle viscosity: role of water. Earth and Planetary Science Letters 222, 451–467.

Hartog, R., Schwartz, S.Y., 2001. Depth-dependent mantle anisotropy below the San Andreas fault system; apparent splitting parameters and waveforms. Journal of Geophysical Research 106, 4155–4167.

Titus, S.J., Medaris, L.G., Wang, H.F., Tikoff, B., 2007. Continuation of the San Andreas Fault system into the upper mantle: evidence from spinel peridotite xenoliths in the Coyote Lake basalt, central California. Tectonophysics 429, 1–20.

Palasse, L.N., Vissers, R.L.M., Paulssen, H., Basu, A.R., Drury, M.R., 2012. Microstructural and seismic properties of the upper mantle underneath a rifted continental terrane (Baja California): An example of sub-crustal mechanical asthenosphere? Earth and Planetary Science Letters, 345-348, 60-71.

Diversity of mafic layers in the Beni Bousera massif and its relation with peridotite structure and evolution

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The Beni Bousera orogenic lherzolite (Rif Belt, northern Morocco) is composed of peridotites with subordinate amount of pyroxenites. Previous studies of pyroxenites have focused mostly on the geochemistry and petrology of garnet-bearing lithologies (Kornprobst *et al.*, 1990, Pearson *et al.*, 1989, Pearson & Nowell, 2004). Here we present a comprehensive major and trace element study of Beni Bousera pyroxenites aimed at investigating their compositional variability and its relationship with the tectono-metamorphic zoning recently documented in this massif (Frets *et al.*, 2014). On the basis of their structural and compositional characteristics, the Beni Bousera pyroxenites can be classified into four main types. Type 1 pyroxenites comprise garnet-bearing clinopyroxenites and mafic garnet granulites; this group includes corundum-bearing granulites (grospydites) and pyroxenites with graphite pseudomorphs after diamond. Type 1 pyroxenites crop out within the garnet-spinel mylonite and the spinel tectonites of the Ariègite subfacies domain. They occur as centimeter- to meter-scale layers with rather sharp contacts to the host peridotite, and are commonly isoclinally folded or boudinaged parallel to the peridotite foliation. They have a low, but variable, Mg-number (ca. 76) and display strong variations of LREE and HFSE. They show trace elements and isotopic signatures indicating recycling of different components from the oceanic lithosphere (Kornprobst *et al.*, 1990, Pearson *et al.*, 1989, Pearson & Nowell, 2004), and likely represent old vestiges of crustally derived components in the subcontinental lithosphere. Type 2 pyroxenites are garnet-spinel websterites occurring at the transition between the Ariègite and Seiland subfacies domains, and, sporadically in the Ariègite domain, at the boundaries of thick garnet pyroxenite layers. Similarly to Type 1 pyroxenites, these websterites crop out as layers —commonly boudinaged— parallel to the peridotite foliation. Type 2 pyroxenites display major and trace elements compositions transitional between those of Types 1 and 3. Their bulk rock composition is characterized by high Na_2O, CaO and Al_2O_3 contents, intermediate Mg-number, and REE-normalized patterns depleted in LREE depleted and enriched in HREE. Type 3 pyroxenites are centimeter-thick, olivine-bearing websterite layers with diffuse boundaries with host spinel peridotites; this type mostly occur in the structurally lowest part of the Seiland subfacies domain, which is composed of coarse-porphyroclastic to coarse-granular spinel peridotites (Frets *et al.*, 2014). Types 2 and 3 pyroxenites were most likely formed at the expense of Type 1 pyroxenites by melting and melt–rock reactions with peridotite melts at increasing melt mass. The melting and melt-rock reaction event was likely coeval with partial melting of peridotites during thinning of the subcontinental lithosphere (Frets *et al.*, 2014). Type 4 pyroxenites are spinel chromium websterites and websterites that mainly occur in the Seiland subfacies domain, but also as thin layers and rims associated to Type 1 and 2 pyroxenite layers. These websterites show major and trace element compositions akin to segregates of boninite to high-Mg andesite, and likely imply involvement of a fluid-derived crustal component; these pyroxenites might have formed at different stages of the evolution of the massif.

Cited references:

Frets, E. C., Tommasi, A., Garrido, C. J., Vauchez, A., Mainprice, D., Targuisti, K. & Amri, I. (2014). The Beni Bousera Peridotite (Rif Belt, Morocco): an Oblique-slip Low-angle Shear Zone Thinning the Subcontinental Mantle Lithosphere. Journal of Petrology. 10.1093/petrology/egt067.

*Kornprobst, J., Piboule, M., Roden, M. & Tabit, A. (1990). Corundum-bearing garnet clinopyroxenites at Beni-Bousera (Morocco) - original plagioclase-rich gabbros recrystallized at depth within the mantle. Journal of Petrology **31**, 717-745.*

*Pearson, D. G., Davies, G. R., Nixon, P. H. & Milledge, H. J. (1989). Graphitized diamonds from a peridotite massif in Morocco and implications for anomalous diamond ocurrences. Nature **338**, 60-62.*

*Pearson, D. G. & Nowell, G. M. (2004). Re-Os and Lu-Hf isotope constraints on the origin and age of pyroxenites from the Beni Bousera peridotite massif implications for mixed peridotite-pyroxenite mantle sources. Journal of Petrology **45**, 439-455.*

190Pt-186Os versus 187Re-187Os: A single-grain to whole-rock scale study of >3.8 Ga peridotites and chromitites from Earth's oldest layered intrusion

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The 187Re-187Os isotope system is used as both a tracer and chronometer, and is particularly useful for dating ultramafic samples, to which lithophile element systems cannot be applied. However, we find that the Re-Os system is sensitive to disturbance during metamorphism of ultramafic rocks, whereas the (as yet less exploited) 190Pt-186Os system preserves exciting age information with implications for the timing of the "late veneer bombardment" and crustal growth during the Hadean.

We present evidence from whole-rock peridotites and chromitites from a highly deformed fragment (~100 × 800 m) of a layered intrusion at Ujaragssuit nunât, SW Greenland, combined with the first ever single-grain chromite Re-Os isotope analyses. These data demonstrate disturbance of both Re and 187Os, which we interpret to have occurred as a result of fluid movement during metamorphism up to amphibolite grade. Isotopic and elemental disturbance is more severe in silicate-rich, Os-poor samples compared to chromite- and Os-rich rocks. Rhenium-Os model ages and Re-depletion model ages are artificially young as a result of this disturbance. However, the Pt-Os systematics of the chromitites yield young (<3.8 Ga) model ages but also preserve a record Hadean mantle melting events in the most Os-rich chromitites, with Pt-Os model ages from ~3.9 to >4.3 Ga. Different aliquots of one whole-rock sample can yield either unradiogenic 186Os/188Os ratios or disturbed, radiogenic values.

This suggests that while the Pt-Os system is certainly more robust during metamorphism than the Re-Os system, its daughter isotope is also more heterogeneously distributed within these samples, likely reflecting the existence of at least two populations of Pt-Os host-phases. We show that Hadean mantle melting events have been recorded by one of these populations of robust, Os-bearing phases and preserved despite intense deformation and metasomatism of their host rocks. This is the first study investigating Earth's Hadean history from a mantle perspective. We find that our Hadean Pt-Os model ages are coincident with peaks in the crustal zircon record, indicating a coupled relationship between large mantle melting events and crustal growth in the Hadean. Our data also support the existence of an Os-rich mantle by 4.1 Ga or earlier, requiring that the "late veneer bombardment" occurred at least 0.2 billion years earlier than previously proposed.

Ultra-depleted, ultra-deformed peridotite emplaced onto the New Zealand Gondwana margin

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The Anita Ultramafics in the mountains of western New Zealand represent a several km wide, tectonically emplaced slice of ultra-depleted lithospheric mantle. The rocks are dominantly spinel facies harzburgites and dunites. Olivine Mg# of ~ 93, spinel ~Cr#70 and low orthopyroxene Al2O3 attest to extreme melt depletion, probably during hydrous melting conditions. Proterozoic Re-depletion ages indicate melt extraction occurred well before any adjacent continental crust formed.

The peridotites preserve evidence for multiple episodes of deformation and metasomatism, both at mantle conditions and during their exhumation and emplacement into the crust. Mantle metasomatism included growth of amphibole, phlogopite and tremolite. Trace element compositions of the amphiboles indicate that the metasomatising agent was enriched in LREE, K, Ti, with the most likely candidate being a low-degree silicate melt. The variety of trace element patterns attest to several occurrences of metasomatism, including at least one at shallow mantle or crustal levels as indicated by a strong negative Eu anomaly.

After accretion the peridotites have been very highly sheared. Deformation took place in the crust, but at the equivalent pressures to the spinel facies. The fine grainsize in monomineralic olivine assemblages implies that the rocks cooled rapidly before grain growth could occur, possibly during exhumation. EBSD analysis indicates that the prominent mechanism of recrystallisation was subgrain rotation and that much of the deformation was accommodated by grain size sensitive creep.

The redox state of iron in serpentine from Western Alps ophiolites

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Serpentinites may be present in more than 40% of the oceanic lithosphere that formed at slow to ultra-slow spreading centers. Serpentine could thus be one of the most abundant hydrated minerals recycled into the mantle in subduction zones. Prograde metamorphism in subducted serpentinites is characterized by the destabilization of lizardite into antigorite, and then into secondary olivine. The nature of the released fluid (e.g. H_2O vs H_2) during those phase transitions is controlled by redox reactions and can be inferred from Fe oxidation state of serpentine. To investigate the evolution of serpentinites and serpentine Fe redox state during their formation at mid-ocean ridges and along their way down to dehydration in subduction zones, we studied serpentinites from oceanic settings and from different alpine ophiolites that record various metamorphic grades. We then used whole rock analyses, magnetic measurements, SEM observations and µXANES to establish the evolution of Fe_{total} and magnetite content in serpentinite as well as Fe speciation in serpentine minerals.

At the mid-ocean ridge, during the alteration of peridotite into serpentinite, the iron is mostly redistributed between magnetite and oceanic serpentine (usually lizardite). The Fe3+/Fetotal ratio in lizardite and the modal magnetite progressively increase with the local serpentinization degree to reach 0.8 and 7 wt% respectively in fully serpentinized peridotites.

During subduction, the Fe_{total} of serpentinite remains constant (=7-10 wt.%, depending on the primary mode of the peridotite) while the magnetite mode decreases from greenschist to eclogite facies to reach less than 2% under the eclogite facies. Also, the Fe3+/Fetotal ratio in serpentine progressively decreases down to 0.4 during the transition from lizardite to antigorite.

Our results show that, in the first 70 km of subduction, the transition from lizardite to antigorite is accompanied by a global reduction of Fe in serpentinite and in serpentine. This redox reaction allows the oxidation of reduced oceanic phases such as sulfurs, and the formation of oxidized fluid. At greater depths, the beginning of antigorite dehydration leads to an increase of Fe^{3+}/Fe_{total} in the remaining antigorite suggesting in agreement with the preferential partitioning of ferric iron into serpentine rather then into olivine.

Distribution of Hydrogen in the Mantle Lithosphere

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Most of the mantle minerals are nominally anhydrous minerals (NAMs), and may contain hundreds of parts per million of hydrogen (H) atoms. The NAMs hence represent an important potential deep reservoir of H and as such, an important portion of the deep water cycle. In order to size this reservoir, the maximum amount of H which can be hold by NAMs needs to be assessed with precision and was effectively quantified by experimental mineralogy and petrology. In parallel to experimental studies, the H concentrations and distribution of natural specimens must be measured to better constrain the real quantity of H stored in the NAMs of the mantle lithosphere. These data are essential to decipher the nature of interactions at depth (e.g., metasomatism) and exchange with the Earth's exosphere, including the mechanisms of magma degassing, whether past or present.

We report a compilation of H concentrations in upper mantle minerals from xenoliths of peridotites (olivine, pyroxenes and garnet) transported by different types of lavas from various geological settings (cratons, hot and cold subduction zones, oceanic plateau). Quantification based on unpolarized FTIR analyses show that H concentrations in olivine, orthopyroxene, and diopside are not systematically function of the geological setting. Xenolith minerals related to subduction zones (Kamchatka, Papua New Guinea, Japan) are not particularly enriched in H. The concentration of hydrogen within individual olivine and pyroxene grains is most of the time homogeneous, indicating that evidence of diffusive dehydration 'caught-in-the-act' remains scare. The concentration of H in olivine tends to increase weakly with depth, consistent with the increase of water solubility with increasing water fugacity and pressure, but concentrations remain well below H saturation values determined experimentally in simple system, notably CO2-free. The highest concentration of H in olivine (>200 ppm wt H2O) is, however, found in garnet-bearing peridotites transported in kimberlites, but refractory spinel-bearing harzburgites can also have abnormal high H concentrations relative to their genesis. Mechanisms of dehydration and/or preservation of high H concentrations in NAMs will be discussed.

Water content and hydrogen behaviour during metasomatism in the uppermost mantle beneath Ray Pic volcano (Massif Central, France)

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From experimental studies, we know that a significant part of the Earth's water can be stored as hydrogen (H) dissolved in point defects in the nominally anhydrous minerals (NAMs) of the Earth's mantle. These NAMs (e.g. olivine, ortho- and clinopyroxene and garnet) can contain up to hundreds of parts per million hydrogen atoms, and thus represent an important deep water reservoir and a key component of its cycle. In addition, the presence of H in NAMs significantly affects many physical and chemical properties of mantle minerals. In order to understand this reservoir and its properties, water content must be quantified as well as the H behaviour during mantle key processes such as melting and metasomatism.

Nine xenoliths of spinel peridotite from the Ray Pic locality, in the southern part of the French Massif Central (France) have been characterised by petrological and geochemical analyses. Major, minor and trace elements compositions including water contents were obtained by electron microprobe, laser ablation-ICPMS and FTIR, respectively. The sample suite investigated here is composed of 8 lherzolites and 1 harzburgite ($3 < \text{cpx} < 1\ 3$ %; $1.54 \leq Al_2O_{3\,WR} \leq 3.84$ wt%; $89.7 \leq \text{Fo} \leq 91.1$%) equilibrated mostly at relatively low temperatures ($700 < T \leq 1000$ºC, using Ca-in pyroxenes, [1]). All samples show recrystallized microstructures varying between porphyroclastic, coarse granular and equigranular. Bulk major element compositions, modal abundances, mineral compositions and equilibrium temperatures are typical of the cold-uppermost part of the 'fertile' mantle lithosphere beneath the Ray-Pic area [2] [3]. However, contrary to previous studies, 6 xenoliths out of 9 show pargasite, with modal abundances varying from 0.2 up to 8.2%.

Abundances of the heavy rare earth elements (H-REE) in cpx confirm the overall fertility of the Ray Pic sample suites ($(Yb)_N = 8.6 \pm 1.8$; N, chondrite CI1 normalised). Cpx's normalised REE patterns show a continuum between light REE depleted ($(La/Sm)_N \approx 0.3$) to L-REE enriched patterns ($(La/Sm)_N \approx 16$) and a relatively flat M-REE to H-REE segments ($(Sm/Yb)_N = 0.91 \pm 0.26$). L-REE enriched patterns show also U and Th enrichments but HFSE negative anomalies. Such range of trace element patterns is usually ascribed to the percolation of volatile-rich small volume melts within the cold sub-continental lithosphere [4] [5] [3].

H_2O contents for the nominally anhydrous mineral (NAMs: ol, opx, cpx) are within the common range of other spinel peridotites; with the highest hydrogen concentration in cpx and the lowest in olivine. No correlation between hydrogen concentrations and $(La/Sm)_{PM}$ was observed. Therefore despite large L-REE enrichment, water contents of the NAMs (including cpx) do not seems to be controlled by this type of metasomatism. Further, there is no correlation between H_2O content in NAMs and the occurrence and/or abundance of amphibole. However, broad correlations between water content in minerals and $(Yb)_{PM}$ in clinopyroxene were found, suggesting that the variability of H_2O content in NAMs is primarily due to melt depletion. Implications for hydrogen behaviour and water contents during key mantle processes such as metasomatism and melting will be further discussed.

1. Brey, G.P., Kohler, T., 1990. J. Pet., 31(6): 1353-1378.
2 Lenoir, X., Garrido, C.J., Bodinier, J.-L., Dautria, J.-M., 2000. EPSL, 181(3): 359-375.
3 Zangana, N.A., Downes, H., Thirlwall, M.F., Hegner, E., 1997. CMP, 127: 187-203.
4 Bedini, R.M., Bodinier, J.-L., Dautria, J.-M., Morten, L., 1997. EPSL, 153(1-2): 67-83.
5 Navon, O., Stopler, E., 1987. J. Geol., 95: 285-307 .

The SW Indian Ridge - remelting the Gondwanan mantle

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The Southwest Indian Ridge is an ultraslow spreading ridge (~14-mm/yr) that formed ~150 Ma with the breakup of Gondwana. It extends 7700 km from the Bouvet to the Rodriguez Triple Junction, crossing over the flank of the large southern Geoid high centered over Marion and Crozet islands and the Conrad Rise. There is a fundamental break in the physiography and geochemistry of the SWIR where the SW Indian Ridge intersects the Nubia-Somalia plate boundary at the 750-km long Andrew Bain FZ on the flank of the Marion Rise. To the west, the ridge spreads largely orthogonal to the spreading direction and is locally influenced by the Bouvet Mantle Plume, which is centered on the ridge axis at Speiss Ridge, just east of Bouvet Triple Junction. To the east of the Andrew Bain FZ is the 3400-km long Marion Rise, which is associated with the Marion Hotspot some 260 km to the south. Unlike the western SWIR, the eastern two thirds of the ridge is oriented at an extreme highly oblique angle to the spreading direction, and contains many oblique amagmatic ridge segments. Mantle peridotites are exposed on the seafloor over its entire length, and it is evident that the crust is thin and discontinuous over the Marion Rise. The thin crust, refractory basalt and mantle peridotites there show that the rise is supported by a large block of depleted mantle that is the residue of a prior mantle melting event associated with the Karoo large igneous province, or an even earlier event in Earth history. The Marion Rise is dominated by the Marion Platform, which consists of an 2000-km long section of the SWIR between the Andrew Bain and Gallieni transforms, which has an average ridged depth ~1000 m shoaler than that of the entire 2000-km length of the western Southwest Indian Ridge. This argues for denser more fertile mantle beneath the western SWIR. These differences are matched by a clear difference in isotopic composition of the basalts, with 206Pb/204Pb greatly elevated along the western SWIR. Hence, there is a major difference in both major element and isotopic composition of the mantle sources, which reflect the respective isotopic compositions of the two hotspots. It is clear however, that the Marion Hotspot is too small to support the Marion Rise, while the bathymetric anomaly along the western SWIR associated with the Bouvet Hotspot is restricted to a ~500 km region in the immediate vicinity of this ridge centered hotspot. So it is apparent that both the Bouvet and Marion Hotspots are reflecting the regional compositions of the respective underlying mantle sources, rather than producing them. This then reflects a fundamental difference in the mantle from beneath Gondwana. A likely possibility is that the asthenosphere beneath the western SWIR represents mantle emplaced into that region during the Karoo Magmatic event, while that beneath the Marion Platform represented metasomatized cratonic lithosphere that delaminated during breakup of Gondwana and due to its inherent buoyancy, now forms the mantle substrate of the SWIR along the central SW Indian Ridge.

Subduction Initiation Record (SIR) in Suprasubduction Zone Ophiolites

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The internal structure-stratigraphy and geochemical characteristics of suprasubduction zone (SSZ) ophiolites in different orogenic belts indicate a seafloor spreading origin in forearc-incipient arc settings during the initial stages of subduction. In general, there is a well-developed magmatic stratigraphy in the extrusive sequences of these ophiolites from older MORB-like lavas at the bottom towards younger island arc tholeiite (IAT) and boninitic lavas in the upper parts. A similar progression of the lava chemistry also occurs in crosscutting dike swarms and sheeted dikes, indicating increased subduction influence in the evolution of ophiolitic magmas through time. Lherzolitic peridotites in structurally lower parts of the upper mantle sequences of these ophiolites represent the residue after MORB melt extraction. Harzburgite and harzburgite-dunite associations higher up in the mantle sequences and below the mafic-ultramafic cumulates (transitional Moho) are crosscut by networks of orthopyroxenite (opxt) veins, which include hydrous minerals (amphibole). These orthopyroxenite veins represent a reaction product between the host harzburgite (depleted, residual peridotite) and the migrating Si-rich (boninitic) melt. The harzburgite-dunite-opxt suites characterize melt-residue relationships and melt migration patterns in the mantle wedge during the initial stages of subduction and incipient arc construction. Thus, most SSZ ophiolites display a lateral and vertical progression of melt evolution in their crustal and upper mantle components that traces different stages of subduction initiation-related magmatism, reminiscent of the forearc magmatism in some of the modern arc-trench rollback systems as in the Izu-Bonin-Mariana and Tonga-Kermadec subduction factories. The along-strike continuity for more than 1500 km of this well-documented chemostratigraphy and geochemical progression in different ophiolite belts is strong evidence for spontaneous subduction initiation followed by rapid slab rollback in ancient ocean basins. I will discuss the global SSZ ophiolite record in light of our new ophiolite classification and evaluate the secular trends in SSZ ophiolite evolution in Earth history through time.

Textures of sub-continental mantle peridotite rocks revisited

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Textures in mantle peridotite rocks have been the subject of detailed qualitative description and interpretation. Qualitative assessment is, however, subjective and in practice there is little agreement between workers of the terms to be applied. To provide an observer-independent quantitative method of description of grain-size texture, as seen in thin-section, a method has been established using optical scanning, skeletonisation and computerised measurement of individual grain-section areas. This has been applied to 92 spinel peridotite xenoliths from intraplate continental volcanic regions, 11 kimberlite-hosted garnet peridotite and spinel peridotite xenoliths, 5 tectonically emplaced massifs and 7 ultramafic ureilite meteorites. For some of the samples, multiple thin-sections had been prepared so that variability within these samples could be explored.

All the samples, from the finest to the coarsest grained, show a linear relationship of the arithmetic mean grain size against the standard deviation. This suggests that peridotite textures form a continuous series rather than discrete groups, as implied by qualitative assessment. The marked positive skewness of the distributions is consistent with log-normal or power-law functions with fractal characteristics, suggesting that textural development is the result of processes dependent on the “Law of Proportionate Effect”.

The mineral skeleton outlines have non-convex features, so that classical assumption-based stereological interpretation of their three-dimensional shape is not admissible. Three dimensional visualisation using X-ray C-T techniques, together with SEM images of mineral components isolated by Electric Discharge Disaggregation, suggests that some of what is seen in thin-sections results from a random sectioning plane passing through involuted mineral grains.

A possible difference in cooling rates recorded in REE in coexisting pyroxenes in peridotites from ophiolites and mid-ocean ridges

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Mantle peridotites from ophiolites are commonly interpreted as having mid-ocean ridge (MOR), supra-subduction zone (SSZ), or subcratonic (SC) affinity. Recently, a REE-in-two-pyroxene thermometer was developed (Liang et al., 2013) that has the potential to extract meaningful near-solidus temperatures and cooling rates from ophiolitic peridotites and thus shed new light on the thermal history of the different tectonic regimes. We calculated REE temperatures for available literature data from ophiolites around the world (Alps, Coast Range, Corsica, Lherz, Oman, Othris, New Caledonia, and Turkey), and augmented the data with new measurements for peridotites from the Trinity and Josephine ophiolites and the Mariana trench. On average, SC ophiolites have lower temperatures (804±69°C) than ophiolites with SSZ (1145±76°C) or MOR (1172±89°C) affinity. Abyssal peridotites from slow spreading centers appear to cool more slowly than peridotites from ophiolites, suggesting ophiolites evolve at faster spreading ridges or in distinct tectonic environments.

Liang et al. (2013) A REE-in-two-pyroxene thermometer for mafic and ultramafic rocks. Geochimica et Cosmochimica Acta 102, 246-260

Decoupling among trace elements and Ni during melt percolation and melt-rock reaction in the mantle: An example from a dunite-harzburgite-lherzolite sequence from Trinity Ophiolite

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Trace elements were measured in clinopyroxene (cpx) across an ~20m long dunite-harzburgite-lherzolite-plagioclase lherzolite (DHL-PL) transect at the Trinity Ophiolite. Rare earth element (REE), high field strength element, and transition metal concentrations in dunite, harzburgite, and lherzolite are much lower than in lherzolite and plagioclase lherzolite. The transition from lower to higher concentrations occurs over a narrow interval 7.5-9.5m from the dunite-harzburgite contact. Pyroxene in the dunite, harzburgite, and lherzolite are in equilibrium with melts with REE patterns similar to depleted mid-ocean ridge basalt. Pyroxene in the lherzolite and plagioclase lherzolite are highly light rare earth element depleted but middle and heavy rare earth element enriched, similar to other plagioclase lherzolites. A gradient in NiO in olivine was previously observed at this transect by Morgan et al. (2008), who argued it originated by flow of dunite hosted melt into the surrounding peridotite. Unlike trace elements, NiO increases from lower to higher abundances ~3.5m from the dunite-harzburgite contact. The new data is consistent with the hypothesis of Morgan et al. (2008) and demonstrates decoupling between incompatible trace elements and Ni as melt flowed from dunite into host peridotite. Due to its high bulk partition coefficient and relatively fast diffusivity in peridotite Ni transport was chromatographically retarded. Incompatible trace elements, which are not fractionated from one another, likely experienced disequilibrium transport owing to their sluggish diffusivity in peridotite. They may increase from low to high concentrations at a former clinopyroxene saturation front. This locality demonstrates that in some cases tabular dunites are sources for melt impregnation and can play an important role in geochemical cycling.

*Morgan, Z., Liang, Y., Kelemen, P. (2008) Significance of the concentration gradients associated with dunite bodies in the Josephine and Trinity ophiolites. G^3 **9**(7), doi:10.1029/2008GC001954.*

Tectonic evolution of Neoproterozoic ophiolites of the Central Eastern Desert of Egypt from MORB to SSZ tectonic setting

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Numerous ophiolite occurrences are reported in central eastern desert of Egypt. Based on geological setting and mode of occurrences, ophiolites occur as intact ophiolite succession, exotic masses, blocks and fragments in mélange matrix and dismembered slices and sheets along inherent planes of weakness essentially within host rocks other than mélanges. Some ophiolitic rocks are closely associated with arc volcanic and not included in mélanges. Ophiolitic rocks include serpentinized peridotite and metamorphosed ultramafics, metagabbros, pillowed and massive metabasalts and sheeted dykes. They are covered by pelagic sedimentary rocks of red shale, cherts, and tuffaceous sediments.

Most of the serpentinites and metamorphosed ultramafic ophiolite blocks within the melange, display mainly supra-subduction zone (SSZ) tectonic setting but still other minor blocks show MORB tectonic setting. There are two groups of ophiolitic metagabbros, a high-Ti, high- Zr group and appears to posses N-MORB features and a low-Ti, Low Zr group displays arc-like features which may suggest a supra-subduction zone setting (SSZ). The basaltic rocks at the top of intact ophiolites and the blocks of metabasalts within the mélange matrix apparently displaying N-MORB affinity and are closely comparable to MORB or back-arc basin basalt (BABB) ophiolites. The gabbroic and basaltic rocks, which are associated with arc volcanics and boninites, have arc affinity and display SSZ tectonic setting.

The rocks of the ophiolites have undergone two main phases of deformation and metamorphism: The first deformation phase (D1) was manifested in imbricate thrusting (T1) and folding (F1), cleavage formation (S1), stretched lineation (L1), shearing and stratal disruption was related to the tectonic emplacement of the ophiolites. During D2 the rocks are later disrupted and tectonically emplaced along low angle thrust faults (T2) and strike-slip shear zones. There are features indicative of two phases of metamorphism; ocean-floor event and regional metamorphism.

Ophiolites of the central eastern desert fall into two groups, MORB or BABB and SSZ ophiolites, which are spatially and temporally unrelated and thus it seems likely that the two types are not petrogenetically related. Ophiolites underwent multiple phase of deformation and metamorphism, and successive tectonic emplacement as a consequence of a collisional events during back arc–arc-continent collision.

Regional variability of lithospheric mantle beneath the Middle Atlas (Morocco)

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The ‘tabular’ Middle Atlas, between Azrou and Timahdite, is an area where intra-plate Cenozoic volcanism coincides with nearly 2000m uplifting of the undeformed Mesozoic cover and the maximum of lithospheric thinning beneath continental Morocco (Fullea *et al.*, 2010; Bezada *et al.*, 2014). This region also concentrates the principal mantle xenolith localities in Morocco (Moukadiri, 1983). It is therefore a key area to study the mechanisms of lithospheric thinning and constrain the component of mantle buoyancy that is required to explain the Moroccan reliefs (see references in Bezada *et al.*, 2014). Previous studies have focused on a single locality - the Bou Ibalghatene maar, in the central part of the volcanic district. There, the mantle xenoliths show extensive reactions with silicate and carbonate melts that led to the formation of a range of lithologies characterized by substantial olivine, clinopyroxene or amphibole enrichment, as well as incompatible trace element enrichment (Raffone *et al.*, 2009; Wittig *et al.*, 2010; Natali *et al.*, 2013). However, a survey of mantle xenoliths from nine localities distributed throughout the Azrou-Timahdite district indicates that the reaction and metasomatic imprints are less pronounced or virtually absent in the other suites. The Bou Ibalghatene suite could represent a restricted area of focused melt flow through the lithosphere. The present study focuses on mantle xenoliths from the Tafraout maar, located 45km to the North-East of Bou Ibalghatene and distal to the main volcanic district. The maar is situated on the NE-SW North Middle Atlas Fault, a major transpressive fault separating the ‘folded’ Middle Atlas, to the South-East, from the ‘tabular’ Middle Atlas, to the North-West. The samples have been investigated for their mineralogy, microstructures, crystallographic preferred orientation (EBSD-SEM), and bulk rock and mineral compositions (XRF, EPMA and LA-ICP-MS). They differ from the Bou Ibalghatene mantle xenoliths by the presence of fine grain samples (mylonites), the lack of hydrous metasomatic phases (amphibole and phlogopite), somewhat lower equilibrium temperatures, a higher fertility degree, and less enriched trace element compositions. Several samples show LREE-depleted clinopyroxene compositions that have not been observed at Bou Ibalghatene. These results indicate significant variations of the mechanisms and degree of lithosphere-asthenosphere interaction across the Azrou-Timahdite plateau. The Tafraout xenoliths may represent distal and attenuated effects of a mantle upwelling centered on the Bou Ibalghatene maar and bordered by the Middle Atlas Fault to the South-East. The Tafraout suite also records incipient stages of lithosphere-asthenosphere interaction that were erased by subsequent melt/fluid processes beneath Bou Ibalghatene.

Cited references:

Bezada, M. J., et al. (2014). Piecewise delamination of Moroccan lithosphere from beneath the Atlas mountains. ***G3****, doi:10.1002/2013GC005059.*

Fullea, J. M., et al. (2010) The structure and evolution of the lithosphere-asthenosphere boundary beneath the the Atantic-Mediterranean Transition Region. Lithos ***120****, 74-95, doi: 10.1016/j. lithos.2010.03.003.*

Moukadiri, A. (1983). Les enclaves ultrabasiques associées aux basaltes alcalins dans le district volcanique d’Azrou-Timahdit (Moyen Atlas, Maroc). Thèse 3ème cycle, Université Blaise-Pascal, Clermont-Ferrand, 150 pp.

Natali, C., et al. (2013). Carbonated alkali-silicate metasomatism in the North Africa lithosphere: Evidence from Middle Atlas spinel-lherzolites, Morocco. Journal of South American Earth Sciences ***41****,113-121.*

Raffone, N., et al. 2009. Metasomatism in the lithospheric mantle beneath Middle Atlas (Morocco) and the origin of Fe- and Mg-rich wehrlites. Journal of Petrology ***50****, 197-249.*

Wittig, N., et al. (2010). Tracing the metasomatic and magmatic evolution of continental mantle roots with Sr, Nd, Hf and Pb isotopes: a case study of Middle Atlas (Morocco) peridotite xenoliths. Geochim. Cosmochim. Acta ***74****, 1417-1435.*

The Beni Bousera Peridotite (Rif Belt, Morocco): an Oblique-slip Low-angle Shear Zone Thinning the Subcontinental Mantle Lithosphere

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Detailed structural and petrological mapping in the Beni Bousera peridotite (Rif Belt, northern Morocco) shows that this orogenic peridotite massif is composed of four tectono-metamorphic domains with consistent kinematics, marked by a pervasive, shallowly dipping foliation with a NW-SE stretching lineation that progressively rotates towards a NNE-SSW orientation in the lowermost part of the massif. From top to bottom, these domains are garnet-spinel mylonites, Ariegite subfacies fine-grained porphyroclastic spinel peridotites, Ariegite-Seiland subfacies porphyroclastic, and Seiland subfacies coarse-porphyroclastic to coarse-granular spinel peridotites. Microstructures and crystal preferred orientations point to deformation dominantly by dislocation creep in all domains, but the continuous increase in average olivine grain size indicates decreasing plastic work rates from top to bottom. This evolution in deformation conditions is consistent with the change in synkinematic pressure and temperature conditions, from 900°C at 2 GPa in garnet-spinel mylonites to 1150°C at 1.8 GPa in the Seiland domain. A pervasive diffuse dunitic-websteritic layering subparallel to the foliation suggests deformation in the presence of melt in the Seiland domain. Gravitational instabilities owing to local melt accumulation may account for ca. 200 m wide areas exhibiting a vertical lineation in this domain.To account for the consistent kinematics and the tectono-metamorphic evolution, which implies a temperature gradient of ca. 1258C km-1 preserved across the Beni Bousera massif, we propose that the entire massif records the functioning of a low-angle shear zone, a few kilometres wide, which accommodated exhumation of the base of the lithosphere from ca. 90 to ca. 60 km depth. Partial melting in the Seiland domain may be explained by fast decompression of the footwall, without the need for exotic heat sources. Moreover, if the present-day orientation of the shear zone is similar to that when it was active in the mantle, the stretching lineations at high angle to the metamorphic gradient imply that shearing parallel to the trend of the belt accompanied thinning; that is, a transtensional deformation of the margin.

Electrical Petrology of mantle melting: a methodology to reconcile the petrological and the geophysical asthenosphere

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The asthenosphere and the lithosphere are globally composed of similar minerals, but they have very different physical properties: The asthenosphere, in its upper part, shows slow S-wave velocities and high electrical conductivities, whereas the lithosphere is not conductive and shows high S-wave velocities. The asthenosphere is also considered as mechanically weak and chemically enriched compared to the lithosphere. Since we have no rock samples from the asthenosphere, only experimental petrology at high P and high T and geophysical observations can be used to reconstruct the nature of the asthenosphere. The aim of our work is to confront and reconcile the geophysical observations and the petrology of the asthenosphere.

Volatile enrichments in the asthenosphere have long been shown to trigger incipient melting, that is small degree of partial melting due to small amounts of CO2 and H2O. A link between incipient melting and seismic low velocity zone has also long been suggested, but it remains poorly documented how incipient melting can affect mantle conductivity.

Based on a large set of experimental data, we are developing models that describe (1) how incipient melting affect the P-T-chemical space of the asthenosphere and (2) how this can trigger electrical and possibly seismic discontinuities. This approach is then confronted to geophysical observations. We show that many geophysical discontinuities can be converted into petrological boundaries and used as geothermometers and sometimes oxybarometers. An application to the oceanic low velocity zone is proposed.

A combined basalt and peridotite perspective on multi-stage melt extraction at the 53° E amagmatic segment of the Southwest Indian Ridge

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The peridotite-basalt association at the 53°E amagmatic segment of the Southwest Indian Ridge, provides the opportunity for examining mantle melting and melt-extraction processes from both products and residues beneath ultra-slow spreading ridges. Most peridotites are highly depleted, clinopyroxene-poor, harzburgites extremely depleted in MREE and HREE. Partial melting models suggest that (1) some of the peridotites are residuals by 10 to 15% fractional melting in the spinel stability field; (2) the most depleted peridotites experienced 10% fractional melting in the garnet stability field, followed by an additional 18% fractional melting in the spinel stability field. This suggests that peridotites at the 53°E amagmatic segment are residues of multi-stage melt extraction in the mantle. All the samples, however, show whole-rock incompatible element abundances higher than expected, some with positive Ce and Eu anomalies. These features suggest the incompatible element enrichments are due to the contamination by cobalt-rich and/or manganese-rich crusts, and refertilization by basaltic melts and/or gabbros.

Compared with normal depleted N-MORB, 53°E amagmatic-segment basalts are enriched in Large Ion Lithophile Elements (e.g.: Rb, Ba, Sr, Th and Pb) and slightly depleted in High Field Strength Elements (e.g.: Nb, Ta, Zr, Hf and Ti). The REE patterns of the 53°E basalts show systematic changes, ranging from more depleted than N-MORB to slight enriched than N-MORB. Neither partial-melting models of the primary mantle nor the depleted mantle can reproduce their compositions, implying that mantle source heterogeneity can account for the variations of basalts compositions. The modelling results, basalts from the 53°E amagmatic segment match with the melts by 5 ~ 10 % partial melting from residual peridotites refertilized by 1 ~ 1.5 % basaltic-melt percolation. The decoupled compositions of basalts and peridotites suggest these basalts were extracted from depleted mantle that experienced prior melting event(s) and refertilizations.

Channeling of reactive porous flow in the subcontinental lithospheric mantle: lherzolite-harzburgite-dunite layered peridotite bodies of the Ronda massif (Betic Cordillera, S-Spain)

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The Ronda massif (S-Spain) is the largest (ca. 300km^2) of several orogenic peridotite massifs exposed in the Betic and Rif (northern Morocco) mountain belts in the westernmost part of the Alpine orogen that was tectonically emplaced during early Miocene times. One of the most remarkable features of the massif is the 'recrystallization front' that divides overlying spinel tectonite and underlying granular spinel peridotite domains, and that is interpreted as a narrow boundary of a partial melting domain formed by thinning and coeval asthenospheric upwelling at the expense of former subcontinental lithospheric mantle, associated to melting and kilometer-scale migration of melts by diffuse porous flow. Detailed mapping revealed the existence of bands and elongated bodies of a few meters to ten meters thick, composed of coarse-grained olivine-rich lherzolite, harzburgite and dunite embedded in porphyroclastic plagioclase lherzolite underneath the recrystallization front, at the transition from granular spinel peridotite to underlying plagioclase tectonite domain. Dunites occur at the center of the layers rimmed by progressively less refractory peridotites towards plagioclase lherzolite. Our petrologic and geochemical study shows that the refractory peridotites were formed by reactive porous flow rather than by partial melting and melt extraction as indicated by high Cpx/Opx ratio, low Mg# and Cr abundance as well as overall enrichment in highly incompatible elements (LREE, Th, U, Nb, Ta and Sr) relative to the less compatible ones (HREE, Zr, Hf and Ti).

The zoned bodies of refractory peridotites are considered to record progressive channeling of porous melt flow occurred during thermal relaxation of the Ronda lithospheric mantle after a major event of thermo-mechanical erosion by upwelling asthenosphere. During this event, the peridotites were heated up close to the potential temperature of the adiabatic mantle (thermal erosion) and were pervasively infiltrated by melts (chemical erosion). During thermal relaxation, the interstitial melt reacted with the peridotites at a temperature range of 1060-1160 °C. Our geochemical modeling shows that at short distance from the reaction front secondary olivine formed at increasing melt mass, and then secondary clinopyroxene crystallized at decreasing melt mass. At this stage the recrystallization front acted as a permeability barrier where melts were progressively channeled along dunite, in the middle of layered peridotites.

Pristine melts from lithosphere-asthenosphere boundary preserved within sheared peridotite xenoliths from kimberlites

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Kimberlites are very rare and exotic rocks among terrestrial magmas, but important to scientific and exploration communities because they provide critical information regarding the deep Earth and serve as the principal diamond source. Kimberlite melts are derived from the depths 200-650 km (Mitchell, 2008) and sample variable mantle rocks from different levels up to ~ 230-240 км. Despite of numerous publication devoted to kimberlites the composition of the kimberlite primary/parental melt remains under debate. The primary ideas of this study were to found of relics of most primitive melts, generated at least at lithosphere-asthenosphere boundary of ancient craton or even deeper, and estimates of their chemical compositions. The study of melt inclusions in rock-forming minerals from the deepest mantle xenoliths from kimberlites provide unique opportunity for direct solving of the problem. The minerals of sheared peridotite xenoliths in kimberlites are among the deepest mantle samples. We attempted a search for the deepest mantle melts using samples of fresh sheared garnet peridotite xenoliths from unaltered kimberlites the east body of the Udachnaya pipe. Amazing secondary melt inclusions, representing of "snapshots" of pristine kimberlite liquids from near the lithosphere-asthenosphere boundary, were found in rock-forming olivine from the sheared peridotite xenoliths. Alkali-carbonate secondary melt inclusions consist of mainly of Na-Ca, Na-Mg and Ca carbonates, alkali sulphates and chlorides (not less than 81 vol. %, (Na+K)/Ca ~1.7, Cl > 5 wt. %, S > 2.5 wt. %). Studies of unaltered kimberlites from the Udachnaya-East pipe, one of the largest diamond deposits on the Siberian craton and in the world, have lead to the conclusion that at least some primitive kimberlite liquids are alkali-carbonate and not ultrabasic in composition. Here we present first direct evidence of alkaline-carbonatite nature of kimberlite melts, supporting early proposed model, as well as chemical characteristics of these liquids and their relations with diamond formation and metasomatism in the Earth's mantle.

Transition-Zone mineral assemblages in peridotite massifs, Tibet: Implications for collision-zone dynamics and orogenic peridotites

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Diamonds have been reported from Tibetan "ophiolites" for ≥30 years, but have been widely dismissed as contaminants, because their unusual morphology and light C ($d^{13}C$=-18 to -27) are unlike those of kimberlitic diamonds. However, the diamonds have now been found *in situ* in the chromitites and peridotites of "ophiolites" along the Yarlung-Zangbo suture (Tibet) and the Polar Urals [5]. These massifs are dominated by depleted spinel harzburgite; some yield whole-rock Re-Os T_{RD} ages back to 3.4 Ga [2], suggesting ancient SCLM.

LA-ICPMS analyses of the diamonds show LREE-enriched trace-element patterns parallel to those of kimberlitic fibrous diamonds; the "ophiolitic" diamonds thus appear to be natural. However, the Tibetan diamonds also have: negative anomalies in Sr, Sm, Eu, Yb; very low Fe; high Ta and inclusions of $Ni_{70}Mn_{20}Co_5$ alloy. The diamonds are accompanied by a range of alloys, native metals, carbides and silicides, implying fO_2 down to IW -8. High-Si rutile and coesite after stishovite suggest P ≥10 GPa. Exsolution of coesite, diopside and enstatite from chromite implies the former existence of the CF ($CaFe_2O_4$) structure, stable at P≥12.5 GPa (380 km) [4]. The highly-reduced assemblage and the diamonds appear to reflect interaction of the peridotites and chromitites with low-fO_2 fluids in the upper part of the Transition Zone (TZ).

The presence of these super-reducing ultra-high pressure (SuR-UHP) assemblages in "orogenic peridotites" raises many questions. Some have suggested that the chromitites crystallised in the TZ, and rose to be emplaced in suboceanic mantle. However, the trace-element signatures of the chromites are indistinguishable from those of typical ophiolitic chromitites, and imply primary crystallisation at shallow depths. *In situ* analyses of Ru-Os-Ir sulfides give TRD=290-630Ma, peaking at 325Ma. Euhedral zircons separated from the chromitites give U-Pb ages of 376±7Ma, and εHf= 9.7±4.6 (TDM ca 2 Ga), suggesting some crustal input. However, TRD model ages of Os-Ir nuggets in the chromitites are much younger: 234±3 Ma [1]. We interpret the sulfide+zircon ages as dating the shallow formation of the chromitites, while the Os-Ir model ages record the timing of intense reduction and chromite recrystallisation in the TZ following deep subduction. Dynamic modeling suggests that the rise of the peridotites from the TZ to the crust during the Early Tertiary/Late Cretaceous was rapid (ca 6 Ma), driven by the rollback of the Indian slab after it had stalled in the TZ.

Mantle samples from the TZ thus may be present in other collision zones; how should we recognize them? One striking feature is the *absence* of eclogites or similar UHP crustal rocks in or around the peridotite massifs, or along the 3000 km of the Yarlung-Zangbo suture. If these massifs represent oceanic mantle, or ancient SCLM that became seafloor as in Liguria [3], their deep subduction was driven at least in part by the negative buoyancy of an eclogitic crust. If that detached from the slab near the TZ, it would sink deeper into the mantle, while the buoyant harzburgites would try to rise. These SuR-UHP massifs carry unique information on the tectonics of collision zones, and the physical and chemical makeup of the TZ and may be widespread, indicating an important global and repeating geodynamic process.

[1] Shi, R., et al. (2007) Earth Planetary Sci. Lett. 261, 33–48; [2] Shi, R. et al. (2012) Geol. Rev. 58, 649-652; [3]Rampone et al. (2005). J. Petrology 46, 799-827; [4] Yamamoto, S. et al. (2009). Lithos 109, 314-322; [5] Yang, J.S. et al. (2014). Nature Communications (subm.).

Determination of the boron concentration and isotopic composition of the subcontinental lithospheric mantle by secondary ion mass spectrometry

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Boron concentrations and isotopic compositions (δ11B) of phlogopite mica, amphibole, and clinopyroxene were determined by SIMS in mantle xenolith samples from south Africa to gain a better understanding of the volatile element transfer processes in the mantle. The diversity of the samples derived from the SCLM of the Kaapvaal Craton reflects a complex history including partial melting, and metasomatism related to group I and II kimberlite emplacement and subduction processes. Micas and amphiboles from MARID xenoliths, sub-calcic clinopyroxene megacrysts and clinopyroxene-rich peridotite have δ11B of ~−10‰, indistinguishable from primitive mantle estimates. Micas, not reflecting canonical mantle δ11B values, fell into two broad categories, either with light signatures (−20‰ to −30‰) and often low B contents (a few ppb to 100's ppb) or heavy signatures (~−5 to +15‰) and relatively B-rich and heterogeneous. Light signatures we associate with subduction-related metasomatism. Increasing modal metasomatism intensity from garnet harzburgites to mica-rich websteritic garnet lherzolites show a broad positive correlation of B and δ11B, where garnet harzburgites represented the most B-depleted samples. The mica samples exhibiting secondary textures and serpentinization have heavy δ11B values, interpreted as fluid processes associated with kimberlite emplacement and/or near-surface fluid alteration. The current dataset shows that boron isotopes are a useful tracer of fluids in the mantle and can contribute to the understanding of global geochemical cycles.

Petrogenetic significance of anorthite as inclusions in spinel of the Purang ophiolite (southwestern Tibetan plateau)

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The Purang ophiolite located in the western part of the Yarlung Zangbo suture zone in Tibet where it is in fault contact the surrounding Cretaceous sedimentary and volcanic rocks. It crops out over an area of ca. 600 km2, and is composed chiefly of depleted mantle peridotite, with lesser amounts of gabbro and basalt. The mantle peridotites consist mainly of harzburgite, lherzolite and dunite, probably of MOR type, that were modified in a SSZ environment. Microscope study on the harzburgites revealed common inclusions of anorthite in the spinel. The inclusions range from about 10-80 microns and are vermicular to subhedral in shape.

The anorthite inclusions are unzoned with An values >95, indicating rapid cooling at low pressure. The anorthite inclusions have relatively contents of Cr_2O_3 (0.28 wt. %~0.79 wt. %, average 0.48 wt. %), whereas the host grains have low Cr# (Cr/Cr+Al, 0.34~0.46) and contain much lower TiO_2 (~0.16 wt. %) than spinels in typical abyssal peridotites. We inferred that both anorthite and spinel crystallized at the same time. The anorthite inclusions are thought to have formed at high temperature in a closed system when basalt melt, which produced by decompressional melting of ascending mantle peridotite, intruded into shallow harzburgite. Under such conditions, spinel containing inclusions of Cpx and Opx can be partially melted to produce olivine and plagioclase according to the reaction: Cpx + Opx + Spl = Pl + Ol. The new formed minerals, olivine and plagioclase, are still trapped in the residual spinel grains, and then form anorthite inclusions in spinel.

The formation of anorthite inclusions in spinel is consistent with decompression of high temperature peridotite. Because these unusual inclusions are only found in harzburgite associated with basalt, we infer that they reflect melt-rock reaction perhaps as the Purang peridotite rose to a shallow depth.

The Sulfide and Graphite Mineralization of the Ultramafic Massif of Beni Bousera (Internal Rif, Morocco)

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The ultramafic massif of the Beni Bousera (internal Rif) is portion of an old subcontinental lithospheric mantle that suffered partial melting, just before their tectonic emplacement probably during the Middle Miocene. This result is recrystallization of the rocks from spinel tectonite domain in the center to spinel/garnet mylonite domain in the massif's periphery. Peridotites are most common facies of Beni Bousera massif, and are associated with minor pyroxenite layered whose frequency increase from the center to the massif‘s periphery.

Fe-Ni-Cu Sulfide and graphite (S-G) occurrences in the Beni Bousera massif average a tectonic zone oriented ENE -WSW dipping 60-80° to the NW. They present different morphology; veins, stoskworks, lens or heaps, are very commons and they crosscut foliation of hosted peridotites. The thickness of the mineralized structures varies from a few centimeters to 10 m, with an extension of 30 to 40 m.

The S-G ores are mainly composed by sulphides (pyrrhotite, pentlandite, and chalcopyrite) with low arsenides (maucherite, nickeline) and sulfarsenides (cobaltite) ± chromite ± graphite. This primary assemblage is associated with silicate gangue as phlogopite, pyroxene, and quartz from high pressures ± plagioclase.

The magmatic sulfide and graphite mineralization are formed from hybrid melt resulting from mixing between cool hydrous siliceous magma, rising from subducted oceanic crust, and the hotter overlying mantle peridotite. This melt is richer, than primitive mantle, with chalcophile elements, precious metals (PGE and Au), and volatiles (CO2 and H2O). It produced a series of discrete masses composed largely of phlogopite, orthopyroxene, and clinopyroxene, and quartz in the lowest part of the masses. Early separation of immiscible arsenide melt and sulfide melt causes enrichment in PGE in arsenide melt. Those melts are generated from the fractionation of some small fragments of oceanic crust, as confirmed by the carbon isotopic and REE data.

A post tectonic hydrothermal alteration in the Beni Bousera massif, product in S-G ores a secondary assemblage constitute by chlorite, amphibole, after silicate gangue; and magnetite from chromites, following it we attend depletion PGE in ores.

Keywords: Beni Bousera, peridotites, hybrid melt, mineralization, sulfides, arsenides, PGE.

The interplay between deformation and microstructure in olivine-rich rocks

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Olivine is the dominant mineral in the upper mantle, and therefore, its material properties play an important role in large-scale geodynamic processes. Much work has been done to characterize the viscosity of olivine aggregates through laboratory-based experimentation, providing constraints on the viscous flow of the upper mantle. The constitutive models resulting from this work have been applied to numerous processes including mantle convection, postglacial rebound, shear-zone formation, the seismic cycle, and plate-boundary longevity. A potential cornerstone of many of these geodynamic processes is the feedback between microstructural evolution and viscosity, which allows heterogeneities in viscosity to develop. Here we describe a recent experimental campaign to quantify the relationships between viscosity and two key microstructural parameters, grain size and crystallographic fabric. We conducted experiments on olivine aggregates at high temperature (~1200 °C) and high confining pressure (300 MPa) in a gas-medium deformation apparatus. Samples with different mean grain sizes were deformed in compression, tension, or torsion to determine the sensitivity of viscosity to grain size. Based on the observed grain-size sensitivity, we have identified dislocation-accommodated grain-boundary sliding (disGBS) as a key mechanism in the deformation of olivine-rich rocks at both laboratory and upper-mantle conditions. We additionally performed experiments in which torsion and tension tests were conducted in series. The mechanical response of samples during these complicated strain paths demonstrates that the viscosity of olivine aggregates deforming by disGBS also depends on the strength and orientation of the olivine crystallographic fabric. We have quantified the viscous anisotropy that results from olivine fabric development, yielding a constitutive model that describes the interplay among grain size, crystallographic fabric, and viscosity. We compare our results to microstructures in shear zones in orogenic peridotites and to observations of seismic anisotropy in the oceanic upper mantle to demonstrate that our constitutive model is applicable to a wide range of geological conditions.

Ductile strain localization in the shallow subcontinental lithospheric mantle during the final exhumation of the Ronda massif (Betic Cordillera, S-Spain)

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The Ronda massif (S-Spain) is the largest (ca. 300km^2) of several orogenic peridotite massifs exposed in the Betic and Rif (northern Morocco) mountain belts in the westernmost part of the Alpine orogen that was tectonically emplaced during early Miocene times. Its latest evolutionary stages and mechanisms of exhumation and crustal emplacement are suggested to be controlled by km-scale folding and shearing along mylonitic-ultramylonitic shear zones at the base of the subcontinental lithospheric mantle section. Here we report a microstructural study of strain localization in mylonitic peridotite and pyroxenite shear zones that have been formed during the latest ductile history of the massif. The shear zones first occur as thin (<10 cm) and discontinuous bands at the base of the granular spinel peridotite domain, systematically located within thin pyroxenite layers, but they get progressively wider (up to 5-10 m width) downwards in the plagioclase tectonite domain where they propagate in peridotite. In either cases, strain localization is associated with a sudden decrease of grain size but in the pyroxenites with increasing volume fractions of plagioclase and amphibole too, as a result of a spinel to plagioclase phase transformation reaction during decompression. This reaction produced fine-grained olivine and plagioclase, allowing the onset of grain-size sensitive creep and further strain localization in these pyroxenite bands, however it resulted in a weak crystallographic preferred orientation (CPO) and a nearly random fabric of the shear zone. In contrast, the wide peridotite mylonite shear zone at the base of the mantle section records gradually increasing fabric strength from the plagioclase tectonite ground rock to the mylonite, accompanied to the progressive dominance of the unusual (001)[100] olivine slip system.

The strain localization in the pyroxenites is explained by their more fertile composition, which allowed earlier onset of the phase transformation reactions. Geothermobarometry undertaken on compositionally zoned constituent minerals of the pyroxenite suggests this positive feedback between reaction and deformation is associated with cooling from at least 1000 °C to 700 °C and decompression from 1.0 GPa to 0.5 GPa. In the peridotite mylonite shear zone we propose that the switch of dominant slip systems is the result of preferential reutilization of favorably oriented slip planes of earlier deformation events. Overprinting of pre-existing structures can be achieved by a rapid change in the kinematic regime, such as the back-arc basin inversion proposed to be responsible for large scale folding at the base of the Ronda mantle section.

Analysis of strain localization in the subcontinental lithospheric mantle under retrograde conditions on the example of the southern Lanzo shear zone (Alps, northern Italy)

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The Lanzo massif is a 150 km^2 body of relatively fresh plagioclase peridotite located in the Piedmont Alps. Although it has been subducted to eclogite facies before fast exhumation during the Alpine orogenesis, eclogitic metamorphic equilibration is restricted to the borders of the massif and most of the massif records lithospheric thinning associated with formation of Piemont-Ligure ocean. The massif is composed of three units (the northern, the central and the southern bodies) separated by two mylonite shear zones, several hundreds of meters wide. Here we present field observations and microstructural data for the shear zone that separates the southern and the central units of the Lanzo massif, which were interpreted as a high-temperature asthenospheric mantle diapir, which rose from the garnet stability field to shallow depths, being submitted to a large degree of melt extraction, and subcontinental mantle lithosphere fragment modified by reactive melt percolation, respectively. This shear zone is marked by a sharp reorientation of the N-trending, subvertical high-temperature peridotite foliation of plagioclase peridotite in the southern body towards a SE direction with a moderate dip to the NE. This reorientation is accompanied by development of mylonitic textures in the peridotites, marked by a decrease in grain size and development of orthopyroxene stretching lineations. The latest stages of deformation are characterized by development of antigorite in the foliation. Analysis of the microstructures and of the crystallographic preferred orientation of the constituent minerals in a detailed section across the shear zone, from the high-T peridotites to the low-T serpentine-bearing mylonites allows determining the active deformation mechanisms and the thermo-mechanical evolution of the shear zone. These data and the decreasing metamorphic grade of the shear zone rocks indicate ductile deformation and strain localization under retrograde conditions and in presence of fluids, with the final stages of deformation within the antigorite stability field.

The Role of the Mantle Lithosphere in the History and Dynamics of Central Mongolia

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Central Mongolia, an area near the middle of the Asian continent, is far removed from plate boundary processes yet in the Hangay Mountains shows elevations over 4 km with low-relief topography interpreted as an uplifted paleo-erosional surface. The Cenozoic uplift and faulting are accompanied by extensive basaltic volcanism. When and why these processes initiated or how they relate in space and time is poorly known. We use xenoliths in the volcanic rocks to place constraints on the thermal state and composition of the lithospheric mantle and its role in the lithospheric dynamics.

Ninety-seven spinel peridotite xenoliths were collected at four eruption centers in the Tariat region of the NE Hangay including 57 from a single eruption center (Shavaryn-Tsaram). The xenoliths were selected based on their homogeneity, large size (≥5-10 cm across) and minimal alteration without preferring any specific rock type. We believe that the collection is representative of the abundances of major rock types in their mantle source region as sampled by the host magma. All the samples were analyzed for major elements in bulk rocks and minerals and for trace elements in pyroxenes. The equilibration temperatures from two-pyroxene and Ca-olivine thermometry range from 850 to 1100°C, which corresponds to the depth range of 45 to 62 km by reference to the local geotherm established earlier from data on garnet-bearing xenoliths, i.e. between the crust-mantle boundary and the transition zone from spinel to garnet-bearing lherzolite facies (Ionov 2007, CMP).

In contrast to cratonic and many off-craton continental domains, mantle xenoliths from the Hangay region are dominantly fertile peridotites. More than half the peridotites have more than 3.5% Al_2O_3 and only four relatively small samples have Al_2O_3 contents of less than 2%; the median contents are 3.9% for Al_2O_3, 3.2% for CaO and 38.9% for MgO, with Mg# of 0.894. Some fertile xenoliths have major oxide compositions similar to estimates for asthenospheric mantle, the most fertile are close to primitive mantle estimates. Variations of major oxides and their ratios in bulk rocks and minerals for nearly all the samples are consistent with the origin by different, but generally low, degrees of melt extraction; their residual nature is also supported by LREE-depleted trace element patterns of the cpx and unradiogenic $^{87}Sr/^{86}Sr$ and radiogenic Nd and Hf isotopic compositions. Three lherzolites appear to have been enriched in pyroxenes by modal metasomatism (refertilization), one refractory peridotite is Fe-enriched. Overall, metasomatized rocks appear to be subordinate in the mantle beneath Hangay. There is no evidence for major compositional changes with depth.

The lithospheric mantle beneath Hangay can be ‘frozen’ asthenosphere; alternatively, the lithospheric accretion could be accompanied by minor melting, but the age and conditions of this event are not clear. The recent regional tectonic activity and uplift, and possibly the volcanism, may be related to the unusually fertile lithospheric mantle compositions. Cenozoic basalts from the region have zero or negative εNd and MORB-like He isotopic compositions (e.g. Barry et al., 2007, Lithos) not obviously consistent with a plume contribution to this activity, nor a source in a lithospheric mantle of similar composition to the xenoliths. Because the Hangay peridotite suite has experienced little melt extraction, it may be used to better constrain the composition of the convecting mantle and of primitive mantle models.

Osmium isotope heterogeneity in the Pacific uppermost mantle

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The 187Re-187Os decay system has long been recognised as having great advantage on determining the age of melt depletion of peridotites because ingrowth of radiogenic 187Os in residual peridotites are hampered by extraction of moderately incompatible 187Re associated with partial melting. This is well illustrated by the fact that old and highly depleted cratonic peridotites stored in Archean subcontinental lithospehere tend to show lower 187Os/188Os ratios than those of relatively fertile abyssal peridotites recovered from oceanic lithosphere, regarded as a representative sampling of modern convecting mantle (e.g. Pearson et al., 2007; Rudnick & Walker 2009). Recent accumulation of Os isotope data obtained either from abyssal peridotites (e.g., Harvey et al. 2006; Liu et al., 2008) or from ocean island peridotite xenoliths (e.g. Bizimis et al., 2007; Ishikawa et al., 2011) clearly demonstrated that the modern convecting mantle is substantially heterogeneous in Os-isotope composition. Unlike other radiogenic isotope heterogeneities observed in oceanic basalts, largely controlled by incorporation of recycled crustal materials, it seems likely that the observed range of Os-isotope compositions in oceanic peridotites directly reflect varying degrees of ancient melt extraction in peridotitic mantle. Hence global variations of Os-isotope compositions in oceanic peridotites may provide an important piece of information in unraveling geochemical/geodynamic evolution of the largest part of the Earth's interior, namely convecting mantle.

In this contribution, we focus on the Os-isotope variations in peridotite-serpentinite recovered from Pacific area because the number of data available is as yet scarce when compared with the data from other ocean (e.g. Atlantic and Indian Ocean). Our primary purpose is to test whether mantle domains underlying three major oceans are distinct in terms of Os isotope variations. For this purpose, we examined Os isotope variations in (1) harzburgite-serpentinite recovered from Hess Deep in East Pacific Rise (~0 Ma), (2) mantle section in Taitao ophiolite, Chile (~6 Ma; Schulte et al., 2009), (3) harzburgite-serpentinite bodies in Izu-Ogasawara and Tonga forearc (Parkinson et al., 1998), (4) peridotite xenoliths from Pali-Kaau vent in O'ahu island, Hawaii (~90 Ma; Bizimis et al. 2007), (5) low-temperature type peridotite xenoliths from Malaita, Solomon Islands (122-160 Ma; Ishikawa et al., 2011). The results demonstrated that samples from each area exhibit very similar Os-isotope variations with a pronounced mode in 187Os/188Os = 0.125-0.128. Moreover, relatively larger dataset obtained from (1) Hess Deep, (2) Taitao and (3) Malaita indicate the presence of secondary peak in187Os/188Os=0.117-0.119, similar to the global population mainly comprised of data from other ocean. These observations suggest that the small-scale heterogeneity is distributed homogeneously within the convecting mantle at large-scale, although the significance of unradiogenic secondary peak remains elusive (cf., Pearson et al., 2007; Bizimis et al., 2007; Simon et al., 2008; Ishikawa et al., 2011).

Microstructures, composition and seismic properties of the Ontong Java Plateau mantle root

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Plume-lithosphere interaction has been considered to play an important role on lithosphere evolution by the interplay between thermal erosion, partial melting, and melt-rock interaction. However, its consequences on the physico-chemical structure of the lithosphere are poorly understood. In order to characterize the physical properties of oceanic lithosphere atop a major partial melting domain, we studied the microstructures and crystal preferred orientations (CPO) of a xenolith-based vertical transect of the mantle root of the Early Cretaceous Ontong Java Plateau (OJP), which is the most voluminous large igneous province on Earth. Previous petrological and geochemical studies on the xenoliths revealed a compositional stratification of OJP lithosphere, most likely created by impingement/accretion of plume materials on the base of pre-existing normal Jurassic oceanic lithosphere (Ishikawa et al., 2004; 2011). In addition, seismological studies have suggested that the present-day plateau is underlain by an abnormal mantle keel, which associates low S-waves velocities and low attenuation (Richardson et al., 2000, Gomer and Okal, 2003). Comparison between the seismic properties computed based on the xenoliths equilibrium P-T, CPO, and modal/chemical compositions and seismic data for the OJP region allows constraining the spatial extent of the plume-related petrological processes and constructing a model for a plume-modified lithosphere.

In spite of the strong compositional variability, all peridotites, with exception of those equilibrated at the shallowest and deepest depths that are porphyroclastic, show coarse-granular to tabular microstructures, but clear olivine CPO, indicating that deformation was followed by annealing in response to reactive melts/fluids percolation and to slow cooling following the plume activity. The compositional and textural variations among the studied xenoliths results in some dispersion, but the density and the mean P-wave velocities decrease in average weakly with depth. S-waves show a more marked decrease, resulting in an increase in the Vp/Vs ratio with depth. The calculated seismic velocity profiles are consistent with those estimated for normal mantle compositions under a relatively cold oceanic geotherm leading to a 120 km thick lithosphere. The enrichment in pyroxenites of the OJP mantle lithosphere that might be predicted based on xenoliths' abundances might result in further increase in seismic velocities, because of their high content in garnet. The xenoliths' seismic properties are thus coherent with the high-Q values derived from the analysis of ScS waves reverberating beneath the OJP (Gomer and Okal, 2003), but cannot explain the low S-waves velocities predicted by Rayleigh wave tomography models (Richardson et al., 2000). Possible explanations for this discrepancy are: (1) the low-velocity anomaly imaged beneath the OJP results from smearing from low velocities actually located in the New Hebrides subarc region, (2) it is restricted to the sublithospheric mantle (>120 km) beneath OJP, probably related to the source region of the xenoliths-carrying magma; (3) it developed post-xenoliths' extraction (at 34 Ma) in response to subduction of the Australian plate under the OJP. Seismic anisotropy of the peridotite xenoliths is variable (2-12%), but the deeper part of the lithospheric section (below ca. 80 km) tends to show higher anisotropy. However, because olivine has dominantly [010]-fiber CPO patterns, if foliations are horizontal, vertically propagating S-waves and Rayleigh waves will sample very weak anisotropy in the OJP mantle lithosphere.

Gomer, B.M., Okal, E.A., 2003. Multiple-ScS probing of the Ontong-Java Plateau. Phys. Earth Planet. Inter. 138, 317–331.

Ishikawa, A., Maruyama, S., Komiya, T. 2004. Layered lithospheric mantle beneath the Ontong Java Plateau: implications from xenoliths in alnöite, Malaita, Solomon Islands. J. Petrol. 45, 2011–2044

Ishikawa, A., Pearson, D.G., Dale, C.W. (2011). Ancient Os isotope signatures from the Ontong Java Plateau lithosphere: Tracing lithospheric accretion history. Earth Planetary Sci. Lett. 301: 159-170

Richardson, W.P., E.A. Okal, van der Lee, S. 2000. Rayleigh-wave tomography of the Ontong-Java Plateau, Phys. Earth Planet. Inter., 118, 29-51.

The Coast Range Ophiolite: Evaluating ophiolite genesis at subduction zones, melt extraction history, enrichment processes, and capturing the MOR-SSZ transition

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The middle–Jurassic Coast Range Ophiolite (CRO) is one of the most important tectonic elements in western California, and has long been central to our understanding of Jurassic Cordilleran tectonics. The volcanic and plutonic sections are commonly interpreted to represent a supra–subduction zone (SSZ) ophiolite, but models specifying a mid–ocean ridge origin have also been proposed. If an SSZ origin is confirmed, we can use the underlying mantle peridotites to elucidate melt processes in the mantle wedge above the subduction zone.

We use high–precision LA–ICPMS analyses of relic pyroxenes (clino– and ortho–) to record trace element signatures and use trace element systematics to constrain melting processes and melt enrichments in the mantle wedge above the Cordilleran subduction zone. Melt extraction models call for 1–3% partial melting of MORB–source asthenosphere in the garnet lherzolite field, with an additional 15–20% partial melting in the spinel lherzolite field (Jean et al., 2010). These geochemical variations and occurrence of both styles of melting regimes within close spatial and temporal association suggest that certain segments of the CRO may in fact represent oceanic lithosphere, attached to a large–offset transform fault and that east–dipping, proto–Franciscan subduction may have been initiated along this transform. These models, however, cannot account for highly enriched fluid–mobile elements, which are enriched by factors of up to 100x DMM. The high concentrations of fluid mobile elements in supra–subduction peridotite pyroxene can be attributed to a flux of aqueous fluid or fluid–rich melt phase derived from the subducting slab. We model this by deriving a new algorithm that calculates the concentration of fluid mobile elements added to the DMM source (Shervais and Jean, 2012):

$$Cwr,add = [Ccpx,obs/((Dcpx/(Dbulk-PF)) * (1-(PF/Dbulk))(1/P))] - C0,wr$$

$$Ccpx,add = Cwr,add * [Dcpx/(Dbulk-PF)] * [1-(PF/Dbulk)](1/P)$$

Cwr,add = concentration of FME added to mantle wedge during a given melt increment, Ccpx,obs = concentration of observed pyroxene, Dcpx and Dbulk = mineral and bulk partition coefficients, P = melt proportion, and F = melt fraction required to model the observed MREE–HREE concentrations.

Using these new formulations, it was demonstrated that tens to hundreds of ppm were added to the mantle wedge source, i.e., B ~2–6 ppm, Li ~2–4 ppm, Ba ~10–520 ppm, Th ~0.03–0.12 ppm, and Pb ~0.1–0.7 ppm – concentrations that are 10's to 100's times higher than DMM–source compositions. Application of this algorithm to CRO peridotites shows that fluid influx must be continuous with open system melting, which allows us to calculate FME concentrations for small melt increments. Addition of the calculated FME concentrations to DMM–asthenosphere or refractory arc mantle (RAM) results in pooled magmas that match primitive arc tholeiites and boninites. This model can be applied to any refractory mantle peridotite that has been modified by melt extraction and/or metasomatism, and requires no preconceived fluid flux composition.

Structural Evolution for Jabal Tays Ophiolite in Eastern Arabian Shield: Implications for Evidence of Active Ocean-Floor Magmatism

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Neoproterozoic mafic-ultramafic complexes make up less than 1% of the surface area of the Arabian shield. It is represented as remnants of oceanic crust and indicators of arc-arc suturing. Using structural evolution reveals a history of deformation reflecting different tectonic regimes in the Jabal Tays ophiolite. Not all mafic-ultramafic complexes in the Arabian region are ophiolites. Mafic-ultramafic rocks at Jabal Tays include a large amount of serpentinite, subordinate amounts of gabbro intruded by mafic dikes, mélange, serpentinite schist, and listwaenite. The serpentinite makes up the bulk of Jabal Tays, is variably sheared and typically consists of relatively massive serpentinite cut by shear zones marked by serpentinite schist. The penetrative subhorizontal foliation is subparallel to the tectonic contacts between the serpentinite and ABT Schist rocks with the overlying nappes and foliation was formed during nappe thrusting and intrusion of mafic rocks under semi- brittle to ductile deformation in the Jabal Tays area. It is concluded that the transport direction is compatible with an E-W elongated chromite lineation described from deformed gabbro in the central part of the ophiolite and with the southwesterly plunge of stretched pebbles observed by us in Abt formation in the footwall of the ophiolite on the southeastern flank of Jabal Tays. Our structural data provides evidence of active ocean-floor magmatism in association with development of the tectonostratigraphic terranes in the shield and the process of suturing during terrane amalgamation.

Keywords: Structural evolution, ophiolites, Jabal Tays area, Arabian Shield, Saudi Arabia.

Petrofabrics of olivine and chlorite in chlorite peridotites and implications for seismic anisotropy in subduction zone

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Chlorite peridotites from Almklovdalen in SW Norway were studied to understand the deformation fabrics and seismic anisotropy in the upper mantle. The lattice preferred orientation (LPO) of olivine and chlorite was determined using electron backscattered diffraction (EBSD) in JSM-6380 scanning electron microscope. A sample with abundant garnet showed [100] axes of olivine aligned subparallel to the lineation, and [010] axes aligned subnormal to the foliation; this is known as A-type LPO. Samples rich in chlorite showed different olivine LPOs. Some samples showed [001] axes aligned subparallel to lineation, and [010] axes aligned subnormal to foliation; this is known as B-type LPO. The other samples showed [100] axes aligned subparallel to lineation, and [001] axes aligned subnormal to foliation; this is known as E-type LPO. Chlorite showed a strong LPO characterized by [001] axes aligned subnormal to foliation with a weak girdle subnormal to lineation. FTIR spectroscopy of the specimens revealed that the olivines with A-type LPO contain a small amount of water. In contrast, the olivines with B-type LPOs contain a large amount of water. The seismic anisotropy of the olivine and chlorite was calculated. Olivine showed Vp anisotropy of up to 3.8% and a maximum Vs anisotropy of up to 2.7%. However, the chlorite showed a much stronger Vp anisotropy up to 21.1% and a maximum Vs anisotropy of up to 31.7%. A strong seismic anisotropy observed in subduction zones at relatively high temperature can be attributed to the development of strong LPO of chlorite in mantle wedge as well as in subducting slab.

Garnet pyroxenites as markers of recurring extension and magmatism at the margins of the Arabian plate

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Several within-plate magmatic events occurred in the Levant during Mesozoic-Cenozoic times and were related to rifting (Triassic, Neogene) and to mantle plume rising beneath the continental lithosphere of the Afro-Arabian plate (Cretaceous). The Cretaceous magmatic province of the Levant, exposed from Syria and Lebanon through Israel to Egypt, ended during the Late Cretaceous with underwater eruptions of alkaline basaltic tuff at the edge of the Arabian continental shelf in Mt. Carmel, northern coastal Israel. The lowest (97 Ma) and uppermost (82 Ma) of the five pyroclastic horizons exposed in Mt. Carmel contain a suite of mantle xenoliths, composed almost solely of garnet clinopyroxenites.

Garnet clinopyroxenites of magmatic texture are characterized by highly variable modal amounts of pyrope-rich garnet, augite, spinel and ilmenite. Kelyphitic rims of micron-sized orthopyroxene, anorthite and spinel, are shown by wide beam EDS analysis to be chemically identical to the parent garnet. In xenoliths of metamorphic texture garnet is interstitial and much less abundant. The coexistence of garnet and spinel in the Carmel clinopyroxenites indicates crystallization at T = 1100-1200°C, P = 13-15 Kb. Modeling of REE contents shows that the pyroxenites could not have formed as residues after melting of subducted mafic rocks, but rather as cumulates by 1% fractional crystallization of OIB- like melts, similar to the magmas that brought them to the surface. Oxygen isotope ratios are within the mantle range [$\delta^{18}O$ Grt = 5.31 ±0.22‰; $\delta^{18}O$ Cpx = 5.18±0.34‰] and also indicate pure mantle origin with neither crustal contribution to the source nor contamination during ascent. Nd and Hf isotope ratios plot on the evolution line of the Arabian sub-continental lithospheric mantle considered to form by a late Neoproterozoic asthenosphere plume head. Nonetheless Sm-Nd and Lu-Hf whole rock isochron ages are 306±8 and 197±13 Ma, respectively, and may represent heating and/or metamorphism.

The Carmel garnet pyroxenites crystallized from OIB-type melts in the uppermost mantle (~ 40 km) either during upwelling of asthenosphere plume at the end of the Pan-African orogenesis or later during Late Palaeozoic - Early Mesozoic rifting. Some pyroxenites recrystallized due to a later metamorphic event. Prior to having been scavenged by ascending magma at the Late Cretaceous, the pyroxenites decompressed to lower crustal conditions as indicated by garnet breakdown to form granulite facies kelyphite.

Mantle xenoliths of both Al-augite and Cr-diopside types are common in volcanic fields of variable age across the Arabian plate. Nonetheless garnet pyroxenite (Al-augite group) xenoliths are extremely rare in the Arabian plate and occur only in the Cretaceous Mt. Carmel volcanos, in the Pliocene Al-Ashaer volcano (Syria) and in Pleistocene basalts of the Saudi coast of the Red Sea. All three sites have a history of at least two tectono-magmatic events, the first having involved extension and crustal thinning and both events characterized by mafic alkaline magmatism. Al-augite garnet clinopyroxenites turn out to be markers of recurring mantle upwelling and melting in the Arabian plate.

Petrophysical and seismological model of the lithospheric mantle beneath the Nógrád-Gömör Volcanic Field (Northern Pannonian Basin)

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Nógrád-Gömör Volcanic Field (NGVF) is one of the five known occurrences in the Carpathian Pannonian region (CPR) where Plio-Pleistocene alkali basalts have sampled the upper mantle, bringing upper mantle xenoliths to the surface. NGVF is located in the northern part of the Pannonian Basin.

For this study, 15 lherzolite and 2 wehrlite xenoliths were selected from the central and southern parts of the NGVF. These xenoliths represent a small volume (~4000 km^3) of the upper mantle from a depth of about 35-50 km. Xenoliths collected from the southern part of NGVF originate from shallower depth (35-40 km) than those from the central part (40-50 km) [1]. Crystal preferred orientations (CPO) of the minerals were measured by electron backscatter diffraction (EBSD). Two distinct orientation types based on the distribution and alignment of crystallographic axes were recognized, which show some correlation not only with the texture types, but also with olivine J-indexes that indicate the strength of the xenolith fabric [2]. Samples from the southern part of the NGVF are characterized by lower J-indexes (2.5-3.6) than those from the central area (3.5-10.4). In addition, samples with porphyroclastic textures showed type-A CPO, whereas the others with equigranular textures, exhibited type-D olivine orientation. The different CPO types could be the result of differences in the amount of stress and water content of the mantle portion represented by the xenoliths. Based on this assertion, the xenoliths probably originate from different domains of the lithospheric mantle [1].

The seismic properties, i.e. seismic anisotropy and velocities, of these 17 mantle xenoliths were calculated based on the CPO and volume fractions of olivine, ortho- and clinopyroxene [3]. It was found that P wave and fast split shear wave polarization direction is always close to the density maximum of the a-axis of olivine. Seismic anisotropy is higher for stronger CPO. Positive, but not linear correlation was observed between the calculated anisotropies and the J-index. Maximum P wave azimuthal anisotropy ranges are 4.5-6.9% and 5.3-11.9%, for the southern and the central area, respectively. Maximum S wave polarization anisotropy ranges are 2.92-5.31% and 3.97-7.46% for the southern area and the central area, respectively.

The anisotropy that would be measured by SKS, Rayleigh and Love waves for end-member orientations of the lineation and foliation could be predicted based on the calculated seismic properties of the xenoliths [4]. The calculated anisotropy is compared to the results of S receiver function analysis based on data recorded at 3 nearby permanent seismological stations. The goal of this study is the development of a petrophysical and seismological model for the lithospheric mantle in order to obtain a better interpretation of the measured seismological data, and hence determine the current and, if possible, the fossil lithosphere-asthenosphere boundary beneath the studied area.

[1] Liptai, N. et al. 2013. (in Hungarian) Bulletin of the Hungarian Geological Society, 143/4, 371-382.
[2] Bunge, H. J. Texture Analysis in Materials Sciences. Butterworths, London, 1982, p. 593
[3] Mainprice, D. 1990. Comp. Geosci. 16, 385-393
[4] Baptiste, V., Tommasi A. 2014. SE, 5, 45-63.

The garnet-spinel transition in Lherzolite and Harzburgite

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We present results from a new and refined thermodynamic model that has been used to predict phase relations and mineral compositions in a wide range of realistic upper mantle compositions, ranging from fertile lherzolite to depleted harzburgite. The results of the model can be integrated with the available data from natural samples and geophysical observations. The generated phase diagrams show that the garnet+spinel stability field is always broad at low temperatures and progressively narrows with increasing temperatures. In lithospheric sections with hot geotherms, garnet coexists with spinel across an interval of 10–15 km, at ca. 50–70 km depths. In colder, cratonic, lithospheric sections, the width of the garnet–spinel transition strongly depends on bulk composition: in fertile mantle, spinel can coexist with garnet to about 120 km depth, while in an depleted harzburgitic mantle it can be stable to over 180 km depth. These results are in agreement with the observed extension of the Hales gradient zone (a seismic impedance increase) in various geodynamic settings. The formation of chromian spinel inclusions in diamonds is restricted to pressures between 4.0 and 6.0 GPa. The modes of spinel decrease rapidly to less than 1 vol% when it coexists with garnet, hence spinel grains can be easily overlooked during the petrographical characterization of small mantle xenoliths. The very Cr-rich nature of many spinels from xenoliths and diamonds from cratonic settings may be simply a consequence of their low modes in high-pressure assemblages. The model also shows that large Ca and Cr variations in lherzolitic garnets in equilibrium with spinel can be explained by variations of pressure and temperature along a continental geotherm and do not necessarily imply variations of bulk composition.

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Rhenium–osmium isotopic composition of mantle xenoliths from the Bohemian Massif

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The Bohemian Massif (BM) is the most prominent relic of the Variscan orogenic belt in Central Europe. Its present-day structure represents a collage of microplates and relics of magmatic arcs, accreted during the Variscan (Hercynian) collision of Laurussia (Laurussia–Baltica) and Africa (Gondwana) supercontinents. The BM underwent asthenosphere doming and subsequent continental rifting (represented by predominant Ohře/Eger rift) associated with intra-plate volcanism during the Cenozoic (Oligocene–Pliocene) with many primitive lavas hosting abundant mantle xenoliths. The xenoliths predominantly consist of spinel harzburgite and lherzolite, which underwent variable degrees of partial melting from ~5 to ~35 % and subsequent metasomatism by basaltic [1,2] and alkaline/CO2-rich melts [3,4,5].

In this study, we have analyzed 35 new samples of well-characterized mantle xenoliths hosted by Cenozoic lavas from several different localities in the BM: the České Středohoří Volcanic complex (CSVC) located in the central part of the Ohře/Eger rift, NE Bavaria representing the western continuation of the rift system, volcanoes in the NE continuation of the rift system (Lusatia, Lower Silesia) and an isolated volcano in E Bohemia representing the off-rift settings. We aimed at using Os isotopes in mantle xenoliths to assess differences between individual mantle domains of major tectonic units of the BM and link them with their potential source mantle signatures. The samples exhibit high scatter in Re and Os concentrations (0.004–0.44 ppb and 0.073–6.8 ppb, respectively) with some important differences among studied areas. Seven samples from the three different CSVC localities and Lusatia have highly variable Re and Os contents (0.04–0.12 ppb Re, 0.42–4.3 ppb Os, respectively) paralleled by their variable 187Os/188Os ratios of ~0.1162 –0.1282. In contrast, six samples from Lower Silesia (Poland) contain 0.08–0.27 ppb Re and 0.11–3.47 Os and yield very homogeneous 187Os/188Os of ~0.1270 and limited range in γOs between –4 and 0.9. The highest variation in Re-Os composition was found in the xenoliths from NE Bavaria with the highest Re contents (up to 0.44 ppb) and present-day 187Os/188Os ratios ranging from subchondritic ~0.1135 to superchondritic values of up to ~0.1474 and corresponding γOs values ranging from –11 to +14. A single sample in the off-rift group contains 0.009 ppb Re and 1.7 ppb Os. This sample displays subchondritic 187Os/188Os of ~0.1212.When previously published Re–Os data for Kozákov xenoliths (NE Bohemia, [6]) are included, suite of 49 samples can be examined for their Rhenium-depletion ages (T_{RD}). Among them, 25 samples exhibit TRD <0.5 Ga, 15 samples lie in the range of ~0.5–1 Ga and TRD ages in nine samples yield vary from 1.0 to 2.0 Ga. The ages show high scatter even in the individual localities suggesting rather heterogeneous lithospheric mantle beneath the BM with likely no clear connection to different tectonic units.

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[1] Ackerman et al. (2007) J. Petrol. 48, 2235-2260. [2] Ackerman et al. (2014) Int. J. Earth Sci., under review. [3] Matusiak-Małek et al. (2010) Lithos 117, 49-60. [4] Puziewicz et al. (2011) J. Petrol. 52, 2107-2145. [5] Ackerman et al. (2013) J. Petrol. 54, 2597-2633. [6] Ackerman et al. (2009) Geochim. Cosmochim. Acta 73, 2400-2414.

Diamond and graphite-bearing eclogite xenoliths from Udachnaya East kimberlite pipe

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The kimberlites are one of the most important diamond sources. Diamond occurs in peridotite and eclogite assemblages. Graphite-bearing xenoliths are less common than diamond-bearing one (Kornprobst et al., 1987, Pearson et al., 1994). Findings of xenoliths with coexisted diamond and graphite within the single xenoliths are very rare (Robinson, 1978; Hatton & Gurney, 1978). This paper deals with the diamond and graphite in four diamond eclogite xenoliths, five diamond-graphite eclogite xenoliths and two graphite eclogite xenoliths from Udachnaya East kimberlite pipe (Yakutiya). Identification of succession of crystallization of carbon polymorphs is the main aim of this study.

Udachnaya East kimberlite pipe is one of the largest diamond deposits in Russia and contain uniquely preserved kimberlite and mantle xenoliths (Kamenetsky et al., 2012). The samples are rounded xenoliths, ranging in size from 3 to 20 cm in diameter. These are coarse-grained rocks, consisting of garnet- clynopyroxene ± kyanite ± coesite/quartz ± enstatite ± phlogopite ±rutile ± sulphides.

Recently for Kokchetav ultra-high pressure metamorphic rocks was shown that diamond and graphite may crystalize simultaneously in diamond stability field (Korsakov et al., 2010). Pearson et al. (1994) were the first to study the possible metastable crystallization of graphite within the diamond stability field for mantle rocks. Now there is general believes that diamond in eclogite xenoliths related to single or multistage metasomatic processes (Shatsky et al., 2008). Graphite in eclogite xenoliths could appear on prograde stage, during subduction of oceanic crust, or on retrograde stage, when eclogite samples were transported to the Earth's surface by kimberlite melt. If graphite formed in its own stability field, this fact should imply partial re-equilibration of rock-forming minerals.

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Hatton C.J., Gurney J.J. (1978) A diamond graphite eclogite from the Roberts Victor Mine, Proceedings of the 2nd International Kimberlite Conference, vol. 1., Washington, pp. 29–36.

Kamenetsky, V.S., Kamenetsky, M.B., Golovin, A.V., Sharygin, V.V., Maas, R. (2012) Ultrafresh salty kimberlite of the Udachnaya–East pipe (Yakutia, Russia): A petrological oddity or fortuitous discovery? Lithos, 152, 173-186

Kornprobst J., Pineau F., Degiovanni R., Dautria J.M. (1987) Primary igneous graphite in ultramafic xenoliths: I. Petrology of the cumulate suite in alkai basalt near Tissemt (Eggtrt, Algerian Sahara). J Petrol 28 : 293-311.

Korsakov A.V., Perraki M., Zedgenizov D.A., Bindi L., Vandenabeele P., Suzuki A., Kagi H. (2010) Diamond-graphite relationships in ultrahigh-pressure metamorphic rocks from the Kokchetav Massif, northern Kazakhstan. J Petrology, 51, 763-783

Pearson et al., 1994 Pearson, D. G., Boyd, F. R., Haggerty, S. E., Pasteris, J. D., Field, S. W., Nixon, P. H. & Pokhilenko, N. P. (1994). The characterization and origin of graphite in cratonic lithospheric mantle: a petrological carbon isotope and Raman spectroscopic study. Contrib Mineralogy Petrology 115, 449-466.

Robinson D.N. (1978). Diamond and graphite in eclogite xenoliths from kimberlite. Proceedings of the 2nd International Kimberlite Conference, vol. 1, Washington, pp. 50–58.

Shatsky V., Ragozin A., Zedgenizov D., Mityukhin S. (2008) Evidence for multistage evolution in a xenolith of diamond-bearing eclogite from the Udachnaya kimberlite pipe, Lithos, 105, 3-4

Nature and evolution of the lithospheric mantle beneath the Hoggar swell (Algeria): a record from mantle xenoliths

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We present the results of an integrated petrological, geochemical and petrophysical study of mantle xenoliths sampled by Cenozoic volcanism in the Hoggar massif (Algeria). The aim of this study was to characterize the lithospheric mantle of the Hoggar swell and its evolution through time. The samples were collected in two volcanic districts (Tahalgha and Manzaz) located at the periphery and in the central part of the Hoggar massif, respectively. The Tahalgha sampling also straddles a mega pan-African shear zone (the 4°35 fault) between two major structural domains of the Tuareg Shield basement: the Central Polycyclic Hoggar to the East (LATEA terranes) and the Western Hoggar domain to the West (Iskel block). The studied xenoliths provide information on the evolution of the lithospheric mantle from the late Pan-African orogeny – i.e. the period when the Tuareg Shield was structured – up to the Cenozoic events responsible for the topographic upwelling and volcanism. The Pan-African heritage is preserved in xenoliths from the peripheral Tahalgha district. These samples are distinguished by low equilibrium temperatures (750-900°C) and LREE-depleted clinopyroxene compositions. They are considered to represent the sub-continental lithosphere after the rejuvenation processes that occured during the late stages of the Pan-African orogeny. They show well preserved deformation textures (porphyroclastic to equigranular) assigned to these events and characterized by preferential crystallographic orientations (CPOs) of olivine (axial-[010]) consistent with a transpressional regime. The Cenozoic events are marked by partial annealing of these textures, particularly pronounced in the Manzaz samples, as well as in the Tahalgha xenoliths equilibrated at medium to high temperatures (900-1150°C). These samples were affected by different degrees of metasomatism. The Tahalgha xenoliths represent a rather unique case study of mantle metasomatism, where coupled textural, mineralogical and chemical variations occur along local temperature gradients. The Cenozoic events were also responsible for a change in olivine CPOs, resulting from both infiltration of metasomatic fluids and reactivation of Pan-African accidents. However, the first-order lithosphere modifications ascribed to the Cenozoic event are observed either at the scale of the whole Hoggar swell, as shown by the increasing degree of textural annealing and metasomatism from Tahalgha to Manzaz (i.e. from outer to central Hoggar), or at the small scale of magma conduits and their wall rocks, as shown by the local variability registered by the Tahalgha xenoliths. Conversely, our data show little changes at intermediate scales, as might be expected, for instance, on either sides - or at different distances - from the 4°35. As regards the origin of the Hoggar volcanic swell, this result favours relatively large-scale asthenospheric upwelling related to upper mantle instabilities or local convections, rather than a process involving merely the reactivation of pan-African lithospheric faults.

Correlations between strain geometry, shape fabric, and crystallographic preferred orientation revealed by microtomography and textural analyses: heterogeneous deformation of mantle xenoliths from Marie Byrd Land, Antarctica

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Marie Byrd Land (MBL), West Antarctica is noted for having active volcanism, a regional thermal anomaly measured by the Gravity Recovery and Climate Experiment (GRACE) satellite, and slow seismic velocities within underlying mantle. The lithospheric mantle of West Antarctica has been subject to active modification from Cretaceous to Present by plate-boundary processes, including orthogonal to oblique plate convergence, intracontinental rifting, continental breakup, and Neogene volcanism. Mantle xenoliths entrained in ca. 1.4 Ma basalts from the Fosdick Mountains and Executive Committee Range provide insight into mantle deformation processes and sources of structural and compositional heterogeneity. We present results from microtomographic fabric studies and textural and petrological analyses that establish the thermal structure of the west Antarctic mantle lithosphere, place quantitative constraints on mantle fabric variations, and inform on the relationship between fabric geometry and patterns of crystallographic preferred orientation.

Temperature estimates for mantle xenoliths from five volcanic centers in the Fosdick Mountains (Marujupu Peak, Mt. Avers, Demas Bluff, Bird Bluff and Recess Nunatak) and two in the Executive Committee Range (Mts. Cumming and Aldaz) were obtained using 2-Px, Ca-in-Opx, Al-in-Opx, and Ol-Spl Fe-Mg exchange geothermometry. These ultramafic xenoliths equilibrated over a wide range of temperatures (600–1100 °C, calculated at P=15 Kbar) and depths (35-85 km), determined by forcing the calculated equilibration temperatures onto the Ross Embayment geotherm. High-resolution X-ray microtomography analyses addressed two complementary goals: (1) to determine the three-dimensional shape fabric of constituent minerals by computing the fabric tensor in all 44 peridotite xenoliths; and (2) to provide the structural reference frame required (i.e. thin sections parallel to the XZ plane of the fabric ellipsoid) in order to interpret patterns of crystallographic preferred orientation (CPO) measured by electron backscatter diffraction (EBSD). Our microtomography data reveal large variations in xenolith fabric geometry as determined from the shape-preferred orientation of spinel and clinopyroxene, ranging from prolate to oblate. The deviation of fabrics from plane strain suggests a departure from simple shear flow, commonly assumed for mantle deformation. Similarly, CPO patterns in olivine are highly variable within the xenolith suite; (010)[100] “A-type”, axial-[010] “AG-type”, (001)[100] “E-type”, and (0kl)[100] "pencil glide" slip systems have all been identified. Comparison of shape fabrics and CPO patterns lead us to interpret that fabric geometry exerts an important control on the development of crystallographic preferred orientations. Moreover, these data suggest that in contrast to the common assumption, upper mantle fabrics may be characterized by significant lateral and vertical structural heterogeneity.

Peridotitic xenoliths from the Feldstein basalt (Thuringia, Germany): preliminary data

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Feldstein is an isolated outcrop of columnar basaltic rock nearby Themar, located 60 km south-west of Erfurt (Thuringia, Germany). The Feldstein alkali basalt (ca. 16.3 Ma) belongs to the Heldburger Gangschar subset of the Central European Volcanic Province (Abratis et al. 2007). The Feldstein alkali basalt contains peridotitic xenoliths, which were the subject of our study. Two groups of spinel peridotite xenoliths occur in the Feldstein basalt. Group A spinel peridotite (2 xenoliths) is characterized by protogranular texture with typical grain size of 2 – 3 mm (max 8 mm). It consists of olivine (90.28 – 91.36 % Fo, 0.35 – 0.45 wt. % NiO), orthopyroxene (mg# 0.91 – 0.92, Al 0.09 – 0.18 a. pfu), clinopyroxene (mg# 0.93 – 0.95, Al 0.06 – 0.21 a. pfu) and spinel (cr# 0.20 – 0.41, mg# 0.66 – 0.78). The orthopyroxene Rare Earth Elements (REE) patterns of group A are strongly depleted relative to primitive mantle (PM) from Lu to Sm (SmN/LuN= 0.01 – 0.04). Orthopyroxene shows significant Pb and Ti positive anomalies. The mg# and Al content in clinopyroxene are negatively correlated following the depletion trend after variable degrees of partial melting of the same source. One of the studied samples is characterized by significantly higher Al (0.15 – 0.21 a. pfu) for similar mg# 0.93 – 0.94. The PM normalized clinopyroxene REE pattern (concave upwards with LaN/YbN=0.11) indicate that this is the residue after significant degrees of partial melting. The most magnesian clinopyroxene is Ca-rich and Al-poor and has concave upwards REE pattern (SmN/LuN =0.05). The group B spinel peridotites have protogranular texture (3-4 mm, max 7 mm grains) and some of them contain several melt pockets of basaltic composition. The peridotites consist of olivine (88.95 – 91.32 % Fo, 0.34 – 0.47 wt.% NiO), orthopyroxene (mg# 0.90 – 0.93, Al 0.04 – 0.16 a. pfu) and clinopyroxene (mg# 0.90 – 0.93, Al 0.10 – 0.20 a. pfu). Group B is characterized by U-shaped REE patterns of orthopyroxene (LaN/YbN = 1.02 – 3.50, LaN/SmN = 3.47 – 74.15). In one xenolith, orthopyroxene has nearly flat REE pattern with slight depletion from Lu to La (LaN/YbN = 0.15, LaN/SmN = 0.45).The clinopyroxene as can be inferred from their high LaN/YbN ratio (7.17 to 41.26), has been strongly but variably affected by metasomatic processes. Furthermore, in the primitive mantle normalized trace element diagrams the majority of the studied clinopyroxene grains have prominent Ti, Zr and Hf negative anomalies. The LaN/SmN ratio changes gradually from 1.60 to 76.69 suggesting melt percolation. The xenoliths with the lowest LaN/SmN ratio should be closer to the melt percolating front and those with the highest LaN/YbN ratio should be located in a longer distance from the melt front. In conclusion: the group A of peridotites records strong melt extraction with evidence for minor metasomatic influence whereas the spinel peridotites from the group B have been variably affected by percolating SiO2-undersaturated melts.

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Abratis, M., Mädler, J., Hautmann, S., Leyk H.J., Meyer, R., Lippolt, H.J., Viereck-Götte, L., (2007) Chemie der Erde – Geochemistry, 67, 133-150

PX-MELT: a predictive model for the melting of pyroxenites in the mantle

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Melting of mantle sources with multiple rock types, each with their own melting behavior, chemical and isotopic properties, is believed to be an important factor in producing the range of magma types characteristic of individual igneous provinces. An important example of such a compound source is a peridotitic mantle with minor pyroxenitic veins. Melting models of such mixtures require knowledge of the relationships between melt fraction (F), temperature (T), pressure (P), and bulk composition (X) for both peridotites and pyroxenites. While various parameterizations are available to model the melting behavior of peridotites, none yet exist to model pyroxenite melting.

Although empirical melting parameterizations are a useful and simple way to incorporate melting into tectonic models and have the advantage that they often better reproduce existing experimental data than exclusively thermodynamically models, current experimental data for pyroxenite melting are too sparse and show a large amount of scatter. Hence, we took an approach that incorporates thermodynamical concepts, using pMELTS [1] to guide our choice of functional forms, and calibrates them against the current experimental database. In this way, our parameterization becomes a reliable tool for compositions not used to calibrate the model.

Our model, PX-MELT is calibrated on 193 experiments (20 bulk compositions) in which F has been determined up to the clinopyroxene exhaustion (cpx-out) for pyroxenites over a substantial range of P and T (0.9–5 GPa; 1150–1675°C) and the parameterization is of the form of:

$F = A\cdot T'^2 + B\cdot T' + 5$ with $T'=(T - T5\%)/(Tcpx - T5\%)$

where F is the weight fraction of melt present, T5% is the temperature at F = 5%, Tcpx is the cpx-out temperature in the pyroxenite assemblage and A and B are functions of the pressure (P, in GPa) and of the bulk composition of the pyroxenite.

PX-MELT, reproduces the melting degree undergone by a pyroxenite with a mean standard deviation of 11% absolute, T5% and Tcpx are reproduced with a standard deviation of 30°C and 32°C over a temperature range of ~ 500°C, respectively. To measure the success of our melting parameterization, we used the variance reduction [2], i.e. the percentage of the total variance of experimentally determined F explained by the parameterization. The mean variance reduction on the 18 compositions used in the model is 83%. This value is similar to those obtained with parameterizations on peridotite melting (72-85%) and is much higher than the value obtained with pMELTS for this experimental dataset (55%).

While remaining mathematically simple, PX-MELT succeeds in capturing the important features of the behavior of pyroxenites melting. It can be used to model the partial melting of multilithologic mantle sources, including the effects of varying the composition and the modal proportion of pyroxenite in such source regions. Several examples will be present and the potential implications for the magma production and transport will be discussed..

[1] Ghiorso et al., 2002, doi:10.1029/2001GC000217; [2] Katz et al., 2003, doi: 10.1029/2002GC000.

Understanding the complex physico-chemical features of the upper mantle beneath the Nógrád-Gömör Volcanic Field (Northern Pannonian Basin) - A study on peridotite xenoliths

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The Nógrád-Gömör Volcanic Field (NGVF) is located in the northern part of the Pannonian Basin, and is one of the five occurrences in the Carpathian-Pannonian region where xenoliths from the upper mantle and lower crust were enclosed and brought to the surface by Plio-Pleistocene alkali basalts. Upper mantle peridotite xenoliths of the NGVF can be divided into two lithologically different suites: lherzolites, which represent the depleted lithospheric mantle, and wehrlites, which were formed from lherzolites by cryptic and stealth metasomatism during melt-rock interaction. This study focuses on the petrography and geochemistry of the lherzolite suite because recent studies proved that these xenoliths are geochemically diverse and have suffered cryptic metasomatism to various extents.

Out of more than 200 collected samples, 15 representative lherzolite xenoliths were selected from the central and southern part of the NGVF for detailed petrographic study, analyses of major and trace element contents and measurements of crystal preferred orientation (CPO). Major element geochemistry revealed that composition of most of the lherzolite xenoliths match that of the average, depleted lithospheric mantle with approximately 20 % partial melting; however, some of the samples exhibit characteristically lower Mg-numbers, indicating metasomatic effect resulting in Fe enrichment. This suggests reaction with a melt whose composition is different from the host magma, and which could be the metasomatic agent that created the wehrlite bodies by alteration of the lherzolites. This assumption is supported further by trace element analyses that show various amounts of LREE enrichment, proposing that metasomatism has affected parts of the upper mantle to different degrees.

CPOs of olivine show a difference in fabric strength between lherzolite xenoliths from the central and the southern part of the NGVF, which may be attributed either to the difference in the depth of origin or the vicinity of major structural lines in case of the central part. Samples from the central part of the volcanic field represent a deeper domain of the lithospheric mantle than the ones from the southern part, and therefore may have been affected by a different deformation mechanism. Based on the results, we concluded that the xenoliths were not only subject to metasomatic processes, but also went through various deformation episodes, which occurred most probably during the Neogene evolution of the Pannonian Basin.

Relic of Paleoproterozoic mantle lithosphere beneath southeastern (SE) China: constraints from the Sr-Nd-Hf-Os isotopes of Mingxi mantle xenoliths

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Mantle xenoliths entrained in the Cenozoic basalts, including both spinel- and garnet-facies peridotites, have been studied with aim of identifying and characterizing the ancient mantle relic preserved beneath southeastern China. Whole-rock major elements suggest that most Mingxi peridotites have been subjected to ~ 5-25% degrees of partial melting, which is consistent with constraints from trace elements (i.e., Y and Yb contents) of clinopyroxenes, i.e., <5% vs ~10-20% for spinel lherzolites and spinel harzburgites, respectively. Pressures of the garnet peridotites have been calculated to be ~20-25 kbar, indicating a thickness of ~80-90 km for the mantle lithosphere beneath Mingxi. Spinel lherzoliates have temperatures of 786-1065 oC, which are remarkably lower than those of both spinel harzburgites (1086-1222 oC) and garnet peridotites (1068-1185 oC). Most Mingxi mantle xenoliths have experienced cryptical metasomatism, as evidenced by clinopyroxene trace element compositions. Presence of amphibole and phlogopite in two samples indicates the local occurrence of modal metasomatism by hydrous melts.

Present-day Sr-Nd-Hf isotope compositions of clinopyroxenes from 24 peridotites are highly variable, with 87Sr/86Sr ranging from 0.702238 to 0.704557, 143Nd/144Nd varying from 0.512793 to 0.514763 (εNd from +3.1 to +41.5), and 176Hf/177Hf from 0.282888 to 0.285791 (εHf from +4.2 to +106.4). In contrast, garnets from four garnet lherzolites have less variable Sr-Nd-Hf isotope compsotions: 87Sr/86Sr=0.704068 to 0.704708, 143Nd/144Nd=0.513346 to 0.513666 (εNd=+13.9 to +20.1) and 176Hf/177Hf=0.283348 to 0.284040 (εHf from +4.2 to +106.4). The Sr-Nd isotopic systems have been strongly reset by recent metasomatic processes and provide no useful age constraint for Mingxi peridotites, although some samples have Paleoproterozoic ages. The Mingxi clinopyroxenes yield a Lu-Hf correlation trend corresponding to an apparent age of 1.09±0.23 Ga (2σ), which are younger than their whole-rock Os model ages (~ 1.8 Ga). All spinel harzburgites have sub-chondritic 187Os/188Os ratios of 0.11685-0.12400, giving TRD ages of ~0.79-1.79 Ga relative to the primitive upper mantle. Two garnet harzburgites have187Os/188Os ratios of 0.11736 and 0.12313, giving similar TRD ages of 0.91 and 1.72 Ga, respectively. This suggests that the Lu-Hf isotope system has also been disturbed by melt metasomatism. Melt metasomatism also resulted in a decoupling between εNd and εHf of clinopyroxenes. However, ancient melt depletion is also recorded by clinopyroxenes in some samples with extremely high εHf values. Our results confirm the existence of Paleoproterozoic mantle beneath Mingxi, which is also widespread beneath the costal areas of southeastern China. Therefore, old continental mantle beneath SE China has not been completely removed, although might have significantly thinned, by the subduction of the paleo-Pacific plate since the early Mesozoic.

Dongbo and Purang Ultramafic Massifs in the Western Yarlung Zangbo Suture Zone, Tibet, as the Remnants of an Ocean–Continent Transition (OCT)

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The Yarlung-Zangbo Suture zone (YZSZ), extending more than 2000 km across southern Tibet and into Myanmar, marks the tectonic boundary between India and Asia. Several large ophiolitic massifs (Dongbo, Purang, Dangqiong and Xiugugabu) that crop out discontinuously in the western part of YZSZ represent the fragments of Neotethyan ocean lithosphere emplaced prior to the India – Asia collision. The Dongbo and Purang ophiolites show a seamount-like stratigraphy consisting of, from bottom to top, peridotites, mafic dikes, massive basaltic lavas and hyaloclastites, mudstone – silty shale, and radiolarian chert locally containing basaltic lava flows, and siliceous to massive limestones with minor oolites. The peridotites are composed mainly of depleted harzburgite with minor lherzolite and dunite, and show mineralogical, textural and geochemical evidence of high degrees of partial melting and subsequent enrichment by later fluids/melts. Mafic dikes intruding these peridotites have zircon U-Pb ages ranging from 128±1.1 Ma to 130 ±0.5 Ma, and exhibit N-MORB-like chondrite-normalized REE patterns with negative Nb anomalies on multi-element diagrams. These geochemical features are similar to those of volcanic-rifted margin basalts (Pearce, 2008; Dilek and Furnes, 2011). Some OIB-like basalts occurring between the silty shale and peridotites in the Dongbo ophiolite have a zircon U-Pb age of 140±0.6 Ma. These basalts have much higher TiO_2 (aver. 3.27 wt.%) contents than the MORB-like lavas and may characterize limited seamount volcanism. Sparse E-MORB-like basaltic lavas intercalated with the radiolarian cherts in the upper part of the volcanic-sedimentary sequence have a zircon U-Pb age of 137 Ma, in agreement with the Upper Jurassic to Lower Cretaceous ages of radiolarian fossils in the host cherts (Liu et al., 2013). Field and geochemical evidence suggests that these cherts were deposited in a continental rifted margin environment. Similar Cenozoic fossil fauna and flora have been reported from both sides of the Yarlung-Zangbo Suture zone (Hu et al., 2008; Xiao and Wang, 1998; Yin and Enay, 2004). We infer that the Dongbo and Purang peridotites represent blocks of oceanic mantle exhumed in the ocean-continent transition (OCT) environment between the rifted northern margin of India and the adjacent Neotethyan basin to the north.

Dilek, Y., Furnes, H. (2011). Ophiolite genesis and global tectonics: Geochemical and tectonic fingerprinting of ancient oceanic lithosphere. Geological Society of America Bulletin ***123****, 387-411.*

Hu, X., Jansa, L., Wang, C. (2008). Upper Jurassic–Lower Cretaceous stratigraphy in south-eastern Tibet: a comparison with the western Himalayas. Cretaceous Research ***29****, 301–315.*

Liu, F., Yang, J.-S., Chen, S.-Y., Liang, F.-H., Niu, X.-L., Li, Z.-L., Lian, D.-Y. (2013). Ascertainment and environment of the OIB-type basalts from the Dongbo ophiolite in the western part of the Yarlung Zangbo Suture Zone. Acta Petrologica Sinica ***29****, 1909–1932 in Chinese with English abstract.*

Pearce, J.A. (2008). Geochemical fingerprinting of oceanic basalts with applications to ophiolite classification and the search for Archean oceanic crust. Lithos ***100****, 14–48.*

Xiao, X.C. & Wang, J. (1998). A brief review of tectonic evolution and uplift of the Qinghai-Tibet plateau. Geological Review ***44****, 372–381 in Chinese with English abstract.*

Yin, J. & Enay, R. (2004). Tithonian ammonoid biostratigraphy in eastern Himalayan Tibet. Geobios ***37****, 667–686.*

Peridotite-melt reaction as a cause of upper mantle heterogeneity beneath the eastern part of the Cenozoic Central European Volcanic Province

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The study of peridotitic xenolith suites from 8 sites located in the eastern branch of Cenozoic Central European Volcanic Province (CEVP, SW Poland) shows that the upper mantle beneath this region consists of two main peridotite groups (see Puziewicz et al., this issue). Both of them are mostly of harzburgitic composition. Olivine forming group A is rich in Fo (90.5-92.0), the group B olivine is poorer in Fo (84.0-90.0). The B harzburgites contain very little clinopyroxene (<1 vol. %) whereas the contents of orthopyroxene vary from ca. 25 vol. % to less than 8 vol. %, leading to dunitic compositions in extreme cases (e.g. Krzeniow xenolith suite, Matusiak-Małek et al. submitted). Both A and B group xenoliths were recovered in four out of eight studied sites. Group B olivine is enriched in MnO (0.002-0.008 a. pfu) and depleted in NiO (0.28-0.42 wt.%) compared to the A harzburgites. The same refers to B pyroxenes, which are not only richer in Fe (mg#Opx=0.85-0.89, mg#Cpx=0.86-0.92) and Mn, but also in Ti and Al. Spinel occurring in the B harzburgites contains significant Ti (TiO2=0.80-1.89 wt.%). Orthopyroxene primitive-mantle normalized Rare Earth Elements (REE) patterns show strong depletion in LREE ((La/Lu)N=0.023-0.056), while clinopyroxene is LREE enriched ((La/Lu)N= 1.322-11.304) with negative inflection at Pr-Nd. This REE characteristics of both ortho- and clinopyroxene is typical for equilibration with silicate melt. High amount of orthopyroxene and low amount of spinel and clinopyroxene, NiO content in Ol typically exceeding 0.3 wt.%, Cr-rich nature of clinopyroxene and low Al content in pyroxenes possibly exclude B harzburgites as a high pressure cumulates. The lowered mg# of silicates forming the B harzburgites corresponds to those produced experimentally by reaction of mantle lherzolites with alkaline silicate melt (Tursack and Liang 2012 and references therein). We suggest that the B peridotite group of subcontinental lithospheric mantle originated due to percolation of this kind of melt in a depleted peridotitic protolith. The high-pressure basaltic melts are undersaturated in ortho- and clinopyroxene in lower pressures, but melt chemical evolution due to reaction with surrounding peridotite and temperature decrease leads to saturation in ortho- and, in more advanced stages, in ortho- and clinopyroxene (Kelemen et al. 1992). We suggest that B harzburgites were formed in systems in which orthopyroxene was dissolved or precipitated, depending on local conditions, but clinopyroxene was dissolved. This affected the modal content of phases leading to formation of harzburgites of varying orthopyroxene contents and changed mineral's major element composition.

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Kelemen, P.B., Dick, H.J.B. and Quick, J.E., 1992. Formation of harzburgite by pervasive melt/rock reaction in the upper mantle. Nature, 358(6388): 635-641.

Experimental study of serpentine dehydration

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Serpentinites are rocks formed at the oceanic floor by peridotite hydration and carry significant amounts of water to the mantle wedge via oceanic lithosphere subduction. Antigorite is the high temperature phase of the serpentine group, it can contain up to 13 wt% water. Its breakdown at depth then involves water release and triggers partial melting of the mantle wedge. In this study, phase relationships occurring during dehydration of natural antigorite have been experimentally investigated at 3 GPa as a function of temperature and time. Experiments have been conducted in a multi-anvil apparatus at the Laboratoire Magmas et Volcans in Clermont-Ferrand, France. The starting material is natural antigorite put in contact with either dunite or forsterite. Most of the experiments were performed in the chlorite stability field (700°C) for durations from 3 to 12 hours. The initial antigorite contains inherited oxides minerals such as spinel and magnetite, we were therefore able to characterize both oxides and silicate phases (remaining antigorite, enstatite, olivine, chlorite) according to different run duration of experiments.

Cracking cratons & the China syndrome

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Cratons are synonymous with the presence of Archaean crust (>2.5Ga) and an underlying mantle keel of Fe poor/Mg rich peridotites. Cratonic lithosphere is tectonically stable & devoid of volumetrically significant volcanism (<2.5Ga). Low heat flow (shield geotherm), thick crust (*ca.* 40-50km) and a deep lithosphere-asthenosphere boundary (*ca.*200km) define a high velocity seismic lid. Most cratons are stable but a rare case of a failed craton exists in the eastern part of the North China Craton [ENCC] which has a present-day "basin & range" crust-mantle structure (*i.e., high heat flow, shallow low velocity zone, volcanism & tectonic activity*). The timing of failure of the ENCC is well constrained at *ca.*125Ma with the loss of 80% (>120km) of the mantle keel. Coveniently on-craton kimberlite-borne xenoliths (early Phanerozoic) define the nature of the craton prior to re-activation as does the western part of the NCC.

Wetting cratons? The NCC has been affected by subduction-related processes over a prolonged period of time including deep subduction of the Yangtze plate. Recent seismic tomographic models indicate a slab graveyard at ≤660km, supporting palaeo-Pacific subduction as active within the upper mantle to the east of the craton. Normally destructive plate margin processes build continents so a fundamental change must have happened to allow subduction processes to destroy stable continents. If upwelling hydrous fluids are the key to destruction one might expect enhanced water contents in the mantle rocks, evidence of hydrous fluid-peridotite interaction, & silica enrichment. None of these are widely reported and to date mantle peridotites from the NCC [and Kaapvaal] have *low water contents*. So the accreted mantle is dry with little evidence of extensive rehydration. Without hydration the mantle would have remained strong, viscous & highly resistant to failure. *So how and why did the craton fail beneath North China but survive beneath South Africa/Kaapvaal? Was focused, instead of pervasive, wetting associated with cratonic failure in North China? Is it significant that Kaapvaal sits atop a major deep mantle upwelling (plumes) whilst the NCC has been, and is, closely associated with subduction zones.*

Cracking cratons? Discontinuities or faults provide crucial pathways for the ingress of fluids that help focus fluid-assisted deformation and have been described and imaged within the NCC. The early stages of craton failure may be preserved in the WNCC where seismic tomographic models reveal major trans-lithospheric discontinuities. The Tan-Lu fault traverses the ENCC and is associated with (a) sheared mantle xenoliths, (b) mafic igneous provinces, & (c) high heat flow/thinnest crust. *Did these strike-slip sub-Moho faults play a key role in initiating craton failure at 120Ma since they active in the Jurassic-Cretaceous period?*

Future research We are currently exploring mechanical hypotheses in which local volume changes triggered by melts (*i.e., carbonate & silicate*), and the production of heat & excess volatiles may play a vital role in the "swelling" and cracking of strong cratons. Even a ~1% local volume increase will generate GPa-level stresses if the surrounding lithosphere is too viscous (*i.e., dry*) for these elastic stresses to quickly relax. These volume changes can further crack vertical strike-slip faults, with serpentinized mantle faults remaining weak. If CO_2-rich gases exsolve at ~80km (~2.7GPa) or deeper then this high-reflectivity horizon can form a horizontal cracking-layer within the lithosphere. *Can these intersecting vertical and horizontal cracking fronts be linked to the rare geologic conditions that allow cratons to crack and fail?*

Thermorheological constraints on the timing of olivine petrofabric development and the significance of measured mantle anisotropy beneath the European Cenozoic Rift System

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Spinel peridotite xenoliths entrained by 4 Ma basanite lava from Kozákov Volcano, located in the Czech Republic along the flank of the Eger (Ohře) Graben in the European Cenozoic Rift System, provide a remarkably continuous sample of the lithospheric mantle from depths of 31.6 to 83.2 km and temperatures of 675 to 1135 ºC. The sub-Kozákov lithospheric mantle is layered, consisting of a medium-grained equigranular harzburgite upper layer (UEL, 32–46 km), a coarse-grained protogranular lherzolite middle layer with spinel-pyroxene symplectite pseudomorphs after garnet (PL, 46–66 km), and a medium-grained equigranular lherzolite lower layer (LEL, 66–82 km). Xenolith and layer depths are constrained by a model geotherm based on heating and protracted cooling of the mantle following underplating at the base of the crust at 35 Ma.

Teleseismic data indicate a regional pattern of subhorizontal rift-perpendicular mantle anisotropy inferred to reflect a consistent preferred orientation of olivine crystal axes and mantle flow. Olivine petrofabrics in the Kozákov xenoliths are characterized by [100] point maxima and [010] girdles, and xenoliths from the UEL exhibit the highest degree of fabric organization, corresponding with olivine M-index and bulk seismic anisotropy values up to 0.38 and 11.24 (AVs), respectively. The degree of fabric organization decreases with depth, and xenoliths from the LEL exhibit weak to no preferred orientation of olivine crystallographic axes (M-index, 0.05; AVs, 3.8).

The cooling history for the mantle beneath Kozákov suggests an evolving olivine rheology that was vertically and temporally partitioned, and we infer that the petrofabrics in xenoliths from different depths record deformation from different time intervals of the 30 M.y. prior to eruption. The thermal pulse provided by basaltic underplating caused a transient (~5 M.y. long) inversion of the vertical viscosity gradient and short-lived high strain rates (>10-13) in the upper-half of the UEL. Stress-strain rate relationships indicated by application of olivine flow laws at cooling rates require that nearly all of the post-underplating strain in the UEL was accumulated within the first 5–10 M.y. and that dislocation creep deformation mechanisms dominated. Conversely, predicted strain rates for the underlying layers continued to increase until the time of xenolith eruption.

We interpret that the measured mantle anisotropy beneath the European Cenozoic Rift System dominantly reflects olivine petrofabric orientations that formed in the UEL during a 5-M.y. spike in deformation following underplating ca. 35 Ma. Additionally, we speculate that feedback between episodic magmatism and thermal weakening of lithospheric mantle results in pulses of transient vertically partitioned flow during continental rifting.

Origin of the lherzolite – megacrystalline orthopyroxenite contact xenoliths from Udachnaya kimberlite pipe

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Peridotite and pyroxenite xenoliths are the unique sources of information about the composition and structure of cratonic lithosphere mantle and an evolution of the Earth as a whole (Kuligin et al. 2003). Udachnaya-East kimberlite pipe (Yakutia, Russia) is likely the most representative on the amount, variability and preservation of the xenoliths. Deformed garnet lherzolites as well as granular lherzolites and harzburgites are common varieties among mantle xenoliths of the pipe.The unique xenolith of megacrystalline garnet orthopyroxenite UV-12-38 (21×13×8 cm), with minor clinopyroxene, olivine, chromite and spinel from Udachnaya-East kimberlite was studied in detail. The nodule comprises two parts: (i) megacrystalline and (ii) fine-grained. The first one consists of 85 vol. % of coarse orthopyroxene crystals (2–6 cm in length). The remaining 15 vol. % are occupied by garnet veins (1–4 mm wide), likely representing exsolution products from initially homogenous solid solution. These veins are dismembered on separate grains by the system of cracks filled by secondary mineralization material including predominantly chromite, serpentine and barite-celestine. The thickness of kelyphitic rims ranges from 1–2 to 40 µm. They are constituted by chromite and pyroxenes. Garnets also occur as individual grains and inclusions in orthopyroxene. Olivines were found as separate grains along the contact of megacrystalline and finer-grained part. The second fine-grained part is lherzolitic and contains relict olivine (1–100 µm), orthopyroxene grains, garnets with wide kelyphitic rims (20–30 µm) and sulfides. This part is observably altered by serpentinisation processes. Major-element compositions of minerals were determined using Cameca Camebax-micro and JEOL JXA-8100 electron microprobes, IGM (Novosibirsk, Russia). Orthopyroxene is mainly enstatitic in composition (Mg# 87-89). NiO content in orthopyroxene increases from megacrystalline part to the border with fine-grained one up to 0.16 wt %. Garnet from veins and inclusions in orthopyroxene can be attributed to websterite paragenesis (Sobolev et al. 1973), whereas granular part contains garnets corresponding to lherzolite, wehrlite and harzburgite parageneses. All garnets from both parts of the sample exhibit similar zoning patterns. Cr2O3 (from 4.5 to 7.7 wt %) and CaO (4.9–8.5 wt %) contents increase from core to rim. The gradual elevation of Cr2O3 (4.5 wt % and higher) from a central part of the xenolith towards the fine-grained lherzolitic part is observed. The highest Cr2O3 (7.7 wt %) content in garnet was measured at the boundary between two parts of the xenolith. Chrome diopside was identified in the intergranular space and is characterized by an admixture of potassium (K2O up to 0.17 wt %) indicating high-pressure formation of the pyroxene and high activity of potassium in a fluid or a melt. Olivine is a forsterite with Mg# 85-86. In lherzolitic part NiO content in olivine varies from 0.4 wt % to 0.47 wt %; Cr2O3 and CaO contents in garnets of this part are generally higher than that in garnets of megacrystalline orthopyroxenite. Xenolith P–T conditions were calculated using the geothermometer of Wood (1990) in combination with the garnet–orthopyroxene geobarometer of Nickel and Green (1985). The studied xenolith from Udachnaya pipe was equilibrated at P–T conditions of 1300 ± 50 °C and 7.2 GPa. However, reconstructed compositions of initial pyroxene crystals suggest that the rock could be formed at higher temperatures under pressures approaching the majorite stability field. Thus, the studied xenolith may represent one of the deepest mantle samples from Siberian craton.

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Kuligin S., Malkovets V., Pokhilenko N., Vavilov M., Griffin W., O'Reilly S. Mineralogical and geochemical characteristic of a unique mantle xenolith from the Udachnaya kimberlite pipe. Abstracts of 8th International Kimberlite Conference, Victoria, BC, Canada, June 22-27, 2003

Nickel K., Green D. Empirical geothermobarometry for garnet peridotites and implications for the nature of the lithosphere, kimberlites and diamonds. Earth Planet. Sci. Lett., 73, 1985. p. 158-70.

Sobolev N., Laurentev Yu., Pokhilenko N., Usova L. Chrome-rich garnets from the kimberlites of Yakutia and their paragenesis. Contrib. Mineral. Petrol., V. 40, 1973, p. 39-52.

Zoisite-grossular exsolutions in omphacite of corundum-bearing eclogite from Siberian craton

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Four new samples of corundum-bearing eclogites from the Obnazhennaya kimberlite pipe in the northern Siberian craton contain clinopyroxene with exsolution lamellae. This type of texture, which is rare in mantle eclogites, reflects changes in P-T conditions (e.g. decreasing temperature and/or increasing pressure). The primary mineralogical assemblage of these eclogites is omphacite-garnet-corundum. The clinopyroxene is usually poikiloblastic (1-2 cm) with euhedral inclusions of corundum (1-2 mm) and garnet (1-2 mm). Late-stage minerals form coronas around garnet with rare grains of kyanite around corundum. The clinopyroxene shows numerous fine exsolution lamellae of grossular-rich garnet and zoisite oriented along crystallographic planes. The major element compositions of minerals vary greatly between primary phases and exsolution lamellae in the same sample. The compositions of clinopyroxenes and garnets place these eclogites in group B with an extension to group A for clinopyroxenes and group C for garnets. The clinopyroxenes range broadly in Al2O3 (6-19 wt%), but not in Na2O, which remains constant and relatively low (~ 4wt%). By comparison, MgO (7-13 wt%) and Na2O in clinopyroxene are negatively correlated. These characteristics clearly differentiate the corundum-bearing eclogites from the Udachnaya eclogite suite. Krogh (1988) thermometer was used to calculate the equilibrium temperatures; pressures were estimated by projecting the temperature estimates to a geotherm for Obnazhennaya (Taylor et al., 2003). The temperature ranges from 950 to 1100°C and pressures from 4 to 4.7 GPa. These conditions are significantly higher in T and lower in P than those calculated in the central Siberian craton (Udachnaya) for type B eclogite. This raises the question if zoisite, a hydrous mineral (~ 1.7 wt% H2O), can be stable in these rocks at these P-T conditions. The scarce experimental data on the zoisite stability at high P-T conditions in the literature (Poli & Schmidt 1998) suggest that zoisite must break down at the P-T values estimated for these samples. Thermodynamic Theriak-Domino simulations were done using reconstructed whole-rock compositions to test the stability fields and to determine the position of mineralogical reactions. The results show that zoisite may be stable below 4.5 GPa and at higher temperatures than those in the literature (<1250° C) if it coexists with a melt. It can be also inferred that the exsolutions of grossular and zoisite can be explained by reaction of the exsolved Ca-Tschermak molecule of omphacite with a pervasive hydrous melt.

Krogh E. (1988) The garnet-clinopyroxene Fe–Mg geothermometer– a reinterpretation of existing experimental data. Contrib. Mineral. Petrol. 99, 44–48.

Poli S. & Schmidt M.W. (1998) The high-pressure stability of zoisite and phase relationships of zoisite-bearing assemblages, Contrib. Mineral. Petrol., 130, 162-175

Taylor et al., (2003) Petrogenesis of group A eclogites and websterites: evidence from the Obnazhennaya kimberlite, Yakutia, Contrib. Mineral. Petrol., 145, 424-443.

Garnet pyroxenites from the External Ligurian mantle sequence (Italy): Evidence for crustal recycling and melt/peridotite interaction

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There is growing evidence that crust-derived garnet pyroxenites are significant components of OIB and MORB sources. In this regard, garnet pyroxenite layers in orogenic massifs may be useful proxy for describing the mixed peridotite–pyroxenite sources of oceanic basalts. The garnet pyroxenite-bearing mantle sequences from the External Ligurian ophiolites were exposed at a Jurassic ocean-continent transition and document an early stage of equilibration in the lowermost continental lithosphere at 2.8 GPa (Montanini et al. 2006). These mantle sequences include frequent websterite layers (commonly 1-10 cm thick) and rare, meter-sized garnet clinopyroxenite layers. The websterites locally form a boundary between garnet clinopyroxenite layers and host peridotites. Clinopyroxenites with preserved garnet have Mg# ranging from 66-71 (Montanini et al., 2012). We recognized clinopyroxenites with marked LREE depletion (CeN/SmN = 0.1-0.2), small positive Eu-Sr anomaly and nearly flat MREE and HREE for LuN = 5-8 (Type-A garnet clinopyroxenites), and clinopyroxenites lacking Eu anomaly and displaying a gradual increase from LREE to HREE (LuN = 13-24; Type-B garnet clinopyroxenites). We have recently found a third type of (retrogressed) garnet clinopyroxenites (Type-C). These rocks are characterized by high Mg# (78-84), slightly depleted LREE (CeN/SmN = 0.4-0.8) and flat to slightly enriched HREE, with LuN = 3-4. Type-C garnet clinopyroxenites display distinct Eu positive anomaly in both whole rocks and clinopyroxene. The websterites showing evidence for a primary garnet-bearing assemblage have higher Mg# (82-90), Cr and Ni, and lower Al2O3, CaO and Na2O than Type A-B-C clinopyroxenites. The REE patterns of the websterites are characterized by moderate LREE depletion and nearly flat to positively fractionated HREE (LuN= 4-15). The Nd-Hf isotopic compositions of Type A-B garnet clinopyroxenites at the time of mantle exhumation (eNd = +4.7 to +7.6, eHf = +4.4 to +12.8) mostly fall below the mantle array, in agreement with recycled ancient MOR-type material (Montanini et al., 2012). The highly radiogenic Hf composition of the Type-C garnet clinopyroxenites, falling above the mantle array, document a time-integrated growth of suprachondritic Lu/Hf ratios originated by ancient garnet fractionation (≥ 550 Ma, assuming a MORB protolith). We ascribe the origin of the garnet clinopyroxenites to melting of gabbro-derived eclogites stored within the mantle and crystallization of garnet-clinopyroxene rocks from the eclogite-derived melts. The compositional diversity of Type A-B-C pyroxenites may be reconciled with heterogeneities of the crustal protoliths and fractional crystallization of the eclogite-derived melts. The trace element composition of computed melts in equilibrium with primary clinopyroxenes from the websterites are compatible with partial melts of gabbro-derived eclogites. Peridotite replacement through olivine consumption and pyroxene + garnet forming reactions by olivine-undersaturated melts derived from partial melting of mafic lithologies may be a viable process for the websterite formation. Two geodynamic scenarios are envisaged for the origin of the garnet pyroxenites from the External Ligurian mantle section: (i) melting of pre-existing lithospheric mafic heterogeneities caused by rifting-related asthenospheric ascent; (ii) infiltration into the lowermost continental lithosphere of melts derived from streaks of recycled crust in the ascending asthenosphere. Both scenarios involve redistribution of crustal melts and crust-peridotite hybridization in the deep subcontinental mantle.

A. Montanini, R. Tribuzio, R. Anczkiewicz (2006) J. Petrol. 47: 1943- 1971
A. Montanini, R.Tribuzio, M. Thirlwall (2012) Earth Planet. Sci. Lett. 351-352: 171-181

Mantle xenoliths from Sardinia (Italy): evidence for reaction between refractory peridotites and carbonatite melts

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The Plio-Quaternary alkaline volcanics from Sardinia include abundant mantle xenoliths which mainly consist of four-phase anhydrous spinel harzburgite and Cpx-poor lherzolites representing the uppermost levels of the Sardinia lithospheric mantle. They are variably depleted rocks generally affected by cryptic enrichment which was ascribed to alkaline silicate melts with EM-like isotope signature (Beccaluva et al., 2001; Rocco et al., 2012). Here we present mineralogical and geochemical data on newly discovered composite harzburgite-wehrlite which record interaction with a carbonatite metasomatic agent.

Composite xenoliths consist of mm- to cm-thick bands of wehrlites cutting previous spinel harzburgites with sharp and irregular contacts. The wehrlites are composed of Cpx (40-50 vol%) + olivine (45-55 vol%) + Opx ($\leq$ 5 vol %) + opaque spinel ($\leq$ 3 vol %) ± Cl-rich apatite. They preserve evidence of replacement of a previous (refractory) harzburgite assemblage, i.e. Cpx + Fo-rich olivine coronas (Fo_{91-92}) developed around Opx and relics of deformed olivine included in the secondary Cpx. Crystallisation of Cpx (+ spinel) as interstitial patches and veins is also observed in the host harzburgites. The metasomatic Cpxs are variably enriched in Cr_2O_3 and Na_2O (up to 2.6 and 2.5 wt%, respectively). The spinels are highly chromian (Cr# up to 0.62) and locally contain carbonate inclusions. The Cpxs from both harzburgites and wehrlites display complex variations of incompatible trace elements. Two types have been recognized: (1) Cpx ranging from slightly to strongly LREE-enriched (La_N = 6-250, La_N/Sm_N = 4-23) with simultaneously increasing HREE fractionation (Gd_N/Yb_N = 1.3-3.2) and increase of absolute HREE concentrations (Yb_N = 2-6); (2) Cpx with more homogeneous compositions, characterized by convex upward REE patterns with strong LREE enrichments (La_N = 50-170) and fractionated HREE (Gd_N/Yb_N = 3-4 for Yb_N = 9-14). All the Cpxs have striking Nb, Zr, Hf and Ti depletions and low Ti/Eu ratios. Type 2 Cpxs most likely reflect equilibration with the reacting melts.

As a whole, the observed reactions, the mineral assemblage described above and the trace element Cpx compositions bear close similarities to those attributed to carbonatite metasomatism in xenoliths from continental (Yaxley et al., 1991, 1998; Beard et al., 2007) and oceanic (Hauri et al., 1993; Coltorti et al., 1999) upper mantle. In particular, the observed Opx-consuming reactions with formation of Cr-Na-rich Cpx + Cr-rich spinel + Fo-rich olivine ± apatite may be ascribed to decarbonation reaction between the host harzburgite and an infiltrating carbonatite melts at $P < \sim 2.0$ GPa. The computed liquids in equilibrium with the Type 2 Cpxs have trace element compositions compatible with average carbonatite melts.

Our results provide robust evidence for the the existence of (ephemeral) carbonatite melts in the lithospheric mantle beneath Sardinia, presumably related to the recent anorogenic magmatism. They may either represent primary melts of a carbonated peridotite or residual melts/fluids from percolating carbonate-rich silicate liquids. Further constraints on the nature and origin of these metasomatic agents are expected from ongoing study of fluid inclusions and their daughter minerals and radiogenic isotope investigations.

Beard et al., 2007 Lithos 94: 1-24
Beccaluva et al., 2001, Contrib. Mineral.Petrol. 142: 284-297
Coltorti et al., 1999, J. Petrol. 40: 133-165
Hauri et al. (1993) Nature 365: 221-227
Rocco et al., 2012 Int. J. Earth Sci. 101: 1111-1125
Yaxley et al., 1991, Earth Planet. Sci.Lett. 107: 305-317
Yaxley et al. (1998), J. Petrol. 39: 1917-1931

Record of subcontinental mantle refertilization: the lherzolite-websterite-hornblendite association from St. Lucia (Corsica)

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The St. Lucia nappe from Alpine Corsica consists of a pre-Alpine crystalline basement, overlain by a Middle Cretaceous detritic cover. The basement represents a fragment of late-Variscan lower crust that was exhumed during Mesozoic continental rifting (Beltrando et al., 2013). The lower crustal rocks include a High Grade Mafic Complex and a Granitoid Complex of Early Permian age (Paquette et al., 2003). The base of the Mafic Complex is associated with up to 50-m thick mantle slices consisting of mylonitic spinel-bearing lherzolites and mm- to cm-thick websterite and hornblendite layers elongated concordantly with the foliation of the host rocks.

The mylonite microstructure in the lherzolites is characterized by aligned porphyroclasts of pyroxene (± spinel) in a fine-grained polyphase matrix composed of olivine + pyroxenes + spinel occurring as mm-size bands, lenses and porphyroclast tails. In the lherzolites, orthopyroxene (Opx) porphyroclasts are stretched along the mylonitic foliation with high aspect ratio. Relics of an older low-strain spinel tectonite predating the mylonite deformation are locally preserved as large exsolved Opx porphyroclasts mantled by neoblastic clinopyroxene (Cpx) + Opx + spinel. The compositions of olivine (Fo = 89 mol%), clinopyroxene (Al_2O_3 = 4.0-6.3 wt%) and spinel porphyroclasts (Cr# = 11-15) of the lherzolites point to a fertile geochemical signature. The websterites are Opx-poor and include disseminated Cr-poor spinel, kaersutite and accessory Fe-Ni sulphides. These rocks have fine-grained granoblastic texture with Cpx porphyroclasts displaying high Al_2O_3 and TiO_2 (5.1-7.2 and 0.9-1.5 wt%, respectively). Temperature estimates for the spinel-facies mylonite recrystallization in both lherzolites and websterites are similar (~850-900°C). The hornblendites are mostly made up of K_2O-rich kaersutitite, Ti-rich phlogopite (TiO_2 ~8 wt%) and ilmenite.

The Cpx porphyroclasts from the lherzolites show heterogeneous trace element compositions. Four different geochemical signatures have been recognized for these Cpx. Type 1 Cpx is markedly LREE-depleted (Ce_N/Sm_N down to 0.05) with nearly flat MREE-HREE at 8-10 times chondrite. Type 2 Cpx is moderately LREE-depleted (Ce_N/Sm_N = 0.31-0.49) and Type 3 has nearly flat LREE. The REE patterns of type 4 Cpx are weakly LREE depleted and peak at MREE; they also show a slight HREE depletion with respect to MREE (Gd_N/Yb_N = 1.1-1.6) and rather variable HREE (e.g. Yb_N = 7-12). The websterite clinopyroxenes have relatively high incompatible trace element concentrations and slightly convex-upward REE patterns. The hornblendite kaersutites are enriched in Rb, Ba, U, Nb, Ta, LREE and depleted in HREE with respect to the websterite ones.

The peridotite protoliths are interpreted as residua after low degrees of fractional melting of spinel facies DM. Computed melts in equilibrium with Cpx and kaersutite from the websterites and the hornblendites suggest transitional to alkaline affinity for the parental melts. Type 4 Cpx most likely reflect equilibrium with infiltrating MORB-type melts. This microchemical investigation has evidenced that the St. Lucia mantle slices experienced injections of melts with MORB to alkaline affinity, associated with metasomatism of the peridotites. Further studies will be devoted to elucidate the possible relationships between these melt injections and the magmatic processes that gave rise to the associated Mafic Complex.

M. Beltrando, I. Zibra, A. Montanini, R. Tribuzio (2013) Lithos 168-169: 99-112
J-L. Paquette, R-P. Menot, C. Pin, J-B Orsini (2003) Chem Geol. 148: 1-120

Self-consistent estimation method for primitive magma compositions by using zoned orthopyroxene phenocrysts to constrain thermal regimes of subduction initiation

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The subduction zone plays an important role in the global material transport; oceanic plates start sinking into the mantle, and continental crusts are generated or eroded there. Although steady state thermal structure and distribution of water in the mantle wedge during successive subduction have been extensively studied by numerical modeling to reproduce geochemical and geophysical observations on the present-day or ancient volcanic arcs (e.g., Iwamori, 2000), the mechanisms of subduction initiation are not well understood. This is because (1) there are a few present-day cases of subduction initiation and (2) it is a short-lived very dynamic and transient process. Information from the ancient subduction zones is indispensable, although it is more fragmental because of decreasing chance of its preservation as it goes back in the Earth's history. In the study of the subduction initiation, temporal change of thermal structure is particularly important because thermal buoyancy inhibits or enhances subduction initiation. Such thermal structure can be revealed by examining generation conditions of magmas formed during the subduction initiation, the principle of which has been applied to estimate the thermal history of the Earth (e.g., Green, 1981; Herzberg et al., 2007). In order to accurately estimate the thermal state of the mantle, crustal processes, such as crystal differentiation, magma mixing, and degassing should be evaluated for precise estimation of chemical composition of the primitive magma. In addition to accurate estimation for individual magmas, temporal and spatial changes of melting conditions on a regional scale must be revealed (Sakuyama et al. 2009) to put stricter constrain on non-stationary features of thermal state during subduction initiation. In this study, we propose a method to estimate primitive magma compositions by using opx exhibiting oscillatory zoning, which is developed based on petrologic and geochemical study of high magnesian andesite (HMA) in the Setouchi volcanic zone.

We investigated an HMA lava exposed at Mt. Kiyama in the central part of NE Shikoku, Japan (e.g., Sato, 1982). It has a primitive composition (SiO2: 57.3wt%, MgO: 8.56wt%, Mg#: 69.3), and it contains olivine, opx, and cpx as phenocrysts. The olivine phenocrysts are normally-zoned, and their highest Mg# (87.6) is lower than the value in equilibrium with the whole rock composition of the HMA. Therefore, the olivine phenocrysts are inferred to have crystallized in a closed system. On the other hand, opx phenocrysts show internal reverse zoning in terms of Mg#, which is sharply drop in the outer zone. Moreover, the reversely zoned Mg# (up to 91.5) is higher than that in equilibrium with the whole rock. Therefore, the opx has a record the composition of more primitive melts mixed into the HMA. Zoning patterns of different opx phenocrysts are consistent, substantiating that they reflect the large-scale mixing events.

The following procedure is adopted to estimate the primitive magma composition. (1) Calculate the melt compositions from opx composition by using compiled distribution coefficients. (2) Compare the change of the melt composition and those expected from fractionation or magma mixing. (3) Estimate mixing ratio and mixing end members by evaluating the pattern of zoning in opx and their frequency ratio (Kuritani, 1998), (4) Estimate primitive magma composition by adding fractionated olivine or opx to the obtained fractionated melt until the melt composition becomes in equilibrium with the opx with the highest Mg# (Putirka, 2005).

Petrological evidence for arc-metasomatized peridotites beneath the mid-ocean ridges

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Here we report for the first time petrological evidence of recycled subduction-modified mantle materials beneath the Mid- Ocean Ridge. We conducted several cruises with submersible SHINKAI 6500 dives and dredges in the south end of the Central Indian Ridges (Phenix knoll). We recovered orthopyroxene-rich lithologies coupled with peridotites and gabbros from a small knoll along the present mid-ocean ridge. The orthopyroxene-rich lithologies can be formed by magmatic processes beneath the present mid-ocean ridges by crystallization from ultra-depleted primary melts (Sobolev and Shimizu, 1993, Nature) in the Mid-Ocean ridge system. Orthopyroxene-rich peridotites are also commonly observed in peridotite bodies of suprasubduction ophiolites (e.g., Morishita et al., 2011 Lithos) as well as in several sub-arc xenoliths (McInnes et al., 2001 EPSL; Arai and Kida, 2000 Island Arc; Arai et al., 2004 J. Petrol; Shimizu et al., 2004 Trans. Royal Soc. London; Ishimaru et al., 2007 J. Petrol). It is also well known that 30% of continental upper mantle samples are enriched in OPX/olivine relative to residual peridotite from partial melting of the primitive mantle (e.g., Boyd, 1989 EPSL; Kelemen et al., 1998 EPSL). Silica-enrichment in the uppermost mantle section under island-arcs is explained by infiltration of silica-rich hydrous fluids/melts derived from subducting slabs. The Re-Os system also supports subduction-metasomatized peridotite origins for orthopyroxene-rich lithologies. The Re-Os isotope system is used for a tracer of recycled crustal materials because oceanic/continental crust possess high Re/Os (parent/daughter) ratios, and develop radiogenic Os isotope compositions over time, which can be readily traced as recycled material if mixed back into the convective mantle. We examined the Os-isotopic compositions of the representative samples: dunite, one harzburgite and one olivine-orthopyroxenite, without signs of petrological and chemical modifications caused by the formation of gabbroic veins. The orthopyroxenite is characterized by a distinctively high in radiogenic Os (187Os/188Os) isotope signatures (0.1475- 0.1499) with relatively high in Re contents (382-402 ppt) whereas the Os isotope of the harzburgite is slightly lower than the present-day depleted MORB mantle (0.123-0.126). High 187Os/188Os ratio coupled with high Os and Re contents of the olivine-orthopyroxenite cannot be accounted for by in situ 187Re decay after interaction between MORBs and peridotites for a million years. Radiogenic Os isotope compositions have been reported for MORB glass, and attributed to the presence of recycled oceanic crust in the upper mantle. Mixing of depleted mantle with exotic component that have an isotopic component with high 187Os/188Os ratios, i.e., radiogenic Os components, are required for the sample. We evaluate the effect of metasomatism of mantle by slab-derived fluids or melts on Os systematics observed in the samples. We conclude that ancient subduction-modified mantle domains, probably formed at continental margin of the Gondwanaland, now exist beneath the Central Indian Ridge.

Os and Hf isotopes in mantle xenoliths from Southern Patagonia: Evidence for Proterozoic SCLM fragments

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Mantle xenoliths transported to the surface by alkali basalts from 6 different outcrops in Santa Cruz Province, Southern Patagonia were studied with focus on their petrography, whole rock and mineral chemistry, as well as their Re-Os and Lu-Hf isotopic compositions. The sample suite collected at Don Camilo, Gobernador Gregores, Tres Lagos and within the Pali Aike Volcanic Field (PAVF) – Salsa, El Ruido and Potrok Aike - comprises sp-lherzolites, sp-harzburgites, one sp-dunite and exclusively within PAVF also sp-gt-lherzolites and sp-gt-harzburgites. Whole rock Al2O3 and CaO contents range from 0.63 to 3.54 wt.% and 0.24 to 3.44 wt.%, respectively and exhibit a linear correlation with MgO ranging from 39.2 to 49 wt.%. Mineral analyses reveal Fo and NiO contents in Ol between 89.4 and 92.2 and 0.38 and 0.44 wt.%, respectively. Cpx are mainly Cr-Diopsides with Mg#*100 between 89.7 and 94.4, compositions of En47-53Fs3-6Wo43-50 and Cr2O3 and TiO2 contents in the range 0.71 to 1.62 wt.% and 0.04 and 0.88 wt.%, respectively. Opx with composition En89-91Fs8-10Wo0.7-2.3 have Mg#*100, Cr2O3 and TiO2 contents between 90.1 and 92.6, 0.23 and 0.85 wt.% and 0.01 and 0.25 wt.%, respectively. Cr#*100 and Mg#*100 in sp range from 6.5 to 56.1 and 57.2 to 77.5, respectively. Gt in PAVF sp-gt-peridotites is pyrope with compositions Alm13-16Py71-74Spess0.6-0.7Gross11-13 and Cr2O3 contents between 1.18 and 1.64 wt.%. The Re-Os isotopic system provides information on the potential formation age of SCLM domains. We have analyzed 24 modally unmetasomatised sp-lherzolites and sp-harzburgites and their Re-Os isotopic composition reveals Neo- to Paleoproterozoic rhenium depletion ages (TRDs). Don Camilo and Gobernador Gregores – located within the Deseado massif – indicate a formation of the SCLM in Mesoproterozoic times (0.9 to 1.3 Ga). Tres Lagos SCLM seems slightly older with a max. TRD of 1.7 Ga. Measured 187Os/188Os ratios in PAVF samples vary more strongly and lead to Neo- to Early Paleoproterozoic TRDs. TRDs of 3 refractory samples indicate an at least 2.45 Ga old formation age of the SCLM domain underneath PAVF. SCLM formation ages obtained from Os isotopic analyses combined with Hf isotopic data provide important information on potential metasomatic overprints. Cpx of the 24 samples analyzed for Re-Os were separated and Hf isotopic ratio were conducted by MC-ICP-MS. Negative to low positive εHf values (-7.7 to +6.6) for cpx separates from Early Paleoproterozoic samples from PAVF indicate ancient Hf addition shortly after SCLM formation. PAVF samples with "younger" TRDs yield variable εHf values between -17.1 and +23. Samples from Tres Lagos show slightly higher εHf values between +15.2 and +52 and mantle xenoliths from within the Deseado massif yield εHf between +5.8 and +41.5. According to the information obtained from Hf isotopic compositions, the majority of the samples show metasomatic overprint of different degrees. This correlates with cpx laser ablation and whole rock trace element data revealing an enrichment of LREE and/or MREE over HREE in most of the samples. Proterozoic mantle formation ages lead to the conclusion that at least the southern part of Patagonia was situated close to Proterozoic domains of Southern Africa and Antarctica during supercontinents Gondwana and Rodinia. The evolution of Neo- and Mesoproterozoic domains might be connected to the evolution of the Namaqua-Natal orogenic belt lying adjacent to the SE margin of the Achaean Kaapvaal Craton while Early Paleoproterozoic mantle fragments from Pali Aike could be an exotic microplate that accreted during the Mesoproterozoic formation of Rodinia. The strain localization in the pyroxenites is explained by their more fertile composition, which allowed earlier onset of the phase transformation reactions. Geothermobarometry undertaken on compositionally zoned constituent minerals of the pyroxenite suggests this positive feedback between reaction and deformation is associated with cooling from at least 1000 °C to 700 °C and decompression from 1.0 GPa to 0.5 GPa. In the peridotite mylonite shear zone we propose that the switch of dominant slip systems is the result of preferential reutilization of favorably oriented slip planes of earlier deformation events. Overprinting of pre-existing structures can be achieved by a rapid change in the kinematic regime, such as the back-arc basin inversion proposed to be responsible for large scale folding at the base of the Ronda mantle section.

Ultra-fine textures along grain boundaries in nominally fresh mantle xenoliths

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It is important for the evolution of the Earth to understand the role of grain boundaries during melts/fluids migrations in mantle peridotites. There are, however, very limited numbers of studies on grain boundaris in natural samples, although many experimental and theoretical approaches have been carried out (e.g., Drury and Fitz Gerald, Geophys. Res. Lett., 1996; Hiraga et al., Nature, 2004).

We focus on nanoscale microstructures of crystal surface (grain boundary) in "nominally fresh" peridotite xenoliths from the San Carlos, USA, which is one of the most famous localities of peridotite xenolith in the world. Thin amorphous films along grain boundaries were already reported in some San Carlos xenoliths (Wirth, Contrib. Mineral. Petrol., 1996). We recovered mineral grains with a selFrag at the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) in order to minimize mechanical damages during mineral separations. We observed multiple grains of peridotite xenoliths using a high-resolution electron microscope (FE-SEM) at JAMSTEC.

Microstructures of crystal surface of these peridotite xenoliths are classified as follows. (1) over micron scale structures such as moth-eaten structures, vermicular structures, automorphic crystals and etch pits. (2) submicron scale structures. It is interesting to note that (2) submicron scale structures are frequently observed on (1) over micron scale structures. These textures suggest that microstructures were developed by several stages. We analysed on the surface of these textures using a micro-Raman and SEM-EDS techniques. We are also planning to perform transmission electron microscope, combined with chemical analyses in order to identify the surface materials that constrain P-T conditions and fluids for the formation of these textures.

Mantle mineralization of the “Chompolo field” kimberlites (South Yakutia)

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Kimberlite field "Chompolinskoe" is located in southern Yakutia, within the Aldan diamondiferous province (ADP). In this field there are 10 intrusive bodies – dikes, veins with length 360-800 meters and pipes with a diameter 60-110 meters. In geological terms kimberlitic field is located within the Central Aldan superterrane of Aldan-Stanovoy Shield, that represented by granulite-orthogneiss complex of Archean and Paleoproterozoic ages with the metamorphism peak 2.1-1.9 Ga (Smelov, Timofeev, 2007). The age of kimberlites after geological data is pre-Jurassic (Vladimirov et. al., 1989) and 233.7±2.2 Ma after 40Ar/39Ar method (unpublished data by Ashepkov I.V.). The results of isotopic age determination (Rb-Sr isochron method) of kimberlite-like body named "intrusions 104" are also available and indicate later age of 131±4 Ma (Zaitsev, Smelov, 2010). The material for investigation was collected after field works on "Chompolo field" in 2012-2013. Heavy mineral concentrate was taken from six kimberlite bodies (Aldanskaya, Sputnik, Gornaya, Ogonek, Perevalnaya, Kilier-E). Preliminary investigations showed that most of the kimberlites characterize by mineral association consisting of pyropes, clinopyroxenes and chromites. Pyrope chemical composition reflects the presence of mantle and crust varieties. Mantle mineralization prevails in Aldanskaya, Sputnik, Gornaya, Ogonek kimberlite pipes, crust and eclogite mineralization is a characteristic of Perevalnaya and Kilier-E pipes. Among mantle garnets several usual types are absent – megacryst, verlite and high-temperature lherzolite garnets. Dunite-harzburgite paragenesis always present in small amount without subcalcic high-Cr varieties. Most of mantle garnets are presented by lherzolitic paragenesis. Among depleted lherzolite garnets shallow-lherzolite type predominates over deep-seated lherzolite type. Nevertheless, there are garnets of deep-seated lherzolite paragenesis with content knorringite minal, in an amount up to 7.7 mol.% (Kostrovitsky, Garanin, 1992). Garnets of deep crustal granulites prevail among garnets of crustal origin. The estimates of lithosphere thickness were performed by single-mineral garnet barometer P38 (Grutter et al., 2006) and single clinopyroxene thermobarometer (Nimis et al., 2000). In the first case the lithosphere thickness is not less than 110 km (3.3 GPa), in the second case proved to be about 130 km (4.1 GPa). Pressure of P38 barometer can be underestimated because of Cr lack in the system. Temperature and pressure points place along the 35 mW/m2 geotherm. Geotherms for most of pipes have a tipical bend in the high-pressure side, indicating the processes of depleted lithosphere interaction with enriched and hot melts of the asthenosphere origin. Heat flow of 35mW/m^2 is typical for ancient (more than 2.5 billion years) and thick (up to 300 km) cratonic lithosphere. In this case the heat flow does not consider with maximum death lithosphere sampling (130 km), although the age of Aldan shield crust more than 2.5 Ga. We can assume that this is a relic geotherm that characterize ancient lithosphere of the region which later became thinner as a result of lithosphere erosion.

Smelov A.P., Timofeev V.F. Gondwana Research. 2007, 12, p. 279–288
Zaitsev A.I., Smelov A.P. DPMGI SB RAS. Yakutsk. 2010, p. 108
Kostrovitsky S.I., Garanin V.K. Zapiski RMO. 1992, 1, p. 67-72
Vladimirov B.M., Dauev Yu.M., Zubarev B.M. et al. M: TsNIGRI. 1989, 1, p. 216
Nimis P., Taylor W. Contrib. Mineral. Petrol. 2000, V. 139, 5, p.541-554
Grütter H.S., Latti D., Menzies A. Journal of Petrology. 2006, 47, pp. 801–820.

Petrological, geochemical and isotopic evidence for lithospheric delamination underneath Far East Russia

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In the back-arc environment of Far East Russia, mantle xenoliths from Sikhote-Alin (KO) and Primorie (SV), Far East Russia are fertile spinel lherzolites with amphibole, phlogopite armalcolite, fassaite and röhnite in some of the studied samples. Though samples from both localities are fertile there are systematic difference in their petrographic features, fertility and T-conditions. The KO xenoliths are coarse-grained with protogranular texture whereas the SV are fine-grained with transitional textures from protogranular to equigranular. The KO samples have mg# varying from 0.891 to 0.899 and are slightly more fertile than the SV samples that have mg# ranging from 0.898 to 0.904. Clinopyroxenes from both localities have concave upwards PM-normalized REE patterns with different (La/Yb)N that range from 0.10 to 1.00 in the KO xenoliths and from 0.15 to 1.73 in the SV xenoliths. Two kinds of amphibole were found in both suites: (1) disseminated amphiboles and (2) fine-grained amphibole blebs present in some clinopyroxenes. The disseminated amphiboles, compared to the clinopyroxenes, have higher (La/Yb)N ratios (~3.3) and are enriched in Nb, Ta, Sr. On the other hand the amphibole blebs have trace element abundances almost similar to clinopyroxenes.The KO xenoliths exhibit equilibration temperatures that vary from 940 to 1030°C whereas the SV xenoliths equilibrated at markedly lower temperatures between 770 and 940°C. The clinopyroxene Sr and Nd isotopic ratios range from 0.702599 to 0.703567 and 0.512915 to 0.513153, respectively showing substantial overlap with Pacific MORB isotopic ratios. En route breakdown of disseminated amphibole produces second generation of clinopyroxene and olivine and traces of glass as well fassaite and röhnite indicating crystallization at very shallow depths. Melt pockets consisting of Ca-rich glass, plagioclase, rutile, ilmenite and armalcolite and Ca-Zr armalcolite, suggest introduction of small amounts of an unusual Ti-Ca-rich anhydrous highly silica undersatutrated melt with carbonatitic components at mantle depths. The reaction of the Ti-Ca-rich melt with clinopyroxenes resulted in the formation of a spongy rim consisting of clinopyroxene rich in MgO and CaO, poor in Al2O3 and of a silca poor glass lacking entirely K2O precluding the contribution of host basalt infiltration. Model calculations reveal that the studied spinel lherzolites represent the residue after batch melting of up to 5% of a primitive mantle. The lithopsheric mantle underneath Far-East Russia experienced modal metasomatism immediately before the entrainment of the xenoliths in the host basalt. This can be inferred from the unmetasomatized nature of the clinopyroxenes (concave upward Primitive Mantle-normalized clinopyroxene REE patterns, high Nd- and low Sr- isotopic ratios), which is unexpected if the dwell time of the metasomatic agent in this particular lithospheric mantle was long. Despite the fact that the studied area experienced several subducting episodes, the lithospheric mantle appears to be insignificantly affected from the upwelling fluids/melts of the subducted slab(s). The unusual Ti-Ca-rich melt is rather of carbonatitic-silicate origin. Since there is no indication for plume activity, and/or evidence for refertilization, it is likely that the lithospheric mantle has been delaminated as the result of tectonic events (lithospheric attenuation, inverse tectonic) associated with the subduction processes and that the studied spinel lherzolites represent upwelling asthenosphere.

Updating metasomatism concepts: Stealth, densification, and geophysical consequences

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The concept of "stealth" metasomatism has been introduced (O'Reilly and Griffin, 2012) to highlight the "deceptive" addition to lithospheric mantle rock-types of new phases (e.g. garnet and/or clinopyroxene) indistinguishable mineralogically from common mantle peridotite phase assemblages.

Recognition of stealth metasomatism reflects the increasing awareness of the importance of refertilisation of ancient refractory mantle regions by metasomatic fluid fronts in modifying the composition (and physical properties) of mantle domains. Recognition of stealth metasomatism is critical to unraveling the geochemical and geodynamic evolution of the lithospheric mantle, and more accurately estimating the composition (and transformation with time) of primitive ancient subcontinental lithospheric mantle (SCLM). Tectonically exposed peridotite massifs provide an opportunity to study spatial relationships of metasomatic processes, including the nature of stealth metasomatism, on m to km scales.

Metasomatism affects not only the geochemical characteristics of the lithospheric mantle, but also its physical parameters (and hence geophysical signatures) including density, seismic response and thermal characteristics (heat production, mantle thermal gradient).

Primitive Archean lithospheric mantle is highly magnesian and has a relatively low density (~3.31 g/cm^3) compared to fertile mantle (~3.37 g/cm^3). Resulting contrasts in seismic response become measurable if metasomatised regions are on the scale of tens to hundreds of km (Griffin et al., Lithos online 2014). Geophysicists commonly interpret lateral variations in seismic velocity in terms of temperature variations, but up to 20% of the observed range in S-wave velocity at depths of 100 -175 km in the continental mantle can be attributed to compositional differences. Strong gradients in Effective Elastic Thickness correlate well with zones of kimberlite intrusion and metasomatised mantle, and with inferred translithospheric sutures. These observations suggest that metasomatic refertilisation of the cratonic SCLM not only lowers its density, but strongly affects its rheology.

Thermal changes are caused by advective transfer of heat by relatively hot metasomatising fluids and by the influx of heat-producing elements (K, U, Th) that accompanies some types of metasomatic enrichment. The heat produced by radioactive decay of these elements can raise the local heat flow by 50-70% compared to the normal reduced mantle heat flow.

The origins of electromagnetic (MT) responses in the lithospheric mantle have not yet been satisfactorily identified. The global 3-D model of Earth's electrical conductivity (Kelbert et al. 2009) reveals significant spatial variations in conductivity especially in the Transition Zone (410 – 670 km depth). High values correlate with domains of high seismic velocity where subducted slabs have ponded at, or penetrated through, the Transition Zone and are interpreted as reflecting high water/fluid contents. Interconnecting carbonate films (Gaillard et al. 2008) are also highly conductive and can wet grain boundaries in mantle rocks. Fluid-related recrystallisation demonstrated in microstructural studies may also result in significant H contents in mantle minerals and may affect electrical conductivity. The key to understanding the electromagnetic signals from the mantle lies in identifying the nature of fluids and their distribution and thus is closely connected with a full understanding of metasomatic processes and fluid movement in the mantle.

O'Reilly, S.Y. & Griffin, W.L. 2012. in Metasomatism and the Chemical Transformation of Rock, Springer-Verlag pp 467-528.

Contrasting P-T histories recorded in exhumed mantle peridotites and its implication in lithosphere-asthenosphere interaction

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Pressure and temperature history of exhumed mantle peridotites shows significant diversities, which may be attributed to several factors such as: (1) lithospheric thermal gradient before exhumation, (2) rate of tectonic motion and thermal and mechanical conditions during exhumation, (3) thermal perturbation shortly before or during exhumation of lithosphere such as episodic asthenospheric thermal convection with lithosphere erosion and related magma generation/transportation, (4) lithosphere formation or growth from asthenosphere through melting and melt separation and subsequent exhumation. These factors may, conversely, be estimated from the mantle peridotites if each effect can be isolated from the others. The first factor is recorded as the initial condition of exhumation potentially providing information on steady-state mantle heat flow. The second is recorded as compositional zoning of minerals in terms of elements sensitive to PT change. Among these factors, (3) and (4) represent direct thermal and mechanical lithosphere-asthenosphere interactions and are examined by whole-rock compositions and its heterogeneity constraining thermal condition of melting and melt segregation processes. The following cooling and thermal relaxation are recorded as compositional zoning in minerals and chemical heterogeneity in a composite lithology over the scale of more than a few centimeters. These approaches are similarly applicable to any types of mantle peridotites such as orogenic peridotites, mantle section of ophiolites, and mantle xenoliths in alkali basalt and kimberlite. Xenoliths provide instantaneous thermal states of the mantle up to the depth as deep as a few hundreds km, and is superior in examination of (1) and (3). Contrary to this, intrusive peridotites always underwent slow exhumation process more or less obscuring steady lithospheric information, and is superior in examination of (2) and (4). Following the above strategy, thermal histories of three peridotite bodies from world orogenic belts are compared. These are the Horoman peridotite in the Hidaka belt, Bestiac peridotite mass in the Pyrénées, and Ronda in the Betic Cordillera. The common feature of these peridotites is that they were initially resided in the garnet stability field before decompression. There are, however, several distinctions: (1) garnet in any rock types is completely transformed into low pressure mineral assemblage (symplectite) in Horoman, garnet in pyroxenites remains but that in peridotites is completely transformed into symplectites in Bestiac, and garnet remains in peridotites as well as in pyroxenites in Ronda, (2) orthopyroxene in garnet- or symplectite-bearing rocks shows remarkable M-shaped Al zoning in Horoman, weaker but distinct M-shaped in Bestiac, and very weakly developed in Ronda, (3), orthopyroxene in peridotite and pyroxenites has a Ca-rich margin in Horoman, but such features are not common in Bestiac and Ronda, and (4) topotaxy is always established in two-pyroxene spinel symplectite in Horoman (Odashima et al., 2008) but not so in Ronda (R. Nagashima, personal communication). These systematic relationships suggest that dP/dT was very small or even negative in Horoman (~adiabatic or heating during exhumation), moderate in Bestiac (~adiabatic), and large in Ronda (effective cooling with decompression). It is inferred that exhumation accompanying active asthenospheric thermal perturbation took place in Horoman, passive exhumation in Bestiac, and transportation towards the cooler region in Ronda, in spite of the suggested asthenospheric thermal perturbation in the spinel and plagioclase facies in Ronda (Garrido et al., 2010).

Silicate melt inclusion study in wehrlite xenoliths from the Nógrád-Gömör Volcanic Field (Northern Pannonian basin, Hungary)

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Silicate melt inclusions (SMI) provide unique opportunity to study the composition and physical features of migrating melts related to deep lithospheric processes, which regularly end up trapping melt as inclusions in upper mantle environment.

The Nógrád-Gömör Volcanic Field is situated in the northern part of the Carpathian-Pannonian region and is one of the five occurrences where Plio-Pleistocene alkaline basalts brought upper mantle xenoliths to the surface. We focused on the central part of the region, from where great numbers of ultramafic xenoliths have been collected and detailed petrographic studies have been carried out.

As a result, in addition to dominating lherzolite xenoliths, large numbers of wehrlite xenoliths have been found with high modal proportion of clinopyroxeneand a nearly total lack of orthopyroxenes. Wehrlite xenoliths show characteristic lithological features containing olivine- and clinopyroxene-rich assemblages. The former can be characterized with coarse-grained olivines having straight grain boundaries and occasionally enclosing orthopyroxene relicts, whereas the latter contain rounded olivines and vermicular spinel inclusions hosted in irregular shaped large clinopyroxenes.

In clinopyroxenes and olivines of the wehrlite xenoliths great number of silicate and sulfide melt inclusions can be identified. In this poster we focus on clinopyroxene-hosted silicate melt inclusions (SMIs). At room temperature these SMIs are rounded, partially crystallized, have a size of 20-60 μm in diameter and are not connected to any healed fractures or pathways but they form clusters or show scattered appearance. Therefore their origin is thought to be primary to their host minerals and could have been associated to process(es) that caused formation of clinopyroxenes beneath the studied area. SMIs consist of glass, tiny clinopyroxene, spinel, amphibole, mica and ±apatite crystals.

Five wehrlite xenoliths have been selected for a detailed SMI geochemical study. As a result, bulk composition of the SMIs depict a pattern which is slightly depleted in incompatible elements but enriched in Si content compared to the host basalts. These suggest the mixing of a Fe- (Mn-, Ti-, Al-) rich mafic melt, migrating though the mantle, with a local Si-rich melt, derived from incongruent melting of the currently missing orthopyroxene, causing pervasive metasomatism during its interaction with the peridotitic wallrock. Strong geochemical similarities of the SMIs in each studied xenoliths confirm that an extensive mantle metasomatism transformed a large portion of lherzolite to wehrlite.

Tectonic and magmatic processes during passive rifting of the Ligurian Tethys: the study case of Erro-Tobbio peridotite (NW Italy)

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Slow-ultraslow passive extension of the continental lithosphere of the pre-Triassic Europe-Adria realm led to early a-magmatic rifting and subsequent magmatic rifting, followed by continental splitting and slow-ultraslow sea-floor spreading. We investigate the structural, petrologic and compositional features recorded by strongly deformed and melt-percolated Erro-Tobbio peridotites (Voltri Massif, NW Italy), in order to demonstrate that the processes of shear zones formation and melt percolation during the passive lithospheric extension were intimately linked by a positive feed-back. Previous studies revealed that the mantle protolith has been deformed by up to km-scale shear zones which developed a tectonitic-mylonitic foliation under spinel- and plagioclase-facies conditions in the absence of melts. In this paper we focus on spinel and plagioclase peridotites and extensional shear zones which show clear structural and compositional records of reactive infiltration of upwelling asthenospheric melts.

Recent numerical models addressing the physical processes underlying extensional systems show that, in the case of slow-ultraslow continental extension and formation of slow-ultraslow spreading oceans, a previously un-patterned lithosphere may lead to formation of shear and porosity localization bands, in the absence of melt. Shear and porosity bands, developed during extension prior to melt infiltration, represent important structural and rheological pathways to facilitate and enhance melt infiltration and ascent into the extending lithosphere to shallower levels. Similarly to peridotites from the fossil slow-ultraslow spreading Ligurian Tethys, asthenospheric melts percolated via porous flow in the extensional system and stagnated at shallow lithospheric levels (the hidden magmatism). Melt thermal advection and "asthenospherization" up to shallow lithospheric levels caused dramatic changes in the thermal regime of the extensional system, leading to significant rheological weakening and softening of the axial zone of the extensional system. Our field, structural and petrologic investigations of the Erro-Tobbio peridotites thus allow to propose a model for inception of continental extension to rifting/drifting of slow-ultraslow spreading oceans, as evidenced by the:

1) the sub-continental lithosphere was firstly extended and thinned by the development of shear zones, that could have developed from early-stage shear and porosity bands in the absence of melt in the system (a-magmatic passive rifting);

2) the structured mantle peridotites were subsequently infiltrated by reactive melts, produced by the partial melting of the upwelling asthenosphere, both channeled along the previously melt-free structural/rheological bands and percolating by diffuse porous flow through the host peridotite, along the thinned axial zone of the extending mantle lithosphere (magmatic passive rifting);

3) this ingress of melts in the extensional system during rifting and the related melt thermal advection led to formation of a wedge-shaped axial zone characterized by strong weakening and softening between the future continental margins;

4) deeper and hotter asthenosphere may find a preferential pathway for active upwelling and "intrusion". In this scenario, the divergent forces induced by the active upwelling asthenosphere may compete with far-field tectonic forces and even drive the system causing a change from passive rifting to active rifting and the installation of a ridge-type system.

Aggregated MORB melts intruded within,and extruded above exhumed and sea-floor exposed lithospheric peridotites (the oceanic MORB magmatism).

Mantle metasomatism of megacrystalline peridotites: chromspinelide and phlogopite from the xenoliths of Udachnaya kimberlite pipe (Yakutia)

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Megacrystalline harzburgite-dunites are rare peridotite rocks, which were met in single kimberlite pipes. The rocks are composed of nearly pure olivine (90% and more) - one, rarely 2-3 megacrystals. Less than 10% of rocks make up a Cr-pyrope garnet ± enstatite ± chromite. Chemical composition of the minerals is identical to that of mineral inclusions in diamonds.

Several generations of spinelides were found in these rocks:

1) Primary chromite (content Cr_2O_3 34-66 wt%) with the typical zoning «centre-edge» and magnetite rim. Fe^{3+}/Fe^{2+} changes from the centre of grain to the edge: 0,14→0,5→to 1.4, then in the rim to 1.96, demonstrating the increasing potential of oxygen during the formation of chromite, then during the formation of the rim.

2) Chromian spinel with a wide range of compositions from the interstitium and microcracks, filled by the low iron serpentine in association with calcite, apatite, ilmenite, high magnesia Ba-containing phlogopite, magnetite, perovskite, sulfides. Fe^{3+}/Fe^{2+} of chromspinelide changes from the centre of grain to the edge: 0,5→2,3. Here as well, too, the increase of oxygen fugacity during the formation of spinelides is observed.

3) The inclusions of chromite in pentlandite, bordered with djerfisherite. This sulphide, measuring about 180 mm, was found in olivine grain of megacrystalline dunite. The chromite ingrowths are present in the central parts of sulfide and on its surface. Fe^{3+}/Fe^{2+} varies from center to edges 0,38→0,77→0,87.

4) Chromian spinel from the rim1 and rim2 around pyrope. Kelifitic rim1 is located between garnet and surrounding olivine.

The thickness of the rim varies from first microns up to 400 microns. There is a gradual or abrupt enlargement of the rim minerals in the direction from garnet grain to the periphery of the rim. In addition to the typical kelifitic minerals (Al-pyroxenes, spinelide, amphibole, phlogopite), sodalite, calcium carbonate, potassium feldspar, magnetite, sulfides were found in the rims of the investigated samples. Phlogopite rim2 (thickness up to 60 microns) is continuous or broken tape around rim1, sometimes together with enlarged of the same name minerals of rim1. pinel ($MgAl_2O_4$) prevails noticeably in rim1 and in the edges of rim2 spinelides; chromite ($(Mg,Fe)Cr_2O_4$) predominates in the central parts of rim2 spinelides.. Fe^{3+}/Fe^{2+} changes from rim1 to rim2: 0,78→0,37. Spinelides of rim2 began to form in redox conditions of continuing growth of the rock-forming chromite and formation of chromite inclusions in sulphide. The final stage of their growth coincided with the emergence of rim1 spinels. Phlogopite is present in all types of rims around pyrope and has wide compositional variations in Ti, Mg, Fe. Zonal phlogopite rims were observed in two samples, instead of the normal kelifitic rims (rim1) and their borders (rim2). Content of Cr_2O_3 in some areas of phlogopite exceed that in the rock forming pyrope. The unusually high Cr# (Cr/(Cr+Al)) of these phlogopites can be attributed to the highly reducing conditions of their formation, or nano-crystalline ingrowths of chromite. However, the studies of these phases on scanning microscopes have not revealed such inhomogeneities of composition. The compositional variations in spinelides and phlogopites of different generations, their zonality and nonequilibrium suggest the abrupt changes in the PT and redox conditions, which took place immediately before the explosion and rocks rise to the surface. The presence of high-chromium phlogopite and chromite ingrowths in sulphide indicates a high activity of Cr in metasomatic fluid on one of the stages of megacrystalline rocks transformation.

Petrological and geochemical features of secondary enrichment of the craton mantle peridotites of the diamond stability field

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Xenogenic upper mantle material in kimberlites carries unique information about the structure, composition and evolution of the ancient craton lithospheric mantle for its vertical cross section from Moho surface up to depth at least 300 km. Very rare finds of majorite-bearing high-Cr subcalcic pyropes inclusions in diamonds with significant content of majorite component definitely are related to depleted lithospheric peridotites of harzburgite-dunite paragenesis, and this fact indicate existence of blocks of extremely thick lithosphere (>300km) inside some cratons. Of special interest are xenoliths the most deep-seated peridotites of the diamond stability field providing perhaps the only opportunity for direct study of the ancient craton lithospheric mantle roots.

We present new results of complex study of harzburgite-dunite xenoliths including their diamondiferous varieties, xenoliths of sheared Cr-pyrope lehrzolites representing of lithosphere-asthenosphere interaction zone and rare xenoliths with clear sings of intensive metasomatic treatment. These results show absence of any significant differences in the P-T conditions of formation for both diamondiferous and diamond barren Cr-pyrope harzburgites and dunites.

Comparative analysis of the geochemical characteristics of subcalcic Cr-pyropes of the diamondiferous and diamond-free harzburgite-dunite xenoliths shows definite distinctions in character and intensity of secondary metasomatic enrichment of diamondiferous and diamond barren roks. The geochemical characteristics of metasomatic agents for the first type of rocks were close to those for carbonatitic melts, and the metasomatic treatment intensity was relatively low. Metasomatic agents in the second case were characterized by significantly higher roles of Ti, Na, Zr, heavy REE, and there was much higher intensity of the secondary enrichment of initial rocks by carbonatitic components especially in Ca, up to appearance of Cr-diopside in harzburgite – prohibited phase in initial ultra-depleted peridotites, and later – up to carbonation of these rocks.

Data about metasomatic treatment related to secondary enrichment of depleted lithospheric peridotites by basanitic components and processes of kimberlite melts generation was obtained from studies of extremely fresh sheared lehrzolite xenoliths from Udachnaya-East pipe, and unique xenolits presenting intermediate stage of process of transformation of ultra-depleted peridotite (harzburgite-dunite) into enriched lehrzolite. Obtained data show that the sheared pyrope lherzolites were intensely deformed under conditions of significant stress pressure in the base of lithosphere, and have a complex evolution of their chemical composition, including stage of partial melting and at least two stages of metasomatic enrichment. A partial melting of the most enriched sheared lherzolites can be related to primitive kimberlite melts formation as well as formation of the kimberlite megacrysts suite.

Of special interest are results obtained from study of sheared lehrzolite and polymict breccia xenoliths related to the processes of the kimberlite formation and providing direct information about processes of kimberlite melts generation and evolution and indirectly related to the processes which occurred at the same time and related to the general activation of cratonic and subcratonic upper mantle.

Lithology of Central European Lithospheric Mantle

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The Oligocene-Miocene alkaline lavas occurring in Lower Silesia (SW Poland) and adjacent part of Upper Lusatia (SE Germany) are related to rifting event which formed the European Cenozoic Rift System (ECRIS) in the foreland of Alpine Orogen. Some of those lavas contain peridotitic xenoliths which are the samples of rocks forming the subcontinental lithospheric mantle at the time of culmination of rifting in the Eger Rift in Bohemian Massif, the easternmost of the ECRIS rifts.

We studied in detail almost 80 xenoliths coming from 8 occurrences (Puziewicz et al. submitted). The xenoliths come from the spinel mantle peridotite facies and evidence that two main lithologies occur in the area, both of harzburgitic composition. The first group of harzburgites (A) are strongly depleted, highly magnesian (olivine Fo 90.5 – 92.0) and are affected by a carbonatite metasomatism, which is commonly overprinted by the silicate melt metasomatism. The harzburgites belonging to the second (B) group are less magnesian (olivine Fo 84.0 – 90.0) and are penetratively metasomatised by percolating alkaline silicate melts (for details see Matusiak-Małek et al. this volume).

The study of A harzburgites shows that they were formed in chromatographic systems in which the silicate melt flow was channelized and metasomatically affected the proximal parts of the systems, whereas only the carbonatite metasomatism is recorded in distal parts of those systems. The harzburgites of group B were shaped by reaction with alkaline silicate melt, which occurred supposedly at the time of volcanism. That metasomatism was mostly anhydrous and typically cryptic. It lowered the Mg/(Mg+Fe) ratio of olivine and orthopyroxene from peridotites subjected to melt percolation and led in places to dissolution of clinopyroxene.

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The trace element chemistry of olivine as proxy of melt-rock reaction in the oceanic lithosphere

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Several recent works on modern oceanic lithosphere and ophiolites have shown that reactions between melt and crystal mush in primitive gabbroic rocks (through reactive porous flow melt migration) have a significant control in the formation of the lower oceanic crust and the compositional evolution of MORBs. The assessment of geochemical and microstructural tools to define mineral-melt reactions in a mantle-gabbroic system is therefore of primary importance. A debated issue in this context concerns the origin of olivine-rich rocks, whether they formed by fractional crystallization of primitive melts or by open system reactive percolation of pre-existing (possibly mantle-derived) olivine matrix. To address this topic, we started a new project on the ideal study case of the Erro-Tobbio ophiolite Unit (Ligurian Alps), where mantle peridotites are intruded by troctolite and gabbroic rocks, and we performed high-quality in-situ trace element analyses (by LA-ICP-MS) of olivine in a pilot selected suite of peridotite and gabbroic samples. Previous work (Rampone et al., 1995; Borghini et al., 2007) documented that the exhumation of the Erro-Tobbio mantle was accompanied by a composite history of melt migration and intrusion. Plagioclase impregnated peridotites show primary gradational contacts with a hectometer-scale body of troctolites (and minor plagioclase-bearing dunites and wehrlites), and both are cut by later decameter-wide lenses and dykes of olivine gabbros. Troctolites and gabbros were interpreted as variably differentiated crystallization products from primitive MORB-type melts (Borghini et al., 2007). Olivines in the three rock types (mantle peridotites, troctolites, ol-gabbros) exhibit distinct geochemical signature and well-defined elemental correlations. As expected, compatible elements (e.g., Ni) show the highest contents in peridotites (2580-2730 ppm), intermediate in troctolites (2050-2230 ppm) and lowest in gabbros (1355-1420 ppm), whereas moderate incompatible elements (e.g., Mn, Zn) show the opposite behaviour. By contrast, highly incompatible elements like Zr, Hf, Ti, HREE are variably enriched in olivines of troctolites relative to olivine in the gabbros, and this is not consistent with the hypothesis that they were simply the result of fractional crystallization from a variably evolved melt. Moreover, the enrichment in absolute concentrations in olivine of troctolites is coupled to the development of significant HFSE/REE fractionation (ZrN/NdN up to 80). Preliminary AFC modeling show that such large ZrN/NdN ratios in olivines are consistent with a process of olivine assimilation and plagioclase crystallization at decreasing melt mass, in agreement with textural observations. Results of this work thus show that the trace element composition of olivine in mantle peridotites amd primitive gabbroic rocks define systematic and reliable trends which can help to unravel their hystory of melt-rock reaction and magmatic crystallization. In the troctolites, differently from olivine gabbros, olivines dysplay significant incompatible element enrichment indicative of dissolution-precipitation processes and re-equilibration with reacted enriched melts. In-situ trace element geochemistry of olivine, possibly combined with CPO measurements, thus appears a powerful tool to investigate reactive percolation and the origin of olivine-rich rocks in the lower oceanic crust.

Borghini et al. (2007) Lithos 94, 210-229.
Rampone et al. (2005) Journal of Petrology 46, 799-827.

The fate of crustal materials subducted into the mantle: Evidence from ophiolites

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It is generally agreed that subduction has been active for at least the last 2.5 Ga, and probably much longer. Seismic tomography indicates that lithospheric slabs can extend to the mantle transition zone and possibly much lower. The fate and evolution of the subducted crustal components, however, remain poorly understood. Our study of oceanic peridotites and podiform chromitites in ophiolites from different parts of the world provides some significant insights into this important issue. Mantle rocks in the Luobusa and Dongqiao ophiolites of Tibet, the Semail ophiolite of Oman and the Ray-Iz ophiolite of the Polar Urals of Russia contain a wide variety of ultrahigh pressure, super-reduced and crustal minerals. Diamonds are relatively common in Luobusa, Dongqiao and Ray-Iz, but have not yet been found in Semail. Moissanite, native elements, and both PGE and base-metal alloys are present in all of the ophiolites, where they are accompanied by various combinations of crustal minerals, such as zircon, corundum, feldspar, almandine garnet, kyanite, sillimanite, andalusite, quartz, titanite, apatite and rutile [1,2] Some of the crustal minerals occur in-situ or are attached to chromite grains, metallic alloys or rutile. Rounded grains of zircon, 50-300 microns across, with very complex internal textures, are present in all of the ophiolites. Most of the zircons contain low-pressure mineral inclusions, including quartz, rutile, orthoclase, mica, ilmenite and apatite. All of the zircons have REE and trace element compositions compatible with a crustal origin [3]. U/Pb SIMS dates for these zircons range from 549 to 1657 Ma in Luobusa, 484 to 2515 Ma in Dongqiao, and 84 to 1386 Ma in Semail. Three grains from Semail have ages of 96.2-99.3 Ma, close to the formation age of the ophiolite; one younger grain (84.3 Ma) may reflect minor lead loss. The crustal minerals, combined with the morphology and ages of the zircon grains, indicate derivation from crustal rocks subducted into the mantle where they were mixed with UHP and highly reduced phases. We suggest that the crustal minerals were introduced into the mantle by subduction of lithospheric slabs and were mixed with the UHP and highly reduced minerals during slab breakoff and rollback, which allowed asthenospheric peridotites to rise to shallow levels. The crustal minerals were most likely preserved by encapsulation in chromite and possibly olivine grains. The lower parts of the broken slabs sink to deeper levels where the crustal minerals react with alloys to form complex overgrowths [4]. Our findings indicate that subducted crustal materials are likely widespread in the upper mantle and may account for much of the observed mantle heterogeneity.

[1] Robinson, P.T., Bai, W.-J., Malpas, J., Yang, J.-S., Zhou, M.-F., Fang, Q.-S., Hu, X.-F., Cameron, S., Staudigel, H., 2004. Ultra-high pressure minerals in the Luobusa ophiolite, Tibet, and their tectonic implications: Geological Society London, Special Publication 226, 247-271.

[2] Xu, X., Yang, J.-S., Chen, S.-Y., Fang, Q.-S., Bai, W.-J., Ba, D.-Z., 2009. Unusual mantle mineral group from chromitite orebody Cr-11 in the Luobusa ophiolite of the Yarlung-Zangbo suture zone, Tibet. Journal of Earth Sciences 10, 284-302.

[3] Grimes, C.B., John, B.E., Keleman, P.B., Mazdab, F.Z., Wooden, J.L., Cheadle, M.J., Hanghoj, K., Schwartz, J.J., 2007. Trace element chemistry of zircon from oceanic crust: a method for distinguishing detrital zircon provenance. Geology 35, 643-646.

[4] Yang, J.-S., Dobrzhinetskaya, L., Bai, W.-J., Fang, Q.-S., Robinson, P.T., Zhang, J.-F., Green, H.W. II, 2007a. Diamond- and coesite-bearing chromitites from the Luobusa ophiolite, Tibet. Geology 35, 875-878.

Textures and geothermobarometry of off-craton spinel & garnet-bearing peridotites from South Patagonia

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While mantle xenoliths are common throughout Patagonia, only two localities in this region have produced garnet-bearing assemblages: Prahuaniyeu (North Patagonia) and Pali Aike (South Patagonia). This work focuses on a suite of fresh xenoliths from the Pali Aike Volcanic Field, which predominantly comprises four or five phase lherzolites, with minor harzburgites, pyroxenites and wehrlites. Five phase lherzolites, containing both spinel and garnet, show good textural equilibrium, i.e. 120° grain boundaries. Equiliibrium is particularly common between adjacent olivine grains, and olivine-orthopyroxene grains. Rounded inclusions of clinopyroxenes and olivines within other minerals are common in some samples. Textures are granoblastic to equigranular mosaic (Mercier 1974). Spinel lherzolites (lacking garnet) are more variable in texture and some show evidence of extensive recrystallization, though re-equilibration appears to be incomplete. Where spinel and garnet co-exist, they share a characteristic relationship: spinels occur almost exclusively as irregular, blebby cores within garnet. The cause of this relationship is uncertain – suggested explanations are lithospheric thickening, growth in the presence of a melt and subsolidus cooling through the spinel-garnet transition.

Pressures and temperatures (PT) of equilibrated garnet lherzolites have been calculated from major element (EMPA) data, using methods based on equilibrium between garnet & orthopyroxene (Nickel & Green 1985) and orthopyroxene-clinopyroxene (Taylor 1998). PT estimates define an elevated continental geotherm with a surface heat flux of 56 mW.m-2. Calculations of PT for garnet lherzolites using a single crystal method (Nimis and Taylor 2000) correlate well with values produced by the two-crystal methods; opening up the possibility of using these methods in the spinel facies mantle. This has important implications for characterising the lithospheric mantle in other regions and to better constrain the Pali Aike geotherm with a broader range of depths represented.

Xenoliths from Pali Aike provide an important insight into mantle processes beneath South Patagonia – with a range of textures, depths & chemistry represented. Accessory phlogopite is more common in deeper samples, concordant with the concept of a metasomatic front at the base of the lithosphere. Observations from this region will help to characterise the off-craton Patagonian mantle, and can be compared with xenoliths from other localities to investigate regional scale heterogeneities in the mantle.

Exploration of new gold occurrences in the alteration zones at the Barramiya District, Central Eastern Desert of Egypt using ASTER data and geological studies

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The use of ASTER data and fieldwork supported by mineralogical and geochemical analyses enabled exploration of new gold occurrences in the alteration zones in the ultramafic-mafic successions at the Barramiya district. Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) band ratios (4/8, 4/2, 8/9 in R, G and B channels respectively) helped in recognizing of two listwaenite alteration zones (area 1 and area 2) promising for gold in the north-east and south-east of the Barramiya gold mine. Mineralogical studies and X-ray diffraction analysis revealed that area 1 and area 2 are characterized by variable concentrations of talc, ankerite, magnesite, quartz and calcite. Ore microscope studies revealed the sulphides minerals carry gold within these alteration zones, moreover, goethite and malachite are also observed. Fire assay results show Au contents in the range of 5.04 ppm in the graphite schist, 4.02 ppm in the quartz veins and 3.76 ppm in the listwaenite alteration. The atomic absorption analysis (AAS) of samples from area 1 yields an average Au content in the quartz-veins of 2.4 ppm, Ag content is 8.0 ppm and Cu content is 2.4 wt%. The listwaenite alteration gives an average Au content of 4.4 ppm and a Cu content of 2.8 wt%. In area 2, the (AAS) of the quartz-veins revealed an average Au content of 2.6 ppm, 6.2 ppm Ag and 1.9 wt% Cu. The listwaenite alterations of area 2 grades 3.5 ppm Au and 2.4 wt% of Cu.

The Barramiya district is made up of ophiolitic ultramafic belts of serpentinites, talc carbonates and talc graphite schists, mainly thrusted over the metavolcanic sequences. They include highly strained and tectonized parts enriched in sulphides, iron oxides and carbonates, with developed listwaenite alterations along the thrust contacts. Gabbro and granitic intrusions were intruded in the ultramafics and metavolcanic rocks. ASTER data is an accurate and helpful tool for detecting and mapping alteration zones for gold exploration.

Keywords: ASTER data, Lithological discrimination, Gold mineralization, Alteration zones, Listwaenite.

Fluid-induced deformation in chromite during metamorphism

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The deep Earth water cycle is strongly coupled to the dynamics of Earth's interior. The amount of water carried by descending oceanic crust into the deep mantle is relatively small, but even a trace amount of water affects physical and chemical properties, including melting temperature, rheology, deformation mechanism and electrical conductivity. Ophiolite chromitites are commonly regarded as resistant to fluid-related processes, and have been used to track the evolution of Earth's mantle convection.

The Golyamo Kamenyane serpentinite is a part of a dismembered metaophiolite located in the Avren synform in the upper high-grade unit of the metamorphic basement of the Eastern Rhodopes crystalline massif in SE Bulgaria. It consists of metaharzburgite and metadunite hosting layers of metagabbro and some chromitite bodies. Chromitites from Golyamo Kamenyane preserve evidence of fluid-rock interaction during metamorphism. The retrograde P-T exhumation path of the Golyamo Kamenyane chromitites allowed almost complete transformation of primary chromite into porous ferrous chromite, and as a consequence, the local formation of homogeneous ferrian chromite as well as minor zoned chromite. Detailed geochemical studies based on major-element components (Gervilla et al., 2012) have classified the chromitites into four textural groups: partly-altered chromite, porous chromite, non-porous chromite, and zoned chromite. Chemical modelling indicates that the chromitites reacted with two kinds of fluids during retrograde metamorphism: (1) Si-rich fluids with very low $fO2$ produced chlorite and form partly altered and porous chromite, and (2) oxidizing fluids produced $Fe3+$-rich chromite and formed non-porous and zoned chromite. Here, we describe the microstructural development in chromites deforming under amphibolite-facies conditions.

To investigate the chromite deformation and identify the slip system, crystallographic orientation measurements were obtained by using the SEM-EBSD (Electron Back-Scattered Diffraction). EBSD reveals significant crystal-plastic deformation, such as inter-crystalline deformation defined by low-angle boundaries. The homogeneous distribution of subgrain boundaries in zoned chromite indicates that it was deformed after the generation of the chemical zoning. Fluid percolation also produces recrystallization of fine grains. The fine- grained aggregates of chromite probably formed by both dynamic recrystallization and nucleation produced by the reaction with oxidizing fluids, whereas there is no significant evidence of deformation in partly-altered chromitite. Overall, fluid-rock interaction leads to deformation of chromitites, which involves not only dynamic recrystallization but also nucleation of new grains.

Multi-stage evolution of peridotites from New Caledonia: preliminary results

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The Peridotite Nappe of New Caledonia, presumably of Late Cretaceous-Early Eocene age, is one of the largest and best exposed ophiolitic complex in the world. It is largely dominated by harzburgite and dunite but it also includes lherzolites in northern massifs and mafic/ultramafic cumulates in the south of the island. Although the mantle rocks have been studied for almost 30 years, their history still remains controversial, partly because of the scarcity of geochemical data and the total lack of isotopic data. Recent studies (Marchesi et al., 2009; Ulrich et al., 2010) proved that these mantle rocks have experienced a complex evolution including different phases of melting, melt-rock interaction and re-melting that led to an overall ultra-depleted composition.

Here, we present the preliminary results of a petrological and geochemical study on a new set of peridotite samples from New Caledonia. Harzburgites, consisting of variable proportions of olivine (from 70-75% up to > 80 vol %), orthopyroxene (from 12-15% to 25 vol %) and Cr-rich spinel (≈1% or less), are highly refractory rocks, as attested by the absence of primary clinopyroxene, very high Fo content in olivine (90.7-92.9 mol%), high Mg# in orthopyroxene ([Mg/(Mg+Fe)]= 91.0-92.7) and Cr# in spinel ([100 • Cr/(Cr+Al)]= 40-71). In contrast, lherzolites (clinopyroxene = 5-10 vol %), display a fairly fertile nature, with lower Fo in olivine (88.5-91.8 mol%), low Cr# in spinel (0.132-0.167) and relatively high Na2O (up to 0.80 wt%) and Al2O3 (3.1-6.7 wt%) contents in clinopyroxene. Secondary, interstitial and undeformed clino- and orthopyroxenes have also been observed in harzburgites. These phases testify melt percolation after partial melting and re-equilibration at lithospheric conditions. Their chemical compositions, i.e. low Al2O3 and CaO contents in orthopyroxene and very low or negligibile Na2O and TiO2 in clinopyroxene, may suggest a metasomatic origin by SiO2-rich fluids and/or depleted melts in a subduction-related setting.

Mineral compositional variations (e.g. Mg# (Ol) vs Cr# (Spl) and Cr# (Spl) vs Mg# (Spl)), show that most investigated harzburgites plot in the field of SSZ (forearc) peridotites, whereas the lherzolites are more akin to (variably refertilized) abyssal peridotites. The peridotites are low strain tectonites with porphyroclastic textures partially overprinted by mosaic equigranular textures, probably recording an asthenospheric HT origin followed by sub-solidus re-equilibration. Geothermometric estimates provide temperatures of 930–1145°C and 870-1080°C for the porphyroclastic assemblages of harzburgites and lherzolites, respectively; lower temperatures are recorded for the spinel facies recrystallization (≈ 830°C-980°C for both lithotypes). These preliminary results are consistent with a multi-stage history of melting, deformation, recrystallization and melt-rock interaction. Geochemical and radiogenic isotope analyses (in progress) are expected to decipher the depletion vs. refertilization evolution of the different peridotite types and provide constrains on their geodynamic significance.

Os isotope ratios and PGE abundances of troctolites from Pacific oceanic lithosphere

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The structure of oceanic lithosphere becomes much clear in these days. Troctolite is a kind of gabbro, mainly consisting of olivine and calcic plagioclase with minor pyroxene, found in oceanic lithosphere. Melt-rock interactions at mantle-crust transition zone are believed to play a main role for troctolite formation. Troctolites are locally found at Atlantis Massif oceanic core complex, Mid Atlantic Ridge 30°N (Blackman et al., 2006), at Kane Megamullion, Mid Atlantic Ridge 23°N (Dick et al., 2008; 2010), at Uraniwa Hills, Central Indian Ridge (Nakamura et al., 2009), and at Godzilla Megamullion, Parece Vela Basin of the Philippine Sea (Sanfilippo et al., 2013). They also occurred as sections of the oceanic lithosphere in ophiolites and show similarity to lower crust sections from slow and ultra-slow spreading ridges (e.g., Herbert et al., 1989; Sanfilippo and Tribuzio, 2013).

The formation process of the troctolites is in debate. From the ophiolite studies, troctolites were formed as cumulates from primitive basalts in a closed system (Bezzi and Piccardo, 1970; 1971; Borghini and Rampone, 2007). Alternatively, troctolites were the results of a substantial amount of mantle olivine incorporated into the lower oceanic crust (Suhr et al., 2008; Drouin et al., 2009; 2010) based on the studies of oceanic core complex. Troctolites were also found in the drilled core at site 895 of ODP Leg 147 in Hess Deep, located at a triple junction between EPR and Cocos-Nazca plate boundary. Hess Deep is a small rift with intra-rift ridges, where deep-seated rocks probably formed at EPR are exposed (Francheteau et al., 1990; 1992). Ultramafic and related rocks were expected to be found at the site in fast-spreading ridge system and sequences of dunite, harzburgite, troctolite, and gabbro were actually drilled (Allan and Dick, 1996; Dick and Natland, 1996; Arai and Matsukage, 1996). Troctolite appears to be transitional from dunite to olivine gabbro (Arai and Matsukage, 1998).

Major, trace and platinum group element (PGE) abundances and Os isotope ratios of troctolites from Holes 895C, 895D and 895E were newly measured using XRF, ICP-MS, and TIMS. The samples are clearly divided in two groups by Al2O3, MgO and NiO. Prichard et al. (1996) reported the PGE and trace element abundances of the ultramafic rocks from Holes 895. Their PGE concentrations of the troctolites were in a similar range to hartzburgites and dunites from the same sites and Pt and Pd are enriched in some troctolites. They also found platinum-group alloys and base metals in troctolites. New data set with Os isotope ratios possibly make constraints on the forming process of troctolites under the oceanic ridge.

Mineralogy and origin of picroilmenite rich vein in coarse-grained garnet lherzolite from Udachnaya East kimberlite pipe

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Picroilmenite is generally considerate as mineral indicator of kimberlites which is very powerful for kimberlite prospecting. Despite the abundance of picroilmenite in kimberlites worldwide the number of picroilmenite-bearing xenolith are very rare(Garanin et al.,1991). In this paper we presented the results of our ongoing research study of unique xenolith. The sample is rounded xenolith 15x20 cm in different dimensions. This sample consist of coarse-grained garnet lherzolite which is cross cut by fine-grained olivine-picroilmenite vein(thickness 3 cm). Mineral assemblage of coarse-grained lherzolite is olivine(75 vol.%), garnet(15% vol.%), clinopyroxene (5 vol.%) and orthpyroxene(5 vol.%). The crystal size of rock-forming minerals varies from 2 to 4 mm. Fine-grained vein composed of olivine (50%), picroilmenite(50%) and accessory minerals (e.g. djerfisherite, chromite,).The crystal size of rock-forming minerals from fine-grained vein varies from 0.001 to 0.1 cm. Garnet, olivine, clinopyroxene and orthopyroxene are chemically homogeneous in coarse-grained part of the sample. Olivine is forsterite (Mg#87), NiO content is 0.3 wt.%. Clinopyroxene is chromediopside (Cr2O3 1.31 wt.%), K2O content in clinopyroxene is generally low (below 0.02wt.% K2O). Garnet is pyrope-almandine (Mg#79), Cr2O3 content is as high as 2.36wt.%. P-T calculations performed using the garnet-orthopyroxene equilibrium of Green (Nickel, Green, 1985) and the Al2O3 content in orthopyroxene expression of Wood (Wood, 1974) indicate temperature and pressure correspond to $T=1340 \pm 50$ C°, $P=5.0 \pm 0.5$ GPa. Olivine-picroilmenite vein has a graphic structure. We have any viewpoint about appearance this structure. There are several possible scenarios formation of olivine picroilmenite vein which can be summarized: 1) Break down of high-pressure mantle minerals. 2) Eutectic crystallization of these minerals. 3) Co-crystallization of olivine-picroilmenite from kimberlitic liquid. We believe that in our sample this vein formed as result of infiltration of kimberlite melt, which occur at about 1300 C° and 5 GPa. Findings of djerfisherite testify that the kimberlite melt was likely enriched in alkali and chlorine. Recently alkali carbonatite nature of kimberlites was proposed in different papers (Kamenetsky et.al., 2007). However lack of alkaline carbonates in ground mass of olivine-picroilmenite vein raises the question – when do alkaline carbonates disappear from the vein?

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Garanin V.K., Sehenko V.P. Mineralogy of garnet-entatite-ilmenite xenolith from pipe Mir// Proceedings Russian mineralogical society №5. p.56-61. 1991.

Vadim S. Kamenetsky, Maya B. Kamenetsky, Victor V. Sharygin, Kevin Faure, Alexander V. Golovin. Chloride and carbonate immiscible liquids at the closure of the kimberlite magma evolution (Udachnaya-East kimberlite, Siberia)// Chemical Geology 2007 p.384-400

Nickel K.G., Green, D. H. Empirical geothermobarometry for garnet peridotites and implications for the nature of the lithosphere, kimberlites and diamonds. Earth Planet. Sci. Lett., 73, 1985. p. 158-70.

Wood B.J. The solubility of alumina in orthopyroxene coexisting with garnet. Contrib. Mineral. Petrol. 46, 1-15. 1974.

Origin of the Balmuccia peridotite massif

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Massif peridotites play a crucial role in revealing the structure and composition of the Earth's mantle by recording textural and chemical relationships between lithologies. The excellent preservation and exposure at Balmuccia makes it an archetype for the study of their composition, field relationships and metamorphic history (Shervais and Mukasa, 1991; Hartmann and Wedepohl, 1993; Rivalenti et al., 1995; Mazzucchelli et al., 2009). The massif consists of lherzolite with subordinate harzburgite and dunite and is riddled with pyroxenite bands, which fall into two suites – Chrome-Diopside (Cr-Di) and Aluminous-Augite (Al-Aug), a pairing present in most massif peridotites. Two-pyroxene thermometry gives temperatures of 850±25°C at 1-1.5 GPa, 500°C lower than asthenospheric mantle at that pressure, thus they do not preserve their original, high temperature mineralogy.

The predominant lithology, CPX-poor (13%) lherzolite, has ≈ 39.3% MgO, 8.2% FeO, 3.1% Al2O3 and 2.9% CaO. In conjunction with HREEN abundances of 0.7–0.8, these may represent residues of ≈7% partial melting of a putative primitive mantle. The very low La/SmN, 0.03–0.3, attests to fractional melt extraction, implying more than one depletion event. These chemical characteristics are observed in other circum-alpine massifs, including Baldissero and Monte Maggiore, with a high CaO/Al2O3 (≈0.9) being particularly diagnostic. They exhibit δ57Fe values of +0.03‰±0.02, a value resolvably lighter than MORB (+0.1‰, Teng et al., 2013) but as expected for depleted lherzolite. There is a paucity of lithologies with 42-47% MgO, however dunites, (47–49%) preserve Mg#s similar to the lherzolites (≈89.5).

Decimetre-sized Cr-Di bands (≈75% CPX, 25% OPX) occur initially Ol-free and bound by dunite, but, as they are rotated into the plane of foliation, they mechanically incorporate olivine. Al-Aug veins (60% CPX, 25% OPX, 15% Sp) discordantly cut the body, intruding lherzolites, which are enriched in Fe, Al and Ti adjacent to the dykes. Both the Cr-Di and the Al-Aug series have Sr-, Nd-isotopic compositions indistinguishable from the host peridotite (Mukasa and Shervais, 1999).

The major element compositions of pyroxenes in the Cr-Di bands and those in the surrounding peridotites are identical. Together with isotopic evidence, this suggests a local source, not only chemically but spatially, where a very low degree melt (≤2%) acts as a transport medium for the pyroxenes and segregates them into dyke-like structures (melt/rock = 0.05-0.1), analogous to 'pressure-solution' creep (Dick and Sinton, 1979). The presence of a melt is required by their REE contents, with moderate La/SmN (0.3 – 0.4) and near-flat HREE (1 < Gd/YbN < 1.1) distinct from the lherzolites with positively-sloping HREE (0.6 < Gd/YbN < 0.8). Models for their formation as cumulates from a melt are untenable, as, upon decompression, olivine is invariably the first phase to crystallise, thereby drastically reducing Mg# and Cr# to values lower than those in the Cr-Di bands.

The Al-Aug veins have lower Mg# (85-87) than the peridotites and Cr-Di series (≈90). However, CPX in both the Al-Aug and the lherzolite preserve REE patterns which are subparallel to, but twice as enriched as those in the normal lherzolites. This characteristic can be explained by focusing of a small (4%), locally-sourced melt similar to that which transported the Cr-Di pyroxenes. This melt was focused to a melt/rock ratio of 0.6 – 0.7, and crystallised to form the cumulus rocks of the Al-Augite suite. The extreme, heavy δ57Fe values observed in both the pyroxenite and adjacent lherzolite (+0.75‰) also point to a low-degree melt.

Linked kinematic and compositional evolution of the Red Hills ultramafic massif, New Zealand: A glimpse at the mantle section of an obliquely spreading forearc center

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The 125 km^2 Red Hills ultramafic massif, part of the Permian Dun Mountain Ophiolite, New Zealand, contains evidence for multiple overprinting fabrics that developed during oblique exhumation during the early stages of subduction initiation. Mapping of the entire massif has allowed subdivision of exposed peridotites into four compositional members. From E to W, these are: 1) Pervasively lineated massive harzburgites (Two Tarns harzburgite); 2) Banded lherzolites and dunites, which contain evidence for pervasive melt percolation and more focused melt channels (Plateau complex); 3) Plagioclase lherzolites (Plagioclase zone); 4) Banded harzburgites and dunites with a strong planar fabric (Ellis Stream complex). A large-offset (> 1 km) serpentinized fault (Porter Fault) separates the latter Ellis Stream complex from the rest of the body.

The different compositional domains record different kinematics that occurred during formation and exhumation of the ultramafic complex. Each stage of the three-stage cooling and exhumation history in the Red Hills reflects differing styles of deformation, but most importantly, each stage requires substantial strike-slip as well as extension. The massive, lineated harzburgite represents the earliest and deepest fabric in the massif, forming at approximately 1200°C and >8 kbar pressure. The nearly pure linear fabric suggests formation in a transtensional setting associated with oblique divergence, and the obliquity of the lineation direction to the trend of the zone suggests a component of right-lateral deformation. The remaining three units equilibrated at similar conditions of approximately 1000°C and 4.3-5 kbar pressure. During progressive exhumation at these conditions, deformation was restricted to specific zones. We interpret the banded harzburgites and dunites with a strong planar fabric (Ellis Stream complex) as a shear zone. This zone restores to a shallowly dipping position, with shallowly pitching lineation (e.g., triclinic deformation) that also indicates a component of right-lateral motion. Finally, the late-state, serpertinized Porter's fault also restores to sub-horizontal orientation. The motion along the fault, when restored, suggest mostly motion parallel to the trend of the ultramafic belt.

This study highlights the three-dimensional aspects of oblique mantle exhumation during subduction initiation. The first phase was accommodated by distributed, homogeneous flow (massive lineated harzburgites) and later phases occurred on localized shear zones (west side of complex; Ellis Stream complex) and faults (Porters fault). If we assume a space-for-time substitution, we can obtain a glimpse of the structures that sequentially develop during the initial formation of a mantle wedge.

History of the subcontinental lithospheric mantle beneath the Carpathian-Pannonian region

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The Carpathian-Pannonian region (CPR) is a typical Mediterranean area characterized by formation of Neogene back arc extensional basin within the orogen and widespread magmatic activity. The area is situated in central Europe, surrounded by the European platform and the Dinarides, and extends to the eastern margin of the Alpine orogenic belt. It was formed by lithospheric extension accompanied by mantle flow and upwelling. After the extension, ascending Plio-Pleistocene alkali basaltic melts sampled the lithospheric mantle and transported the mantle fragments to the surface at five places in the CPR: Styrian Basin (Austria, Slovenia), Little Hungarian Plain (Hungary), Bakony-Balaton Highland (Hungary), Nógrád-Gömör (Hungary, Slovakia) and Persani Mountains (Romania).

Modal compositions of the selected lherzolite xenoliths are in agreement with the average European subcontinental lithospheric mantle. Their textures are varying from protogranular to equigranular types, with some weak poikilitic features. Based on their whole-rock major element composition and clinopyroxene trace element geochemistry, the selected xenoliths reveal minor to intermediate melt removal and weak metasomatism.

Whole-rock analyses show fractionated PGE patterns, which are controlled by partial melting of the upper mantle as indicated by the clear correlation between Al_2O_3 and IPGE/PPGE (Iridium-type/Palladium-type PGE). High and in-situ sulfide abundances of Os, Ir, Ru and Rh were observed in the sulfide minerals, whereas almost all of the sulfides have a strong negative Pt anomaly, due to its residence in Pt-rich nuggets, revealed by time-resolved ICP-MS data.

Most of the Re-depletion (T_{RD}) ages are older than the oldest known Paleozoic crustal rocks of the CPR. Several main peaks can be observed on the age distribution probability plot. The highest peak around 0.6-0.8 Ga could be related to the breakup of Rodinia. The remainder of the model ages scatter between 0.95 and 1.35 Ga, which, in turn, can be related to the amalgamation of Rodinia. Outliers as old as 1.99 Ga (from Nógrád-Gömör) suggest that the subcontinental lithospheric mantle of the region may contain ancient domains dating from the assembly and breakup of the Columbia supercontinent, however these have been overprinted by numerous metasomatic events.

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The ultrabasic massif of Beni Bousera (Internal Rif, Morocco). Mineralogical, geochemical and model study

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The Beni Bousera ultramafic massif (70 km^2), is one of the largest peridotitic blocks of the Western Mediterranean area, cropping out in the Northern Morocco internal Rif. Peridotite assemblages clearly dominate (90 to 95% volume), whereas pyroxenite rocks, forming continuous bodies parallel/sub-parallel to the shear zones, constitute circa 5 to 10%. Peridotite rocks include spinel lherzolites and harzburgites as well as dunites with spinel or garnet. Pyroxenites are subdivided in two distinct groups: pyroxenites with chromiferous diopside and pyroxenites with titaniferous augite.

Garnet peridotites always occur closely associated with garnet pyroxenites either as intercalations in the spinel peridotites of the upper part of the Beni Bousera massif or exposed along shear zones crossing the spinel peridotite bodies. This mixture would have as consequence an increase of the concentration of Fe accompanied with depletion of Cr in the system. This suggests the stability of the secondary assemblage (olivine + garnet) in the rock. The intensive parameters controlling subsolidus evolution of the whole mineral paragenesis of the massif range from 900 to 1100 ºC and from 1.5 to 2.0 GPa.

Whole rock CaO, Al_2O_3, Na_2O and TiO_2 concentrations are correlated with MgO/FeO. $^{87}Sr/^{86}Sr$ ratios vary from 0.7019 to 0.7069, whereas $^{143}Nd/^{144}Nd$ ratios vary from 0.5136 to 0.5129. Trace element and isotope ratios obtained on isolated and leached peridotite clinopyroxene show that LREE, the more incompatible elements (Th, U) and isotope ratios are correlated. A websterite (M5.103) is characterized by a strong LREE/LREE fractionation $[(Ce/Yb)_N>1]$ while $(U/La)_N = 1.95$. This pyroxenite is characterized by a highly radiogenic $^{87}Sr/^{86}Sr$ (0.7085) associated to low $^{143}Nd/^{144}Nd$ (0.5121). The contribution of a crustal component, would be responsible of isotopic and elemental disturbances which interacted to varying degrees with the entire massif. The Nd-Sr isotopic compositions of the clinopyroxene from websterite and peridotites, as well as the distribution of trace elements reflect the signature of recycled oceanic crust and of associated terrigenous sediments.

The temporal evolution of the Beni Bousera massif would begin during lower Cretaceous and ended by high temperature thrusting during the Oligocene and Miocene. Its separation from asthenosphere and its incorporation in the lithosphere would take place approximately at 1.3 Ga. The Beni Bousera block would be the result of a northward subduction related to a lithospheric rupture.

Update on the spatial distribution of highly refractory peridotites in the northern Oman mantle section as proxy for fluid infiltration and flux melting

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Highly refractory peridotites are generally considered as residues after extraction of boninitic melt from residual harzburgite or lherzolite by hydrous flux melting. Flux melting of harzburgite was caused by infiltration of fluid from the base of the ophiolite during oceanic thrusting and resulted in the formation of refractory dunite channels. Thus, the distribution of highly refractory peridotite tells us the locality of flux melting and the pathway of hydrous fluid and boninitic melt in the mantle section of the ophiolite. In this study, we report update on the spatial distribution of highly refractory peridotites in the northern Oman ophiolite and discuss the factors that control their diversity. Our results indicate that the distribution of highly refractory peridotite is variable thereby indicating the scale and magnitude of flux melting were also variable. We have systematically analyzed mineral compositions of harzburgites and dunites in the Fizh and Salahi mantle sections. In the Fizh mantle section, the range of spinel Cr/(Cr+Al) atomic ratio (Cr#) in harzburgite gradually changes from the southern part (Cr# 0.43-0.67) to the northern part (Cr# 0.22-0.78). This may correspond to the compositional variation along paleo-ridge segment. In the northern part (paleo-ridge segment end region), fertile lherzolite and highly refractory harzburgite and dunite in which the Cr# of spinel exceeds 0.7 occur together. The highly refractory harzburgite and dunite are distributed as a belt in the direction of NW-SE (highly refractory zone, hereafter). The presence of highly refractory zone indicates that influx of fluid was also relatively large in the ridge segment end region. The high permeability in the northern Fizh mantle section was due to compositional heterogeneity of peridotites or to the promotion of fluid infiltration by the shear deformation in ridge segment end region. It is thought that fluid infiltration within dunite channels may have further promoted the flux melting of wallrock harzburgite. In the south Fizh and Salahi mantle sections, spinel Cr# of harzburgite ranges between 0.48-0.70 and the Fo content of olivine from 90.1 to 92.2. Moreover, in the northern and southernmost parts of the Salahi mantle section there are some particular regions rich in less refractory harzburgites and dunites with low Cr# spinel (Cr# 0.4-0.5). Fluid infiltration and flux melting of harzburgite may have not been significant in these regions relative to the north Fizh mantle section, thereby preserving the residual compositions maintained at a spreading ridge. The spinel Cr# of dunites in the Fizh and Salahi mantle sections show a large range from 0.45 to 0.8 and is the most frequent in 0.65-0.7. Moreover, in the southwest part of the Salahi mantle section, a highly refractory km-scale massive dunite (spinel Cr# 0.7-0.84) occurs associated with minor amounts of refractory harzburgite (spinel Cr# 0.63-0.72) and pyroxenites. One of the formation mechanisms of large dunite channels is the instability of reaction infiltration flow (Aharonnov et al., 1995). Fluid infiltrates into the place where porosity is high and further reaction is promoted. The presence of large-scale massive dunite suggests a large amount of fluid having intensively infiltrated into the base of mantle section by reaction infiltration instability. At the base of Fizh mantle section, highly refractory dunite bands with high Cr# spinel are heterogeneously distributed within tens of km-scale finger-shaped region. Fluid flow controlled by reaction infiltration instability may also have been responsible for the formation of these dunites.

New interpretation of the tectonic & metamorphic evolution of the Iriri-Tachakoucht arc complex (Sirwa inlier, Moroccan Anti-Atlas)

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The Tachakoucht-Iriri-Khzama oceanic arc complex consists from North to South of the Khzama ophiolitic sequence (dated at c. 762 Ma [1]), the Iriri unit (protolith dated at c. 743 Ma and metamorphic age at c. 663 Ma [2]) and the Tachakoucht metavolcanics. The contact between the Khzama ophiolitic unit and the Iriri-Tachakoucht oceanic arc remnants is marked by a southward thrust fault. The Iriri formation, composed mainly by hornblendites, metabasalts and partially molten metadacitic gneisses, has been interpreted as migmatites formed at the root of an oceanic arc [1]. Our new field and metamorphic investigations show that the contact between the Tachakoucht gneisses (metadacitic plagioclase-biotite-garnet-quartz porphyroclastic gneisses) and the Iriri complex is marked by a progressive increase of hornblendite and metabasaltic intrusions northward. Centimetric to metric relics of Tachakoucht gneiss, locally partially molten, are indeed found within the Iriri complex comforting the intrusive behaviour of the hornblenditic plugs. The described migmatization observed and grouped in 'Iriri formation' is not a consequence of collisional metamorphism but is rather linked to the emplacement of hornblendites. The 743 Ma age is thus interpreted as the volcanic eruption of the Tachakoucht gneiss precursor while the 663 Ma event could represent the intrusion of hornblendites (new U-Pb zircon datings are in progress to confirm this hypothesis). Phase diagram calculations and thermobarometry on Tachakoucht gneisses show that, after sub-aerial emplacement, these shallow volcanics has been buried; recording a prograde P-T path through garnet compositional zoning and medium-pressure peaks under amphibolite facies conditions (~700°C, 5-8 kbars), probably in response to early accretion of an oceanic arc. The hornblendites, characterized by typical oceanic arc geochemistry, then intruded the metamorphosed complex around 660 Ma. Burial of the Tachakoucht rocks and in particular, the intrusion of these hornblenditic plugs leaded to localized partial melting of the Tachakoucht metadacitic gneisses. Traces of oceanic arc magmatism are thus probably disconnected in time (743 and 660 Ma) and likely support two distinct subduction events with different vergences. The 'ophiolite-arc sequence' duality marked by Khzama ophiolite and Iriri-Tachakoucht arc in the Sirwa window is also characteristic of the Bou Azzer-El Graara inlier. The Amslil 'basement gneisses' located in the southern side of the famous Bou Azzer ophiolite is composed of garnet-bearing metagabbros, metadiorites and hornblendites, comparable to the deep portions of an arc (continental or oceanic). Recently, El Hadi et al. [3] dated metagabbroic rocks belonging to the Amslil sequence at c. 697 Ma. The age proximity between Iriri magmatic event and Asmlil metagabbro and their location to the south of both ophiolites (Khzama and Bou Azzer) could evidence a same tectonic and metamorphic evolution. These probable arc units consist of key-complexes to improve our knowledge on regional geodynamics.

[1] Samson et al., 2004
[2] Thomas et al., 2002
[3] El Hadi et al., 2010

Highly siderophile elements and Os isotopes in single sulfides in peridotite xenoliths from the Kangerlussuaq area, S.W. Greenland

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Peridotite xenoliths from the Kangerlussuaq area of southwestern Greenland have been shown to record Mesoarchaean to Paleoproterozoic (1.9-2.8 Ga) mantle depletion events using 187Os/188Os (Wittig et al., 2010). Highly siderophile elements (HSE) in mantle rocks are hosted in heterogeneously distributed sulfide, metal, and alloy grains, and analysis of individual grains may reveal heterogeneities that are not reflected on the bulk rock scale. Most notably, interaction of mafic melt with depleted peridotite wall rock may result in the formation of secondary sulfides that bear the HSE signature of the melt. As a consequence, a mixture of different sulfide generations makes up the HSE budget at the bulk rock scale. Primary melt signatures, most notably melt depletion ages, may thus be obscured by the sulfide generation that formed due to melt-rock interaction and give out inaccurate temporal at the whole rock scale.

Sulfides in the least altered of the Kangerlussuaq samples (474527)_consist predominantly of pentlandite intergrown with magnetite as an alteration product, with minor pyrrhotite and millerite In the more pervasively altered majority of the Kangerlussuaq samples sulfides are altered to magnetite and barite. While the Ni/Fe ratio in pentlandite is variable, Cu-rich sulfides commonly associated with melt percolation were not found. In strongly serpentinized Kangerlussuaq samples, no sulfides of sufficient size for analysis were found, with magnetite and barite are present as alteration products of sulfide. Sulfides occur mainly as clusters in or in the vicinity of cracks and serpentinized veins between olivine and pyroxene fragments. Sulfide grain size is highly variable, from <5 µm to larger than 100µm, and shows no correlation with sulfide composition. For sampling of single-grain sulfides, only grains with a diameter >20µm were chosen.

Compared to a bulk rock value of 0.11193, the 187Os/188Os composition of pentlandite is radiogenic ranging between 0.16 and 0.33, (Wittig et al., 2010). This necessitates the presence of a complementary component in these peridotites which exerts a significant impact of the HSE budget, likely so far undetected alloy grains. As the HSE signatures in these alloy grains are less susceptible to disturbance from secondary processes, the depleted nature of these grains hints at extremely old mantle depletion ages, implying early mantle depletion and the initiation of crustal formation.

Seismic Structure of the Shallow Mantle Beneath the Endeavor Segment of the Juan de Fuca Ridge

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We present tomographic images of the seismic structure of the shallow mantle beneath the intermediate-spreading Endeavor segment of the Juan de Fuca ridge. Our results provide insight into the relationship between magma supply from the mantle and the overlying ridge crest processes. We use seismic energy refracted below the Moho (Pn), as recorded by the Endeavor seismic tomography (ETOMO) experiment, to image the anisotropic and isotropic P wave velocity structure. The ETOMO experiment was an active source seismic study conducted in August 2009 as part of the RIDGE2000 science program. The experimental area extends 100 km along- and 60 km across-axis and encompasses active hydrothermal vent fields near the segment center, the eastern end of the Heck seamount chain, and two overlapping spreading centers (OSCs) at either ends of the segment. Previous tomographic analyses of seismic arrivals refracted through the crust (Pg), and reflected off the Moho (PmP), constrain a three-dimensional starting model of crustal velocity and thickness. These Pg and PmP arrivals are incorporated in our inversion of Pn travel-time data to further constrain the isotropic and anisotropic mantle velocity structure. Preliminary results reveal three distinct mantle low-velocity zones, inferred as regions of mantle melt delivery to the base of the crust, that are located: (i) off-axis near the segment center, (ii) beneath the Endeavor OSC, and (iii) beneath the Cobb OSC near Split Seamount. The mantle anomalies are located at intervals of ~30 to 40 km along-axis and the low velocity anomalies beneath the OSCs are comparable in magnitude to the one located near the segment center. The direction of shallow mantle flow is inferred from azimuthal variations in Pn travel-time residuals relative to a homogeneous isotropic mantle. Continuing analysis will focus on constraining the orientation of azimuthal anisotropy and assessing whether or not it varies spatially. On the basis of our results, we will discuss the transport of melt from the mantle to the crust, the implication of mantle flow patterns on the segmentation of ridges, and assess competing models for the origin of ridge segmentation.

Subduction initiation and recycling of Alboran domain derived crustal components prior to the intra-crustal emplacement of mantle peridotites in the Westernmost Mediterranean: isotopic evidence from the Ronda peridotite

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During Late Oligocene-Early Miocene different domains formed in the region between Iberia and Africa in the westernmost Mediterranean, including thinned continental crust and a Flysch Trough turbiditic deposits likely floored by oceanic crust [1]. At this time, the Ronda peridotite likely constituted the subcontinental lithospheric mantle of the Alboran domain, which mantle lithosphere was undergoing strong thinning and melting [2] [3]coevally with Early Miocene extension in the overlying Alpujárride-Maláguide stacked crust [4, 5]. Intrusive Cr- rich pyroxenites in the Ronda massif records the geochemical processes occurring in the subcontinental mantle of the Alboran domain during the Late Oligocene [6]. Recent isotopic studies of these pyroxenites indicate that their mantle source was contaminated by a subduction component released by detrital crustal sediments [6]. This new data is consistent with a subduction setting for the late evolution of the Alboran lithospheric mantle just prior to its final intracrustal emplacement in the early Miocene Further detailed structural studies of the Ronda plagioclase peridotites—related to the initial stages of ductile emplacement of the peridotite—have led to Hidas et al. [7] to propose a geodynamic model where folding and shearing of an attenuated mantle lithosphere occurred by backarc basin inversion followed by failed subduction initiation that ended into the intracrustal emplacement of peridotite into the Alboran wedge in the earliest Miocene. This hypothesis implies that the crustal component recorded in late, Cr-rich websterite dykes might come from underthrusted crustal rocks from the Flysch and/or Alpujárrides units that might have been involved in the earliest stages of this subduction initiation stage. To investigate the origin of crustal component in the mantle source of this late magmatic event recorded by Crpyroxenites, we have carried out a detail Sr-Nd-Pb-Hf isotopic study of a variety of Betic-Rif cordillera crustal rocks that might have been potentially subducted beneath the Alborán domain before the emplacement of Ronda peridotites. Isotopic data rules out potential crustal sources coming from pre-early Miocene Flysch Trough sediments and crustal rocks from the Blanca Unit currently underlying peridotite. Crustal rocks from the Jubrique Unit overlying the Ronda peridotite are the only crustal samples that may account for the relatively high 207Pb-208Pb/204Pb and low 206Pb/204Pb characteristic of the crustal contaminant added to the mantle source of late Cr-pyroxenites. These data strongly support Alboran geodynamic models that envisage slab roll-back as the tectonic mechanism responsible for Miocene lithospheric thinning, and provides a scenario where back-arc inversion leads to self-subduction of crustal units at the front of the Alboran wedge.

[1]. Durand-Delga, M., et al., Situation structurale et nature ophiolitique de roches basiques jurassiques associées aux flyschs maghrébins du Rif (Maroc) et de Sicile (Italie). CRAS, 2000. 331:29-38. [2]. Lenoir, X., et al., The Recrystallization Front of the Ronda Peridotite: Evidence for Melting and Thermal Erosion of Subcontinental Lithospheric Mantle beneath the Alboran Basin. J. Petrology, 2001. 42: 141-158. [3]. Garrido, C.J., et al., Garnet lherzolite and garnet-spinel mylonite in the Ronda peridotite: Vestiges of Oligocene backarc mantle lithospheric extension in the western Mediterranean. Geology, 2011. [4]. Balanyá, J.C., et al., Alternating contractional and extensional events in the Alpujarride nappes of the Alboran Domain (Betics, Gibraltar Arc). Tectonics, 1997. 16: 226-238. [5]. Platt, J.P., et al. Simultaneous extensional exhumation across the Alboran Basin: Implications for the causes of late orogenic extension. Geology, 2003. 31(3): p. 251-254. [6]. Marchesi, C., et al., A Late Oligocene Suprasubduction Setting in the Westernmost Mediterranean Revealed by Intrusive Pyroxenite Dikes in the Ronda Peridotite (Southern Spain). J. Geology, 2012. 120: 237-247. [7]. Hidas, K et al., Backarc basin inversion and subcontinental mantle emplacement in the crust: kilometrescale folding and shearing at the base of the proto-Alborán lithospheric mantle (Betic Cordillera, southern Spain). Journal of the Geological Society, 2013. 170: 47-55.

Unravelling metasomatic effects on Re-Os ages: A case study from Letlhakane (Botswana)

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Mantle xenoliths have been used for decades as a way to constrain the primary composition of the depleted mantle. However, it is now understood that very few peridotites preserve pristine primary features, which makes unravelling the timing of depletion of the sub-continental lithospheric mantle difficult. Fortunately, when used on a mineral scale, the Re-Os chronometer seems to be fairly robust in the face of metasomatism. Whole-rock Re-Os age analysis of peridotite xenoliths may provide only a minimum estimate for the formation age of the lithospheric mantle, and likely reflects the presence of multiple generations of base metal sulphides (BMS) or platinum group minerals (PGM), which differ in age as well as mineralogy and habit. While metasomatic sulphides and/or PGM are likely to yield 'artificially young' Re-Os ages, refractory PGM such as Os-Ir-Ru alloys and refractory sulphides (e.g. laurite) should preserve older ages as a result of their high Os concentrations and resilience to overprinting and isotopic resetting. Together they provide the perfect target to investigate the Os isotopic heterogeneity in mantle samples.

Peridotite mantle xenoliths from the Letlhakane Kimberlite pipe (Magondi Belt, Botswana) provide us with a unique opportunity to investigate the effects of metasomatism and melt percolation on the Re-Os system. This is due to the widely variable level of metasomatism that has affected these xenoliths [1]. Whole rock analysis of xenolith samples from Letlhakane show co-variations of Re-Os TRD ages and highly siderophile element fractionations (e.g. Pd/Ir: 0.1, TRD: 2.7Ga – Pd/Ir 1.69, TRD 1.6Ga), due to the variable degrees of metasomatic overprint. Three samples that cover the entire metasomatic range were chosen to measure single grain sulphides for Re-Os via micro-distillation. Our results show a wide range in sulphide TRD ages, from future ages to over 3.0 Ga, even in the most metasomatised sample. The habit and structure of the sulphide seems to be the most important factor. Disseminated sulphides occurring in veinlets have the youngest ages and most radiogenic 187Os/188Os. On the other hand, discrete interstitial sulphides exhibit unradiogenic 187Os signatures and Archean model ages. These differing habits likely reflect different late stage processes occurring in the peridotite. Our findings stress the micro-scale heterogeneity of Os isotopic signatures, which likely reflects multiple host mineral generations whose origins are linked to the complex multi-event petrogenetic history of mantle samples.

[1] Stiefenhofer et al. (1997) Contrib. Mineral Petrol. 127, 147-158

Iron isotope tracing of mantle mineralogical heterogeneity

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Mineralogical variations in the Earth's mantle and the relative proportions of peridotitic versus enriched and potentially crustally-derived pyroxenitic domains within the mantle have important implications for mantle dynamics, magma generation, and the recycling of surface material. We present iron (Fe) stable isotope data (δ57Fe, deviation in 57Fe/54Fe from the IRMM-014 standard in parts per thousand) for spinel-peridotite and garnet-pyroxenite xenoliths from Hawaii (Salt Lake Crater, Oahu) as well as garnet-lherzolite, garnet-pyroxenite and websterite samples from the Beni Bousera massif. Pyroxenites from both Hawaii and Beni Bousera have δ57Fe values that are heavy relative to published Fe isotope data for mid-ocean ridge and ocean island basalts and abyssal peridotites. In the case of Hawaii, pyroxenite δ57Fe displays positive correlations with titanium and heavy rare earth element (REE) abundances, which are interpreted in terms of stable isotope fractionation during magmatic differentiation and pyroxene cumulate formation a the lithosphere-asthenosphere boundary. In contrast, the Beni Bousera garnet-pyroxenites and websterites display a much smaller range in δ57Fe and strong correlations between δ57Fe and moderately incompatible elements are absent. Interestingly, the Salt Lake Crater peridotites have light δ57Fe values that display striking negative correlations with Cr-number and radiogenic hafnium isotopes, with the most depleted samples possessing the most radiogenic Hf isotope compositions and lightest δ57Fe values. These correlations are interpreted in terms of a time-integrated pattern of Fe isotope fractionation during partial melting, where isotopically heavy Fe is extracted into the melt phase, leaving behind low-δ57Fe peridotite residues. The data therefore suggest that pyroxenitic mantle components will have comparatively heavy δ57Fe values relative to long-term depleted peridotitic regions of the mantle. Iron stable isotopes may therefore provide a powerful new means of fingerprinting mineralogical variations within the Earth's mantle and identifying the mineralogy of depleted and enriched components within the source regions of volcanic rocks.

Reconstruction of the formation setting of the chromitites from the Central-Sudetic Ophiolite (SW Poland)

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The ultramafic members of dismembered Variscan ophiolitic sequences in SW Poland (geologically the NE margin of the Bohemian Massif in Central Europe) comprise (1) the Gogołów-Jordanów Serpentinite Massif (GJSM) and (2) the Braszowice-Brzeźnica Massif (BBM). Chromitite veinlets and pockets occur in the Czernica Hill area (in the GJSM) or in the Grochowiec Hill area (in the BBM) within strongly serpentinized rocks of harzburgitic protolith. Chromitites consist of rounded chromite grains up to 4 cm and chlorite filling the interstices. Locally, remnants of olivine occur within the chlorite groundmass. The veins are embedded in serpentine-olivine-chlorite aggregates. Four kinds of ore occur: massive, disseminated, nodular and layered one.

Chemical composition of chromite occurring in chromitites defines three varieties differing by cr#, mg# and TiO2: chromite I (cr# = 0.38, mg# = 0.80, TiO2 = 0.10 - 0.14 wt.%), chromite II (cr# = 0.51, mg# = 0.61 - 0.71, TiO2 up to 0.10 wt.%) and chromite III (cr# = 0.50 - 0.80, mg# = 0.80, TiO2 = 0.00 - 0.25 wt.%). The chromite grains are composed mostly of chromite I. Chromite II forms irregular spongy domains up to 150 µm, located at fissures or forming grain rims. The chromite III occurs only in nodular ore as the central parts of the nodules. Chlorite contains 17.5 - 23.0 wt.% Al2O3, 0.6 - 1.8 wt.% Cr2O3 and 31.8 - 34.2 wt.% MgO. Olivine (Fo93.5-96.2) contains 0.44- 0.51 wt.% NiO, its composition is constant. Olivine grains from the host serpentinite rock are zoned - the low-forsteritic (Foxx) cores are surrounded by high-forsteritic rim (Foxx).

The bulk chromitite composition of the massive ores reveals V and Ga enrichment relative to chondrite. The PGE pattern is flat and reveals depletion in PGE relative to chondrite. The massive chromitite contain very low amount of total PGE (42 - 166 ppm). The composition and form of occurrence of both the GJSM and the BBM chromitites is similar. The moderate cr#, low PGE concentrations and the PGE patterns of chromitites are similar to these occurring in the Sangua de Tanamo (Cuba) and Wadi Hilti (Oman) which formed in the relatively shallow, Moho Transition Zone (Gonzalez-Jimenez et al., 2011, Ahmed and Arai, 2002). Similar cr# is considered to occur in chromitites which crystallized from low degree partial melts of the relative fertile mantle (Prichard et al., 2008). On the other hand depletion in PGE and Ti is typical for chromian spinels originating from melt derived from back arc depleted source (cf. Python et al., 2008). Chromite II and chlorite are secondary phases and were formed due to greenschist facies metamorphism (cf. high-Cr chromitite described from Dobromirtsi Massif - Gonzalez-Jimenez et al., 2009).

Multi-stage melting processes of Ophiolitic Chromitites from Dongbo Peridotite, the Western Yarlung-Zangbo Suture Zone, Tibet

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The Dongbo ophiolite, which crops out over an area of about 400 km2 in the western Yarlung-Zangbo suture zone, consists chiefly of mantle peridotite, pyroxenite and gabbro. The mantle peridotites are mostly harzburgite and minor lherzolite that locally host small pods of dunite. Some pyroxenite and gabbro veins of variable size occur in the peridotites, and most of them strike NW, parallel to the main structure of the ophiolite. The pyroxenite consists of about 90 modal% diopside (Wo48En46Fs6), 5% calcic plagioclase (An90) and small amounts of clinoenstatite (Wo2En82Fs16) and tremolite. The gabbros contain pyroxene (Wo47En36Fs17), plagioclase (An47) and minor magnesium amphibole. They are characterized by low contents of K2O (<0.1 wt%) and P2O5 (<0.1wt%), and have depleted chondrite-normalized LREE patterns, similar to those of N-MORB. Zircon U-Pb dating of the pyroxenite and gabbro by LA-ICP-MS yielded ages of 130±0.5 Ma and 128±1.1 Ma, respectively. These dates provide the first age constraints on the Dongbo ophiolite, and show that it belongs to the Neo-Tethyan system of the Yarlung-Zangbo suture zone.

On the basis of their mineral chemistry podiform chromitites are divided into high-alumina (Cr# = 20-60) (Cr# = 100*Cr/(Cr+Al)) and high-chromium (Cr# = 60-80) varieties (Thayer, 1970). Typically, only one type occurs in a given peridotite massif, although some ophiolites contain several massifs which can have different chromitite compositions. However, the Dongbo massif contains both high chrome and high alumina chromitites within a single mafic-ultramafic body. Seven small, lenticular bodies of chromitite ore have been found in the harzburgite, with ore textures ranging from massive to disseminated to sparsely disseminated; no nodular ore has been observed. Individual ore bodies are 2-6 m long, 0.5-2 m wide and strike NW, parallel to the main structure of the ophiolite. Ore bodies 1 and 6 consist of Al-rich chromitite (Cr# = 52-55), whereas orebodies 2, 3, 4 and 5 are Cr-rich varieties (Cr # = 63 to 89). In addition to magnesiochromite, all of the orebodies contain minor olivine, amphibole and serpentine.

Mineral structures show that the peridotites experienced plastic deformation and partial melting. On the basis of magnesiochromite and olivine/clinopyroxene compositions two stages of partial melting are identified in the Dongbo peridotites, an early low-partial melting event (about 8%), and a later high-partial melting event (about 40%). The sparse lherzolites are alpine-type peridotites, depleted in LREE whereas the harzburgites and dunites have “U”- or “V”-shaped REE patterns, indicating variable enrichment by later melts/fluids. The mineralogy and geochemistry of the Dongbo peridotites suggest that they formed originally at a mid-ocean ridge（MOR) and were later modified by suprasubduction zone（SSZ）melts/fluids. We interpret the Al-rich chromitites as the products of early MORB magmas, whereas the Cr-rich varieties are thought to have been generated by the later SSZ melts.

Diamonds and highly reduced minerals from chromitite of the Ray-Iz ophiolite of the Polar Urals: deep origin of podiform chromitites and ophiolitic diamonds

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The Uralide orogenic belt is a major early Paleozoic suture zone extending more than 3000 km in a N-S direction, and geographically divides Europe from Asia [1]. Ophiolites, podiform chromitites and high pressure metamorphic rocks are well developed in the orogenic belt [2]. The Ray-Iz ophiolite occurs at the NE end of the Paleozoic Voikar-Syninsk ophiolite belt in the Polar Urals, where it consists chiefly of mantle peridotite containing over 200 podiform chromitite orebodies [3]. We sampled the Ray-Iz ophiolite and associated chromite deposits for comparison with the Tibetan ophiolites. Over 60 mineral species, including diamond, moissanite, native elements and metal alloys have been separated from ~1500 kg of chromitite collected from two orebodies in the Ray-Iz ophiolite. Of great importance is the discovery of diamond, a typical UHP mineral previously reported in the Luobusa chromitites of Tibet. Other mineral groups from the Ray-Iz chromitite include: (1) native elements: Cr, W, Ni, Co, Si, Al and Ta; (2) carbides: SiC and WC; (3) alloys: Cr-Fe, Si-Al-Fe, Ni-Cu, Ag-Au, Ag-Sn, Fe-Si, Fe-P, and Ag-Zn-Sn; (4) oxides: wüstite, periclase, eskolaite, rutile, baddeleyite, ilmenite, corundum, chromite, NiO and SnO2; (5) silicates: kyanite, pseudomorphs of octahedral olivine, zircon, garnet, feldspar, and quartz; (6) sulfides of Fe, Ni, Cu, Mo, Pb, Ab, AsFe, FeNi, CuZn, and CoFeNi; and (7) iron groups: native Fe, FeO, and Fe2O3. In this report we focus on the composition and character of the diamonds, native elements and metal alloys. Some in situ diamonds and moissanite occur as euhedral to subhedral crystals, mostly 200-500 µm across, that are hosted in small patches of carbon within chromite grains. Both the diamond and moissanite have extremely low carbon isotope values δ13CPDB (-18 to -28), distinctly different from kimberlitic diamonds, suggesting a separate carbon reservoir in the mantle. All of the minerals discussed here are very similar to those reported from the Luobusa chromitites, indicating that they are not restricted to one ophiolite or geographic region, rather they may be widespread in the oceanic mantle. The diamonds recovered from these ophiolites are completely different from those in kimberlites and ultra-high pressure (UHP) metamorphic rocks and represents a new class of diamonds on Earth. Previous work suggests that both the diamonds and chromitites of Luobusa crystallized in the diamond stability field at depths greater than ~150 km, possibly deeper than 300 km, thus raising questions regarding the current models for the formation of ophiolites and podiform chromitites. It is possible that the diamonds formed from C-rich fluids with highly reduced phases and low δ13CPDB values derived from previously subducted slabs.

Chemenda, A.,et al. (1997) A model of Paleozoic obduction and exhumation of high–pressure. Low-temperature in rocks in the southern Urals. Tectonophysics 276, 217-227.

Leech, M.L., Ernst, W.G., (2000) Petrotectonic evolution of the high-to ultrahigh-pressure Maksyutov Complex, Karayanova area, south Ural Mountains: structural and oxygen isotope constraints. Lithos 52, 235-252.

Garuti, G., et al. (1999) Platinum-group minerals as indications of sulfur fugacity in ophiolitic upper mantle: an example from chromitites of the Ray-Is ultramafic complex, Polar Urals, Russia. The Canadian Mineralogist 37, 1099-1115.

Cr-spinels crystal chemistry in Morocco and Libya mantle xenoliths

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The crystal chemistry of about 20 crystals of Cr-spinels from lherzolite and harzburgite xenoliths from the Middle Atlas Neogene-Quaternary Volcanic Field of Morocco and of the Waw-En-Namus volcano in Libya have been studied by means of X-ray single crystal diffraction. Cell edges, a0, for Moroccan spinels are in the range 8.1334 (4) – 8.2021 (2) Å, while the oxygen positional parameter, u, are very similar ranging between 0.2626 (1) and 0.26285 (9) for all of them. Cell edges for Libyan samples are in a range wider than that of the others spanning between 8.1219 (1) and 8.2458 (2) Å, testifying the presence of more Cr-enriched spinels. The most interesting feature is that, for these spinels, we have two distinct oxygen positional parameters. In fact most of the samples (Group I), showing cell variations covering the entire length gap (but mostly longer than 8.1757 (2) Å), has an average value of 0.2626 (1), other samples (Group II), with cell edges comprised between 8.1219 (1) and 8.1542 (1), i.e. a limited Cr content interval, shows an average value of 0.26335 (7), that, at now, is the highest recorded for mantle xenoliths. According to their chemistry, the Libyan samples show a Cr/(Cr+Al) ratio in the range 0.07-0.50 and a Mg/(Mg+Fe2+) ratio between 0.69-0.82, while those from Morocco show a narrower distribution with Cr/(Cr+Al) between 0.10 and 0.40 and Mg/(Mg+Fe2+) between 0.74 and 0.82.

Principalle et al. (1989) observed that u displays a constant value within the spinels from individual geological settings, even if there is a variation in bulk chemistry, whereas spinels with similar bulk chemistry but belonging to different geological environments exhibit a wide range of u values. Differences in cell edges between the Morocco and Libya spinels suggest that the peridotite suffered different melt extraction. Oxygen positional parameters suggest that the cooling history for Moroccan and Libyan Group I spinels was similar reaching intracrystalline closure temperature of about 550-750°C and 480-650°C, respectively and faster than that of the Libyan Group II spinels (intracrystalline closure temperature in the range 680-950°C). Given that we can assume that, within the Libya mantle xenoliths we can distinguish two groups of mantle xenoliths for whom the geological story is different.

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Structure and Mineralogy of Peridotite from Baer ophiolite, Yalung Zangbo Suture Zone, Tibet: Records of Two Stage Evolution from Mid-ocean Ridge to SSZ

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The Yarlung Zangbo Suture Zone (YZSZ), including the ophiolite complexes, the ophiolitic mélange, and metamorphic and sedimentary sequences and mélanges, is thought to be the geological feature of the most important collision event to have happened on Earth since the Cretaceous-Tertiary and mark the most important boundary between India and Eurasia. Rosaries of ophiolitic massifs in YZSZ outcropping from Namche Barwa syntaxis in the east to Ladakh area in the west can be subdivided into several distinct ophiolitic complexes: Namche Barwa syntaxis ophiolites, Luobusa ophiolites, Xigaze ophiolites, Saga ophiolites, Xiugugabu-Dangqiong ophiolites, Yungbwa ophiolites, Dongbo ophiolites, Karzog-Spontang ophiolites and Sapat-Jijal ophiolites. Several big ophiolites exposed in YZSZ, such as Xiugugabu-Dangqiong ophiolites, Yungbwa ophiolites, Dongbo ophiolites, are composed mainly of harzburgite, Cpx-bering harzburgite and minor lherzolite, which are locally cut by gabbronoritic and tholeiitic dykes. The deletion of crustal section of these ophiolites, such as basalts, doleritic dykes and cumulate, displays a distinct feature of Mid-Atlantic Ridge peridotites, and different from the ophiolites exposed in Oman and Troodos.

The Baer ophiolite crops out in the north segment of the Dongbo ophiolites. It extends more than 40km in an E-W and 3-4km wide in an N-S. The tectonites in Baer ophiolite are mainly made of Cpx-bearing harzburgite, minor lherzolite, and no crustal section was found. We examined and analyzed, using a JEOL JXA-8100 wavelength dispersive electron microprobe, the Cpx-bearing harzburgite and lherzolite. According to the texture and structure of the peridotites, the mineral assemblage can be divided into three generations: (1) the first generation mineral assemblage of the residual mantle includes olivine, orthopyroxene and clinopyroxene porphyroclast; (2) the second generation includes olivine, orthopyroxene, clinopyroxene and spinel showing variable Cr# of 0.12-0.5. They have representative features of magmatism and follow always or along in the first generations porphyroclast, and are partial melting and melt-peridotites reaction minerals; (3) the third generation amphibole display low $Na2O$ (1.35%~2.08%) and $TiO2$ (0.26%~0.28%), indicating that they were recorded the event of mantle metasomatism during subduction. The field occurrence, petrography and mineralogy of peridotites from Baer are interpreted to suggest that the peridotites in Baer experienced a two-stage evolution: they were formed at a slow spreading mid-ocean ridge and subsequently entered a subduction zone setting. Compared to the other ophiolitic peridotites and crustal section from YZSZ ophiolites suggesting different ophiolite maybe have different tectonic evolution. The ophiolitic complexes exposed in Xiugugabu ophiolites, Yungbwa ophiolites and Dongbo ophiolites, may be formed in MOR setting, reminiscent of the Mid-Atlantic Ridge system, but reconstructed by SSZ. The other ophiolites, including Namche Barwa syntaxis ophiolites, Luobusa ophiolites, Xigaze ophiolites, Saga ophiolites, Karzog-Spontang ophiolites and Sapat-Jijal ophiolites maybe formed in a complex SSZ setting, reminiscent of the modern IBM arc-trench system.

Sources, migration mechanisms and geodynamic environment of K-LILE-Mg-enriched melts: evidence from the Finero Complex (Southern Alps)

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A precious opportunity to characterize sources, compositions, migration mechanisms and geodynamic environment of K-LILE-Mg-enriched melts in off-craton geological settings is represented by the mantle unit of the Finero Complex (the Phlogopite Peridotite unit), which is a unique example of large orogenic massif made by subcontinental lithospheric mantle pervasively metasomatised with segregation of phlogopite-bearing mineral assemblages.

The Finero Complex is located in the northern sector of the Ivrea-Verbano Zone (IVZ, Southern Alps), being placed in contact with the Austro-Alpine terrains of the Sesia-Lanzo Zone by the Insubric line. It has an antiform structure, consisting of a phlogopite-bearing spinel-facies dunitic-harzburgitic mantle unit at the core, which is surrounded by a layered mafic-ultramafic intrusion, i.e. the Finero Mafic Complex, emplaced at the bottom of the continental basement. Unlike the rest of the IVZ (in which the petrogenetic processes are mainly Permian or older), geochronological investigations provide for both mantle and crustal rocks of the Finero Complex mostly ages over a time span from Middle Triassic to Lower Jurassic. In particular, U-Pb zircon data constrain to 232±3 Ma the intrusion age for the youngest intrusive unit of the Finero Mafic Complex (Zanetti et al., 2013, J. Petrol., 54, 2225-2265).

This contribution is aimed at providing new data about field relationships, petrographic features, major and trace elements mineral chemistry of the main lithologies of the mantle unit (e.g. phlogopite- amphibole-bearing harzburgites, dunites with massive chromitite and pyroxenite bands, phlogopite-bearing websterite, orthopyroxenites, clinopyroxenites and sapphirine-bearing amphibole gabbros), as well as about the O isotopic mineral composition, and in-situ U-Pb and Lu-Hf data for zircons from massive chromitite layers located in large dunites.

Our investigation points out that the mantle unit experienced a virtually complete metasomatic recrystallization triggered by several episodes of pervasive-to-channelled porous flow migration of hydrous melts, alternated with episodes of melt migration in open fractures. The latter mechanism formed pyroxenites usually containing Opx, Cpx, Amph and Phl, with the relevant exception of the latest magmatic event, which was characterised by segregation of banded veins formed by sapphirine-bearing hornblendite and leucogabbro. Both peridotites and pyroxenites related to the pervasive recrystallization event display a similar geochemical signature, characterized by low content in Al, Ti, Nb, Ta, HREE and Y, associated to large Mg# value and K, Th, U, Sr, Pb, Ba, LREE concentration. The finding of $\delta^{18}O_{Opx}$ vs. SMOW‰ up to +8 and of negative εHf in chromitite zircons are the evidence of large crustal component in the migrating melts. The new U-Pb zircon data for the chromitite layers provide Lower Jurassic ages: this finding suggests that the crustal and the mantle units experienced different thermal and structural evolutions until that time, being likely tectonically juxtaposed during the opening of the Jurassic Neo-Tethys or later.

The sources of the migrating melts, the age and geodynamic environment of the mantle metasomatism and the age of the crustal accretion of the mantle unit will be debated. In particular, it will be stressed out the possibility that the K-LILE-enriched melt migration suffered by the Finero mantle unit took place in a post-collisional environment, similarly to the high-MgO ultrapotassic, lamproitic magmatism widespread in different Mediterranean areas from Oligocene to Pleistocene in association with shoshonitic and calk-alkaline rocks.

Evidence for refertilisation of a strongly depleted mantle column in the extra-Andean backarc (Paso de Indios, Argentina)

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In the central part of the Chubut province (Patagonia, Argentina), close to the town of Paso de Indios, there are several outcrops of Cenozoic basalts carrying spinel-facies ultramafic xenoliths. In this area, located in the extra-Andean back-arc region, basaltic necks and dikes outcrop between 43º 36′ – 43º 50′ S and 68º 53′ – 69º 02′ W, along with remnants of lava flows, divided in two groups of Paleocene and Eocene age. This volcanism was generated by extensional tectonic related to a transform plate margin episode that affected the southern South America active margin from the Paleocene to the Oligocene, as the Aluk plate detached and a slab window opened beneath the study area. Some Paso de Indios mantle xenoliths were described in regional works focused on the Patagonian mantle (e.g. Rivalenti et al., 2004, J. S. Am. Earth Sci. 17, 121-152), evidencing peculiar records of large degrees of partial melting, along with the metasomatic overprint of strongly LILE-enriched, HFSE-depleted melts. The aim of this work is to characterize the petrochemical processes experienced by the mantle beneath the Paso de Indios region, investigating spinel-facies ultramafic xenoliths hosted in Eocene basalts of the three magmatic bodies, namely the Matilde lava flow remnants, the León volcano and the Chenque dike.

The studied samples are mainly spinel-facies harzburgites and clinopyroxene(Cpx)-poor lherzolites, with some dunites. The Chenque xenoliths mainly present porphyroclastic to equigranular texture, whereas those from Matilde and León volcanoes have coarse-grained to porphyroclastic textures. Estimated equilibrium temperatures based on pyroxenes solvus range from 800 to 940°C, showing the lowest values so far exhibited by Patagonia mantle peridotites and indicating a provenance from shallow mantle sectors. The refractory character of the mineral assemblages is matched by the major element mineral compositions, which are mostly Al-poor and Mg-and-Cr rich. Spinel composition is consistent with melt extraction from 8 to 14% for Chenque and León samples, and from 14 to 18% for the Matilde samples. The estimated degree of melting rises up to 24% considering the literature spinel data. However, the occurrence of melt-related open-system processes is suggested by local trends of positive correlation between Na and Cr# in Cpx, being fully confirmed by the trace element compositions. Cpxs from a harzburgitic sample from León volcano show composition rich in U, Th, Sr and LREE. The Matilde harzburgites ubiquitously show Cpx with transient U-shaped REE patterns. The LREE fractionation is very strong, with La_N up to 150 and minimum at the M-HREE region between 0.1-1xCI. The HREE level content (Lu_N down to 1) is consistent with 20-23% fractional melting of spinel facies DM. V-to-U-shaped REE patterns are also shown by Cpx from Chenque lherzolites and harzburgites. Their M-HREE are more fractionated than that expected in residue after spinel facies basal removal, thus suggesting an onset of the partial melting at garnet facies conditions. Other Chenque lherzolites seem to result from a more extensive refertilisation processes led by LREE-enriched to LREE-depleted melts. The latter gave rise to transient LREE-depleted sinusoidal patterns through reaction with the depleted ambient peridotite. It is, thus, concluded that the shallow mantle column beneath Paso de Indios records an incomplete refertilisation of strongly depleted protoliths. As far as we are aware, this represents a unique example for the Patagonian region, where the mantle usually results completely overprinted by multiple stages of melt migration.

The general objective of the International Orogenic Lherzolite Conferences is to assemble specialists on mantle processes to share new findings (often resulting from recent PhD theses) that are discussed in a group setting, both on key outcrops and in room sessions.

For this 6th Lherzolite conference, we invite contributions in a large range of topics related to the physico-chemical evolution of the mantle including melting processes, melt transport, crustal recycling, significance of mafic lithologies in orogenic peridotites, metasomatism, lithosphere evolution through rejuvenation/refertilization, supra-subduction fluid/melt processes, feedbacks between deformation and melt segregation/migration, field and experimental studies on mantle rocks deformation, geophysical imaging of mantle structures and flow, mineral ressources related to mantle rocks, etc…

The conference also welcomes contributions on the mantle dynamics associated with the convergence between the African and European plates in the Western Mediterranean, including geophysics, petrology and geochemistry of mantle rocks and volcanism, and modelling.

The 6th International Lherzolite Conference is organized in Morocco in the frame of an ongoing collaborative venture between Abdelmalek Essaâdi University (Tetouan), Moulay Ismaïl University (Meknes), Cadi Ayyad University (Marrakech), Geosciences Montpellier (CNRS & University of Montpellier) and the Instituto Andaluz de Ciencias de la Tierra (CSIG and University of Granada).

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