Abstract Volume

XI International Eclogite Conference

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REPÚBLICA DOMINICANA

Dominican Republic

January 31 - February 7, 2015

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XI International Eclogite Conference (IEC)

Dominican Republic

January 31 - February 7, 2015

IEC-2015 is organized on behalf of the IECCC (International Eclogite Conference Coordinating Committee), President: Daniele Castelli

by:

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Contents

Preface

The International Eclogite Conferences (IECs) were established by David C. Smith, who convened the first meeting in Clermont-Ferrand, France, in 1982. The IECs are organized in different countries every two years and focus on studies in the field of high- and ultrahigh-pressure metamorphism. The main purpose of these conferences is to promote worldwide communication and cooperation among scientists who study HP and UHP rocks. The IECs have been an important event of international reputation for more than 30 years.

The program of the current IEC will comprise a central **4-day conference block** dedicated to a wide variety of topics related to high- and ultrahigh-pressure metamorphism that will also include a **1-day syn-conference field trip**. In addition, **pre- and post-conference field trips** will be offered in order to illustrate the variety of high-pressure, subduction-related rocks representative for the region.

The XI IEC will take place on the northern coast of the Dominican Republic near the town of Rio San Juan. We are looking forward to an outstanding scientific meeting in this unusual setting, and we hope you will also take the opportunity to explore the beauty of this country and to enjoy the friendship and kindness of its people.

Rio San Juan, January 30, 2015 The organizing committee

Organizing Committee:

Hans-Peter Schertl, Institute of Geology, Mineralogy & Geophysics, Ruhr-University Bochum, Germany
Walter Maresch, Institute of Geology, Mineralogy & Geophysics, Ruhr-University Bochum, Germany
Rick Abbott, Department of Geology, Appalachian State University, Boone, USA
Grenville Draper, Department of Earth and Environment, Florida International University, USA
Andreas Hertwig, Institute of Geology, Mineralogy & Geophysics, Ruhr-University Bochum, Germany
Adolfo López, Universidad Autónoma de Santo Domingo, Museo del Hombre Dominicano
Santiago Muñoz, National Geological Survey of Dominican Republic
Eduardo Verdeja, Sociedad Dominicana de Geología (SODOGEO), Dominican Republic

Scientific Committee:

Daniele Castelli, Department of Earth Sciences, University of Torino, Italy
Shah Wali Faryad, Institute of Petrology & Structural Geology, Charles University, Prague, Czech Republic
Jane Gilotti, Department of Earth and Environmental Sciences, University of Iowa, USA
Takao Hirajima, Department of Geology and Mineralogy, Kyoto University, Japan
Walter Maresch, Institute of Geology, Mineralogy & Geophysics, Ruhr-University Bochum, Germany
Daniela Rubatto, Research School of Earth Sciences, The Australian National University
Hans-Peter Schertl, Institute of Geology, Mineralogy & Geophysics, Ruhr-University Bochum, Germany
Herman L.M. van Roermund, Institute of Earth Sciences, Utrecht University, The Netherlands
Yong-Fei Zheng, School of Earth and Space Sciences, University of Science and Technology of China

Sessions

- HP- and UHP-rocks: Keys to understanding the origin of the Caribbean region
- HP- and UHP-terranes: P-T-t paths; geochronological, rheological and geochemical characteristics
- HP- and UHP-fluids and melts and their interaction with rocks
- Recognition and interpretation of nano- to micro-scale fabrics in HP-UHP minerals
- The origin of subduction-related ophiolites, chromitites, peridotites, and pyroxenites
- Large-scale processes: crustal tectonics, mantle dynamics, and their modeling
- Open session

Program

30.01.2015	Arrival of participants
31.01.2015 – 01.02.2015	Pre-Conference field trip
02.-03.02.2015	Conference (talks & posters)
04.02.2015	Syn-Conference field trip
05.02.2015	Conference (talks & posters)
06.-07.02.2015	Post-Conference field trip
08.02.2015	Departure of participants

Members of the International Eclogite Conference Coordination Committee (IECCC)
(as of July 2014)

1. Cho, Moonsup, South Korea
2. Castelli, Daniele, Italy
3. Cuthbert, Simon, United Kingdom
4. De Hoog Cees, Jan, Denmark
5. Faryad, Shah Wali, Czech Republic
6. Ghent, Edward, Canada
7. Gilotti, Jane, USA
8. Hirajima, Takao, Japan
9. Hoinkes, Georg, Austria
10. Jahn, Bor-Ming, Taiwan
11. Janák, Marian, Slovak Republic
12. Liati, Anthi, Switzerland
13. Möller, Charlotte, Sweden
14. Perraki, Maria, Greece
15. Rubatto, Daniela, Canberra, Australia
16. Schertl, Hans-Peter, Germany
17. Shatsky, Vladislav, Russia
18. Smith, David, France
19. Van Roermund, Herman, The Netherlands
20. Vrabec, Mirijam, Slovenia
21. Zheng, Yong-Fei, China

Conference Feb. 2, 2015

Morning Sessions

8:45 - 9:15	Opening ceremony: H.-P. Schertl (Organizing Committee); Daniele Castelli (IEC-President); Santiago Muñoz (Servicio Geológico Nacional, República Dominicana); Eduardo Verdeja (Sociedad Dominicana de Geología); Walter V. Maresch (IMA-Past President)

<u>HP- and UHP-rocks: Keys to understanding the origin of the Caribbean region</u>

Chair: Hans-Peter Schertl

09:15 – 9:45	<u>J. Pindell</u> (invited talk) From Harry Hess to Today: Caribbean Serpentinites and HPLT Metamorphic Belts in the context of Caribbean Tectonic Evolution
09:45 – 10:00	<u>G. Draper</u> Geological Evolution of Hispaniola
10:00 – 10:15	<u>R. Abbott</u>, G. Draper UHP rocks in the Cuaba Unit of the Rio San Juan Complex: A review
10:15 – 10:30	<u>H.P. Schertl</u>, W. Maresch, A. Hertwig High-pressure metamorphic rocks in serpentinite-hosted mélanges of the Dominican Republic and the role of jadeitites
10:30 – 10:45	<u>A. Hertwig</u>, W.C. McClelland, K. Kitajima, H.-P. Schertl, W. Maresch, J.W. Valley A comprehensive ion microprobe study on zircon from jadeitites and related rocks from the Rio San Juan Complex, Dominican Republic

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10:45 – 11:15 Coffeebreak

11:15 – 11:30	<u>A. García-Casco</u>, Y. Rojas-Agramonte, I. Blanco-Quintero, C. Lázaro, C.,J. Cárdenas-Párraga, L. Butjosa, J. Proenza A review of serpentinite mélanges of Cuba. Correlations along the NE leading edge of the Caribbean plate and geodynamic implications
11:30 – 11:45	<u>L. Butjosa</u>, A. García-Casco, J.A. Proenza Contrasted affinities of peridotites and serpentinites from Villa Clara subduction Melange (Central Cuba)

<u>HP- and UHP-terranes: P-T-t paths; geochronological, rheological and geochemical characteristics</u>

Chair: Simon Cuthbert

11:45 – 12:00	K.E. Flores, C. Martin, G. Bonnet, S.R. Hemming, Y. Cai, G.E. Harlow, <u>H.K. Brueckner</u> Metamorphic evolution of high-pressure–low-temperature rocks from the northern section of the Guatemala Suture Zone: *PT*t paths and tectonic implications
12:00 – 12:15	<u>F. Rolfo</u>, C. Groppo, H.K. Sachan, S.K. Rai, S.K. Lawsonite-blueschist from the western Himalaya (Ladakh, NW India): petrologic witness of cold subduction processes
12:15 – 12:30	<u>V.S. Shatsky</u>, V.G. Malkovets, E.A. Belousova, A.L. Ragozin, S.Yu. Skuzovatov Evidence of Neoproterozoic continental subduction in Central Asian Orogenic Belt

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12:30 – 14:30 Lunchbreak

Afternoon Sessions

HP- and UHP-terranes: P-T-t paths; geochronological, rheological and geochemical characteristics

Chair:	Simon Cuthbert
14:30 – 14:45	A. Pilitsyna, A. Tretyakov The details of regressive metamorphism history of eclogites within the Anrakhai complex (Southern Kazakhstan) and some tectonic implications
14:45 – 15:00	J.L. Li, R. Klemd, J. Gao, T. John, T. Multiple subduction-exhumation processes in the subduction channel: Evidence from P–T evolution of an oceanic eclogite with polymetamorphism and multistage mineral growth

Chair: Herman van Roermund

15:00 – 15:15	C. Diwu, Y. Sun, Y. Zhao, B. Liu, S. Lai Geochronological, geochemical, and Nd–Hf isotopic studies of the Qinling Complex, central China: Implications for the evolutionary history of the North Qinling Orogenic Belt
15:15 – 15:30	T. Hirajima, E. Sato, Y. Fujimoto, K. Kamimura Lawsonite-blueschist in the Hakoishi sub-unit, Kurosegawa belt, Kyushu, Japan, as a remnant of late Paleozoic Mariana type subduction, part 1: Geology and Tectonics

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15:30 – 16:00 Coffeebreak

Chair:	Herman van Roermund
16:00 – 16:15	I. Klonowska, M. Janák, J. Majka, N. Froitzheim, K. Kośmińska New discoveries of the UHP rocks in the Seve Nappe Complex (Swedish Caledonides) and their under-pressure–driven exhumation
16:15 – 16:30	J. Majka, Å. Rosén, M. Janák, N. Foitzheim, I. Klonowska, M. Manecki, V. Sasinková, K. Yoshida Underpressure-driven exhumation of a diamond-bearing nappe: an example from the Seve Nappe Complex of the Scandinavian Caledonides
16:30 – 16:45	S.M. Gordon, D.L. Whitney, C. Teyssier, H. Fossen, J. DesOrmeau Pressure–temperature–time–deformation history of the Western Gneiss Region, north and south of the Møre-Trøndelag shear zone: implications from U-Pb and trace-element zircon results
16:45 – 18:00	Poster Session I

Feb. 3, 2015
Morning Sessions

HP- and UHP-terranes: P-T-t paths; geochronological, rheological and geochemical characteristics

Chair:	Georg Hoinkes
09:00 - 9:15	A. Pourteau, E.E. Scherer, A. Schmidt, R. Bast Internal P–T–t structure of subduction complexes — Insights from Lu–Hf geochronology on garnet and lawsonite (Halilbağı, Central Anatolia)

09:15 – 9:30	G. Godard, D.C. Smith Île Dumet (Brittany, France) and its glaucophane eclogite: the little sister of Île de Groix
09:30 – 9:45	S.W. Faryad, M. Fišera Granulite facies overprint in HP-UHPM rocks in the Moldanubian Zone (Bohemian Massif); was it a continuous process or separate metamorphic event?
09:45 - 10:00	P. Štípská, B.R. Hacker, R. Powell, R. Holder, A.R.C. Kylander-Clark Linking zircon ages to P−T paths through textural position and REE patterns: The eclogite-mafic granulite to intermediate granulite transition from the Blanský les, Bohemian Massif
10:00 – 10:15	S.J. Cuthbert Densification of subducted felsic crust: Omphacite-bearing orthogneisses in the Western Gneiss Complex, Sunnfjord, Norway

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10:15 – 10:45 Coffebreak

HP- and UHP-fluids and melts and their interaction with rocks

Chair: Takao Hirajima

10:45 – 11:00	Y.-F. Zheng Composition of deep continental subduction-zone fluids: the message from magmatic leucosomes and multiphase solid inclusions in UHP metamorphic rocks
11:00 – 11:15	P. Hasalová, P. Štípská, R. Weinberg, P. Závada, K. Schulmann, M. Racek High pressure water-fluxed melting of felsic orthogneisses: the Eger complex, the Bohemian Massif
11:15 – 11:30	A.V. Korsakov, X.Y. Gao, A.O. Mikhno, Polyphase inclusions in kyanite from Ky-bearing Kumdy-Kol eclogite and HP veins: evidence for partial HP-UHP melting
11:30 – 11:45	A.O. Mikhno, A.V. Korsakov Evidence for existence of UHP sulfide melt in calc-silicate rocks from the Kokchetav massif (Northern Kazakhstan)
11:45 – 12:00	O.V. Shchepetova, A.V. Korsakov Secondary fluid inclusions study the diamond-grade kyanite gneisses, Kokchetav massif: Evolution of fluid composition.

12:00 – 14:00 Lunchbreak

Afternoon Sessions

HP- and UHP-fluids and melts and their interaction with rocks

Chair: Wali Faryad

14:00 – 14:15	A. Vitale Brovarone, O. Beyssac Organic carbon fluxes in forearc subducting slabs
14:15 – 14:30	T. Kawamoto Role of saline fluids in sub-arc mantle and subducting slab

14:30 – 14:45 J. Liu, N. Cheng, G. Yijie, S. Guo, Y. Chen
Diamond-bearing nano-granitic inclusions in zircons from stromatic metatexite migmatites from the Sulu UHPM belt

14:45 – 15:00 Y. Chen, Su, B., S. Guo, Q.L. Li
Linking halogen (F, Cl) and HFSE mobilization during deep crust-mantle interaction: Evidence from Ti-clinohumite-bearing veins in the Dabie orogenic peridotite

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15:00 – 15:30 Coffeebreak

Chair. Yong-Fei Zheng

15:30 – 15:45 S.G. Song, M.J. Wang, Y.L. Niu, L. Su
Long-lived decompression melting of UHPM rocks during continental subduction and exhumation in the N. Qadiam UHP belt

15:45 – 16:00 D.A. Zedgenizov, H. Kagi, V.S. Shatsky
Deeply subducted crustal environments of sublithospheric diamonds from Sao-Luis (Brasil)

16:00 – 16:15 R. Halama, M. Konrad-Schmolke
Fluid infiltration in an interlayered blueschist-greenschist sequence (Coastal Cordillera, Chile)

16:15 – 16:30 H.-J. Massonne, T. Fockenberg
Melting of eclogite at ultrahigh pressure (UHP) conditions: an experimental study

16:30 – 18:30 Poster Session II

(17:30 – 19:00 IECCC Business Meeting)

Feb. 4, 2015 Syn-Conference Field Trip

Feb. 5, 2015
Morning Sessions

Recognition and interpretation of nano- to micro-scale fabrics in HP-UHP minerals
Chair: William C. McClelland

09:00 – 9:15 H.U. Rehman, D. Mainprice
EBSD-measured crystal preferred orientations of the Himalayan UHP eclogites

09:15 – 9:30 J.-J. Yang, M.-X. Huang, H.-R. Zhang, C. Yu
Coseismic UHP metamorphism recorded by eclogite breccias at Yangkou in the Chinese Su-Lu UHP metamorphic belt

09:30 – 9:45 M.L. Frezzotti, R. Palmeri, S. Ferrando, R. Compagnoni, G. Godard
α-quartz in UH*P* rocks: irrelevant or crucial?

09:45 – 10:00 J. Kotková, R. Wirth, P. Jakubová
Internally flawless microdiamonds: FIB TEM study

10:00 – 10:30 Coffeebreak

The origin of subduction-related ophiolites, chromitites, peridotites, and pyroxenites

Chair: Chris Mattinson

10:30 – 10:45	R.Y. Zhang, J.S. Yang, Y IIzuka, B.-M Jahn New insight into the Earth's Transition Zone: In situ discovery of moissanite, native elements and metal alloys in diamond-bearing chromitites from the Luobusa ophiolites, Tibet
10:45 – 11:00	R.-X.Chen, Y.-F. Zheng, H.-Y. Li, L. Zhang Contrasting crust-mantle interaction in the continental subduction channel: evidence from orogenic peridotite/pyroxenite in the North Qaidam orogen, northern Tibet
11:00 – 11:15	M. Philippon, L. Tual, P. Pitra, J.-P. Brun, F. Gueydan Meta-ophiolite emplacement triggered by continental subduction, Syros Island, Cyclades (Greece)
11:15 – 11:30	A.I. Okay Jadeite and jadeites from Turkey

Large-scale processes: crustal tectonics, mantle dynamics, and their modeling

Chair: Daniele Castelli

11:30 – 11:45	W.C. McClelland, J.A. Gilotti, J.A. Comparing the Caledonian and Himalayan Collisional Orogens
11:45 – 12:00	A.W. Willner, J. Glodny, H.-J Massonne, C. van Staal, A. Zagorevski P-T-t evolution of high pressure rocks during an Ordovician arc-continent collision at the margin of Laurentia in Western Newfoundland (Canada)

12:00 – 14:00 Lunchbreak

14:00 – 14:15	M. Konrad-Schmolke, R. Halama, V. Manea Slab mantle dehydration in Kamchatka – does the water flux directly influence the dynamics of subduction zones?
14:15 – 14:30	S.L.Baldwin, P.G. Fitzgerald, L.E. Webb, M.G. Malusà The (U)HP terrane of eastern Papua New Guinea: a modern analogue for (U)HP terranes globally
14:30 – 14:45	P.G. Fitzgerald, S.L. Baldwin, M.B. Bermúdez, L.E. Webb, T.A. Little, S.R. Miller, M.G. Malusà, D. Seward, D. Exhumation of the Papuan New Guinea (U)HP terrane: Constraints from low temperature thermochronology

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14:45 – 16:00 Coffeebreak with Poster Session III

16:00 – 16:30 Information about IEC future activities; Closing Ceremony

Poster Sessions

HP- and UHP-rocks: Keys to understanding the origin of the Caribbean region

(1) A.P. Willner, W.V. Maresch, H.-J. Massonne, G. Willner
Metamorphic conditions of blueschists in the Mt. Hibernia Schists, Jamaica

(2) K.-P. Stanek, W.V. Maresch
Age of peak metamorphism of eclogites from the Escambray Massif, Cuba

(3) R. Maldonado,.F. Ortega-Gutiérrez, D. Hernández-Uribe
First report of garnet whiteschists in the Central America-Caribbean region (Chuacús Metamorphic Complex, Central Guatemala)

HP- and UHP-terranes: P-T-t paths; geochronological, rheological and geochemical characteristics

(4) G. Hoinkes, K. Krenn, M. Heinisch, P. Micheuz, W. Kurz
High Pressure Metamorphism and Exhumation of Cretaceous eclogites within the Austroalpine nappes, Eastern Alps

(5) S.W. Faryad, G. Hoinkes, R. Jedlicka, C. Hauzenberger, V. Kachlík, S. Jiří
Granulite facies equilibration of HP-UHPM rocks in the Moldanubian Zone; evidence for separate HT-UHT metamorphic event

(6) P. Štípská, R. Powell, M. Racek, O. Lexa
Intermediate granulite produced by transformation of eclogite at a felsic granulite contact, in Blanský les, Bohemian Massif

(7) H.-J. Massonne
A Tertiary high-pressure (HP) interplay of an andalusite-bearing micaschist from the southern Pirin Mts., Pirin-Pangaion unit, SW Bulgaria

(8) M. Vrabec, M. Janák, P. Uher, E. Krogh Ravna, K. Kullerud
Chromium-rich kyanite, magnesiostaurolite and corundum in ultrahigh-pressure eclogites from Pohorje Mountain (Slovenia, Eastern Alps) and Tromsø Nappe (Norway, Northern Scandinavian Caledonides)

(9) W. Cao, J.A. Gilotti, H.-J. Massonne, C.T. Jr. Foster
Variation of metamorphic pressure-temperature conditions in the North-East Greenland eclogite province determined from isochemical phase equilibrium diagrams

(10) K. Kośmińska, J. Majka, S. Mazur, M. Manecki, H. Lorenz
New insights into the early Caledonian subduction in the High Arctic

(11) J.L. Li, R. Klemd, J. Gao
A common HP metamorphic evolution of interlayered eclogites and metasediments from the ‘UHP unit’ of the Tianshan metamorphic belt in China

(12) D.L. Chen, Y.F. Ren, A.C. Hauzenberger, G. Hoinkes, X.K. Gong
Lawsonite-bearing eclogite from Yuka terrane, the North Qaidam, NW China

(13) L. Liu, X. Liao, Y. Wang, C. Zhang, D.L. Chen
Early Paleozoic Tectonic Evolution of the North Qinling Orogen, Central China：Constraints from HP/UHP metamorphism

(14) X.-P. Li, H.-P. Schertl, F.-M. Kong, H. Xu, H.
Eclogite from the Qianliyan Island/Yellow Sea linking the high pressure units of Dabie-Sulu and the Korean peninsula

(15) E. Sato, T. Hirajima, Y. Fujimoto, K. Kamimura
Lawsonite-blueschist in the Hakoishi sub-unit, Kurosegawa belt, Kyushu, Japan, as a remnant of late Paleozoic Mariana type subduction, part 2: Petrology and Mineralogy.

(16) J.W. DesOrmeau, S.M. Gordon, T.A. Little, S.A. Bowring, J. Vry
Timescales of (U)HP metamorphism and melt crystallization: zircon U-Pb and trace-element results from the D'Entrecasteaux Islands, Papua New Guinea

(17) T.A. Alifirova, L.N. Pokhilenko, A.V. Korsakov, N.P. Pokhilenko
Interrelation of metasomatic and exsolution processes in cratonic lithosphere under Zagadochnaya kimberlite pipe: The study of a grospydite xenolith

(18) A. Pilitsyna, A. Tretyakov
HP melanocratic rocks of the Anrakhai complex (Southern Kazakhstan): the general features of chemical and mineral composition

(19) D. Hernández-Uribe, F. Gutiérrez-Aguilar, F. Pérez-López, R. Maldonado, A. Victoria-Morales
Petrologic characterization of the blueschists and eclogites of the northern part of Acatlan Complex, Mexico: New thermobarometric data and their implication for the metamorphic evolution of southern Mexico

(20) T. Hyppolito, C. Juliani, A. García-Casco, A. Bustamante
Relictic eclogite facies metamorphism in amphibolites of the Chilean Patagonia (Diego de Almagro Island): First report and implications for the dynamics of the Early Cretaceous subduction zone at the Pacific margin of South America

(21) M. Konrad-Schmolke, C. Witte, R. Dohmen, P.J. O'Brien, L. Erpel, R. Halama, A. Schmidt
Good news from the garnet front – trace element zoning patterns reflect reaction paths rather than kinetic effects

HP- and UHP-fluids and melts and their interaction with rocks

(22) S. Ferrando, M.L. Frezzotti, C. Groppo, D. Castelli, A. Proyer
Following dolomite fate from HP to UHP conditions: the impure Cal-Dol marbles from Dora-Maira Massif (western Alps)

(23) A. Vitale Brovarone
Omphacitites and Jadeitites from Alpine Corsica: two different types of jades

(24) K. Yoshida, T. Hirajima, A. Miyake, A. Tsuchiyama, S. Ohi, T. Nakano, K. Uesugi
Three-dimensional morphological observation of the small fluid inclusion using FIB-XCT technique.

(25) Y. Mori, M. Shigeno, T. Kawamoto, T. Nishiyama
Saline fluid inclusions in jadeitites from southwest Japan: Records of slab-derived fluid composition in subduction-zone channels

(26) W. Su, X. Liu, X.M. Ge
Featured volatiles of the HP veins and their host rocks from the West Tianshan, China

(27) L. Zhang, R.-X. Chen, Y.-F. Zheng
Synexhumation anatexis of ultrahigh-pressure metamorphic rocks: Evidence from migmatite and felsic vein in the North Qaidam orogen, northern Tibet

(28) S. Guo, Y. Chen, B. Su, J.B. Liu
Formation of multiple HP veins in UHP eclogites (Hualiangting, Dabie, China):
fluid source, element transfer, and closed-system metamorphic veining

(29) P. Liu, J. Zhang, Y. Wu, Z. Jin
Polyphase solid inclusions in garnet: indicator of melt infiltration of earlier mineral inclusions

(30) W.-C. Li, R.-X. Chen, Y.-F Zheng
Multiple anatexis records of ultrahigh-pressure metamorphic rocks during exhumation of deeply subducted continental crust in the Sulu orogen

(31) Y.-X. Chen, K. Zhou, Y.-F. Zheng
Garnet geochemistry records the action of metamorphic fluids in ultrahigh-pressure dioritic gneiss from the Sulu orogeny

(32) H.-Y. Li, R.-X. Chen, Y.-F. Zheng
Crust-mantle interaction in continental subduction channel: Evidence from extremely ^{18}O-depleted zircon from orogenic peridotite in the Sulu orogen

(33) X.-Y. Gao, Y.-F. Zheng, Y.-X. Chen
Composite silicate and carbonate multiphase solid inclusions in metamorphic garnet from ultrahigh-pressure eclogite in the Dabie orogen

(34) C.G. Mattinson, J. Meyer, M.E. Regel, J.X. Zhang, J.X.
Modeling eclogite mineral assemblages and fluid release history, North Qaidam UHP terrane, western China

Recognition and interpretation of nano- to micro-scale fabrics in HP-UHP minerals

(35) S. Jung, H. Jung, H Austrheim
Deformation microstructures of olivine in the presence of fluid and implications for seismic anisotropy and shear localization

(36) D. Kim, H. Jung
Lattice preferred orientation of olivine and chlorite in chlorite peridotites from Almklovdalen in the Western Gneiss Region, southwest Norway, and implications for seismic anisotropy

(37) Y. Park, H. Jung
Petrofabrics of olivine and enstatite in mantle xenoliths in Shanwang, eastern China, near the convergent plate margin and implications for seismic anisotropy

Open Session

(38) R.N., Jr. Abbott
Eclogite in modal space: A brave but not so new frontier

(39) A.C.S. Knaf, J.M. Koornneef, C.L. Hofman, G.R. Davies
A multi-isotopic and trace elemental approach to provenance Caribbean greenstone artefacts in an essentially non-destructive way: Implications for pre- and post-colonial exchange and mobility networks

(40) H.-P. Schertl, A. Hertwig, S. Knippenberg, W.V. Maresch, L. Speich, A. Lopez, C. Hofman, R. Rodríguez Ramos
Jade artefacts from the Playa Grande site, Dominican Republic: mineralogical characterization and archeological implications

(41) D. Castelli, S. Ferrando, C. Groppo, D. Elia, V. Meirano, L. Facchinetti
May ancient quern-stones (III c. AD) carved from Coe-Ctd-Grt-talcschists help in refining tectono-metamorphic Units of Southern Dora-Maira Massif?

Abstracts

Eclogite in modal space: A brave but not so new frontier

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Modal space records changes in the volumes and compositions of minerals in a rock (Thompson, 1991), for instance, in response to P-T-sensitive multivariant reactions. The method is applied to retrograded eclogite (Pl+Cpx+Grt+Qz+Hbl) in the Cuaba Unit of the Rio San Juan Complex (Abbott & Draper, 2007), where the issue is characterizing the highest grade mineral assemblage (Omp+Grt+Coe+/-Ky). For the purpose of comparing volumes, additive mineral components are normalized to one mole of oxygen, such that Grt= $Mg_{1/4}Al_{1/6}Si_{1/4}O={}^{1}/_{12}Mg_3Al_2Si_3O_{12}$(pyrope), Px=$Mg_{1/3}Si_{1/3}O$(enstatite), Pl=$Ca_{1/8}Al_{1/4}Si_{1/4}O$ (anorthite), Qz(quartz)=Coe(coesite)=$Si_{1/2}O$, and Ky(kyanite)=$Al_{2/5}Si_{1/5}O$. A molar unit of each has approximately the same volume, i.e., $V_{Grt}{\sim}V_{Px}{\sim}V_{Pl}{\sim}V_{Qz}{\sim}V_{Coe}{\sim}V_{Ky}$ (10.5+/-1.1 cm^3/mole "O"). For the intended purpose, the error in the approximation is acceptable, given the error in estimating modal proportions, and especially given normal heterogeneity in a rock. Na in the form of $an_{1/3}ab_{2/3}=esk_{1/2}jd_{1/2}$ ($an={}^{1}/_{8}CaAl_2Si_2O_8$, $ab={}^{1}/_{8}NaAlSi_3O_8$, $esk={}^{1}/_{6}Ca_{1/2}[\,]_{1/2}AlSi_2O_6$, $jd={}^{1}/_{6}NaAlSi_2O_6$) is subtracted from the bulk composition. This works because the composition of any plagioclase can be expressed as a linear combination of $an_{1/3}ab_{2/3}$ and an. The conversion of $an_{1/3}ab_{2/3}$ in plagiocase to $esk_{1/2}jd_{1/2}$ in omphacite, and vice versa, becomes trivial. The residual bulk-rock chemistry (after subtracting $an_{1/3}ab_{2/3}=esk_{1/2}jd_{1/2}$) is in the CMAS system, where M=Fe^{2+}+Mg+Mn, A=Al+Fe^{3+}. Two CMAS exchange components are included, tk=$A_2M_{-1}Si_{-1}$ (tschermak) and cm=CaM_{-1}. The modal space is then defined by three independent vectors in CMAS:

$$V_1=Pl-{}^{1}/_{4}Qz-{}^{3}/_{4}Px-{}^{1}/_{8}\mathrm{tk}-{}^{1}/_{8}\mathrm{cm},\ V_2={}^{3}/_{5}Grt+{}^{2}/_{5}Qz-Ky+{}^{3}/_{20}\mathrm{tk},\ \text{and}\ V_3=Px-Grt+{}^{1}/_{12}\mathrm{tk}.$$

For a particular bulk composition, accessible parts of the modal space define a polyhedron. A point within the polyhedron is a linear combination of V_1, V_2 and V_3, and in CMAS relates not only to the modal proportions of the minerals but also to their compositions! The composition and total volume of plagioclase or pyroxene are easily corrected for the amounts of non-CMAS $an_{1/3}ab_{2/3}$ or $esk_{1/2}jd_{1/2}$, respectively. For mafic compositions, different parts of the polyhedron correspond to basalt/gabbro, eclogite, granulite facies rock, upper amphibolite facies rock, and extremely high-P assemblages with majoritic garnet. The modal polyhedron can be calculated in two ways, (1) from the bulk composition, or (2) from mineral chemistry and observed modal proportions. When the description of the system is internally consistent, the two approaches converge on the same polyhedron.

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UHP rocks in the Cuaba Unit of the Rio San Juan Complex: A review

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This presentation follows closely a published review (Abbott & Draper, 2013) of data and interpretations for garnet-bearing ultramafic (UM) rock and retrograded eclogite in the Cuaba Unit of the Rio San Juan Complex in northern Dominican Republic. Except for one deeply weathered *in situ* exposure, the UM rock is known only from cm- to m-scale stream boulders. The distribution of the boulders indicates that they were eroded out of the eclogite. Internal features of the UM boulders (dikes, orthocumulate textures, pegmatitic mineral segregations) indicate a magmatic origin. Mineral assemblages and cross-cutting relationships are consistent with a liquid line of descent controlled by fractional crystallization. Magmatic conditions were inferred by comparison with published results of high-P melting experiments in the CMAS system and high-P experimental determinations of the sapphirine-out reaction in the MAS system. Estimated magmatic conditions, P>3.2GPa and T>1500°C, take into account the influence of components outside CMAS, especially Fe. An alternative, low-P hypothesis for the magmatic origin of these rocks is discredited on several grounds. Thermobarometry involving components in garnet, clinopyroxene, spinel and olivine is consistent with subsolidus UHP conditions, 838(+/-170)°C and 3.4(+/-0.7)GPa. With regard to the eclogite, immobile trace elements indicate an N-MORB provenance for its protolith. Evidence for UHP conditions in the eclogite is not obvious due to the effects of retrograde reequilibration. Two types of symplectic intergrowths, plagioclase + clinopyroxene (Sym-I) and plagioclase + epidote (Sym-II) are interpreted as the products of the decomposition of two types of omphacite, Omp-I and Omp-II. Theoretically, Omp-II formed as the result of a retrograde reaction of the form, Omp-II + coesite = Omp-I + kyanite + /- garnet, according to which the maximum pressure for Omp-II is between ~2.8GPa (~850°C) and ~4.2GPa (~950°C), consistent with subsolidus conditions for the garnet-bearing UM rocks. For eclogite, the highest-pressure mineral assemblage would have been Omp-I + kyanite + garnet + coesite.

We propose an origin for the UM rock in the mantle-wedge above a subduction zone. The UM rock was delivered to the subduction zone by forced convection in the mantle wedge (corner-flow), coupled with erosion of the hanging wall. At the subduction zone, fragments of UM rock were admixed with deep-subducted ocean-floor basalt (eclogite). The eclogite, with fragments of UM rock onboard, was then transported to shallower depths by a still poorly understood mechanism involving reverse-flow up the subduction zone.

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Interrelation of metasomatic and exsolution processes in cratonic lithosphere under Zagadochnaya kimberlite pipe: The study of a grospydite xenolith

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Mantle material from the Zagadochnaya kimberlite pipe (Daldyn-Alakit region, Yakutia, Russia) is presented by rock fragments of eclogitic and peridotitic parageneses. The former paragenesis composes rounded xenolithic nodules, whereas the later one tends to be found as separate grains or xenocrysts (Sobolev, 1977).
A grospydite xenolith Zag5a consists of grossular-rich garnet ($Grs_{65}Alm_{21}Prp_{14}$), omphacitic clinopyroxene ($Jd_{49}Di_{31}Ca\text{-}Esk_{11}Ca\text{-}Ts_5$) and kyanite with minor accessory (rutile, titanite, and apatite) and secondary minerals (chlorite, amphibole, talc). Primary clinopyroxene porphyroblasts with kyanite, rutile and titanite exsolution lamellae are crosscut by spongy-textured veins composed of plagioclase, secondary clinopyroxene and K-feldspar. Coarse-grained garnets contain rutile and apatite needle-like lamellae, while diablastic (vermicular) garnet grains have no exsolution features.
According to geothermobarometric calculations studied rock was equilibrated at 1050-1140°C with given pressure of 3 GPa (Ellis & Green, 1979; Krogh Ravna, 2000). However, the assemblage of garnet-kyanite-rutile-titanite might suggest its stability near the graphite-diamond equilibrium (Manning & Bohlen, 1991) like this found in UHP crustal eclogites from Kokchetav Massif (Kazakhstan) (Sobolev & Shatsky, 1990). In addition, exsolution textures in garnet and primary clinopyroxene assume high-pressure high-temperature stability of precursor minerals. Thus, we assume that the grospydite was subjected to metasomatic treatment after decomposition of garnet and clinopyroxene, and the secondary mineral assemblage (like in spongy-textured intergrowths) was formed. It is consistent with the model of Ziberna et al. (2013) who proposed extensive interactions of mantle and kimberlitic melt under Zagadochnaya kimberlite pipe before the eruption.
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The (U)HP terrane of eastern Papua New Guinea: a modern analogue for (U)HP terranes globally

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The Late Miocene to Recent (U)HP terrane of eastern Papua New Guinea is the youngest known exhumed (U)HP terrane on Earth, and provides a modern analogue for (U)HP terranes globally. It formed within the larger obliquely convergent Australian (AUS)-Pacific (PAC) plate boundary zone, as the leading edge of the northern Australian plate was subducted beneath oceanic lithosphere of the Solomon Sea (Woodlark microplate) at the Pocklington Trough (Baldwin et al., 2012). Subduction of Cretaceous volcaniclastic sediments and basalts, derived from the Gondwana rifted margin (Zirakparvar et al., 2012), led to offscraping, subcretion/underplating, and formation of an accretionary wedge with rocks following many different P-T-t-D paths within the subduction channel. Eclogites, blueschists, and lower-grade metamorphic rocks formed, and now occur throughout eastern Papua New Guinea primarily south of, and structurally beneath, ophiolites. Remnants of the low-pressure part of the accretionary wedge occur on the southern-rifted margin of the Woodlark Basin (i.e., Louisiade Archipelago) where prehnite-pumpellyite to lower greenschist facies rocks (Calvados Schist) preserve a record of Early-Middle Miocene NNE-SSW convergence associated with AUS-PAC transpression (Webb et al. 2014).

The deepest level of the accretionary wedge is preserved as variably retrogressed (U)HP rocks found in the core zones and shear zone carapaces of the D'Entrecasteaux Island domes, where felsic and intermediate gneisses encapsulate Late Miocene–Pliocene mafic eclogites. To date, coesite has been identified in only one mafic eclogite, and its peak mineral assemblages preserve chemical and isotopic variations that can be interpreted to record UHP conditions. Concordant Lu-Hf garnet (Zirakparvar et al., 2011), U-Pb zircon (Monteleone et al., 2007) and $^{40}Ar/^{39}Ar$ phengite data (Baldwin and Das, 2013, and submitted), combined with thermobarometry (Baldwin et al., 2008) on the coesite eclogite indicates UHP metamorphism occurred at ~8 Ma at temperatures <750°C and depths of >90 km. Temperatures in the coesite eclogite did not exceed those required for dehydration melting of phengite and $^{40}Ar^*$ has not been completely outgassed since the phengite formed. The preservation of coesite and phengite constrains possible UHP exhumation mechanisms.

At the UHP locality zircon dissolution and growth occurred, below the closure temperature for Pb in zircon. U-Pb zircon ages (~8-3.4 Myr) vary as a function of bulk composition and lithology (Monteleone et al., 2007; Gordon et al., 2012; Zirakparvar et al. 2014; Kohn et al., 2014). Partial to complete (re)crystallization of mineral assemblages, and chemical and isotopic disequilibrium occurs at all scales as recorded in the different P-T-t-D paths followed by rocks as the (U)HP terrane recrystallized and partially melted during exhumation.

The AUS-WDK plate boundary changed from convergence to divergence (rifting) as the Woodlark microplate rotated counterclockwise (Webb et al., 2008). Divergence between the upper plate (Woodlark Plate) and accretionary wedge led to removal of the upper plate and rapid (U)HP exhumation at cm/yr rates. Stream profile analysis (Miller et al., 2012), and low temperature thermochronologic data (Fitzgerald et al., this meeting), suggest that exhumation of the (U)HP terrane occurred during Plio-Pleistocene to Holocene time. Exhumation may still be ongoing as indicated by intermediate depth earthquakes (70-110 km) that occur ~100 km along strike to the west of the Late Miocene coesite eclogite locality (Dieck et al., 2013). (U)HP rocks may occur at depth there, but have yet to be exhumed.

Many similarities exist between the (U)HP terrane of eastern PNG and those documented in the Eocene (U)HP rocks of the western Alps (e.g., Malusà et al., 2011). These include the time scales of (U)HP metamorphism and subsequent exhumation (<8 Ma), rates (>cm/yr), and mechanisms (divergence within an obliquely convergent plate boundary zone). Removal of the upper plate led to buoyant rise of (U)HP rocks to form topographic highs (i.e., internal massifs of the western Alps and domes of the D'Entrecasteaux Islands).

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Contrasted affinities of peridotites and serpentinites from Villa Clara subduction Mélange (Central Cuba)

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The Northern Cuban ophiolite belt is formed by complex tectonic imbrications of ophiolitic and subduction complexes that record formation and subduction of oceanic lithosphere at the leading edge of the Caribbean plate during the Mesozoic. In the Villa Clara Subduction Mélange (VCSM, Central Cuba), mélange formation started in the Cretaceous and finished during the late Eocene, when it finally obducted over the Bahamas platform (passive margin of North America). The VCSM encompasses bodies of an ophiolite suite (hydrated peridotites, layered and isotropic gabbros, diabase, basalt and pelagic sediments), 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.

Three main groups of peridotites and serpentinites are distiguished by means of field relations, whole-rock composition, mineral assemblages, textures, and mineral chemistry. Group A is composed by hydrated lherzolites and harzburgites associated with basalts and (micro)gabbros (locally metamorphosed at low-P). This group has porphyroclastic texture in a matrix of lizardite and chrysotile. The composition of clinopyroxene (Mg# = 91-92, Al_2O_3 = 4.11-7.50 wt%) ortopyroxene (Mg# = 93-95, Al_2O_3 = 3.38-5.41 wt%) and accessory Cr-Spinel (Cr# = 0.2-0.45, Mg# = 0.54-0.73), and chondrite-normalized REE patterns indicate fertile abyssal affinity. Group B is composed by extensively serpentinized (80 %) harzburgite associated with high pressure tectonic blocks. Only primary Cr-spinel is preserved with Cr# = 0.52-0.64 and Mg# = 0.49-0.62. The REE patterns are U-shaped and are typical of depleted forearc peridotites. Group C (antigoritites >90% antigorite) is typically associated with high pressure blocks of MORB-derived metabasites and metasediments. This group typically shows pseudomorphic interpenetrating textures. The REE patterns suggest a MOR affinity and protolith formation in an abyssal setting.

We suggest that Group A abyssal peridotites generated by seafloor spreading in the Proto-Caribbean basin between North and South America (late Jurassic-Cretaceous), Group B harzburgites formed in the supra-subduction fore-arc (Early Cretaceous- Late Cretaceous) of the Caribbean plate and Group C antigorititites represent subducted abyssal peridotites of Proto-Caribbean origin that underwent strong metamorphism and fluid-rock interaction at 60-70 km depth in the subduction environment related to the Caribbean-Proto-Caribbean plate interface.

Variation of metamorphic pressure-temperature conditions in the North-East Greenland eclogite province determined from isochemical phase equilibrium diagrams

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The North-East Greenland eclogite province (NEGEP), which is divided into three segments by two N-striking strike-slip faults, represents the basal part of the upper plate (Laurentia) during the Caledonian collision with Baltica. Two eclogites from the NEGEP were studied to elucidate the spatial variation of the metamorphic pressure-temperature (P-T) evolution of the province. For this purpose, isochemical phase equilibrium diagrams (i.e. pseudosections) were constructed within the system MnO-TiO_2-Na_2O-CaO-K_2O-FeO-MgO-Al_2O_3-SiO_2-H_2O using PERPLE_X and contoured by various parameters (Connolly, 2005). In addition, Zr-in-rutile thermometry (ZIRT, Tomkins et al. 2007) was applied.

An eclogite from Sanddal in the western block contains zoisite, quartz, and rutile. Kyanite, amphibole, quartz and feldspar occur as inclusions in garnet. Symplectites of biotite and plagioclase indicate the former existence of phengite. Omphacite is partially replaced by symplectites of diopside, plagioclase and amphibole. Garnet is almandine-rich, with a core to rim decrease of Fe and Mn; Ca decreases and then increases from core to rim; conversely, Mg increases and then decreases from core to rim. Intersections of garnet isopleths for core to rim compositions in the P-T pseudosection show a P–T path from 1.8 GPa and 785 °C to 1.1 GPa and 735 °C. ZIRT gave temperatures from 760 °C to 720 °C for 1.8 GPa.

A kyanite eclogite from Danmarkshavn in the eastern central segment of the NEGEP is characterized by anhedral to subhedral garnet containing inclusions of phengite, kyanite and omphacite with various retrograde textures. Garnet grains have mostly homogeneous cores, with an increase in Fe and Mn, and a decrease in Mg and Ca towards the rims. Omphacite is commonly replaced by symplectites of diopside, plagioclase and amphibole. Symplectites of sapphirine, spinel and plagioclase partially replace kyanite. Intersections of garnet isopleths for core and rim compositions in P-T pseudosections yielded a decompression P–T path from 2.0 GPa, 790 °C to 1.2 GPa, 890 °C. ZIRT on the rare (<10) rutile grains gave a temperature range from 684 to 736 °C for 1.8 GPa, possibly reflecting part of the cooling path.

Peak P-T conditions of the studied eclogites are roughly the same, consistent with a model of crustal thickening to form eclogites over a wide area of the basal overriding plate in the Caledonian collision. However, the eclogite from Sanddal cooled during exhumation, while the eclogite from Danmarkshavn was heated as it was exhumed. Thus, exhumation mechanisms must have differed in space based on the granulite facies retrograde history of the eastern HP rocks.

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May ancient quern-stones (III c. AD) carved from Coe-Ctd-Grt-talcschists help in refining tectono-metamorphic Units of Southern Dora-Maira Massif?

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Several fragments of at least six specimens of quern-stones were unearthed at Costigliole Saluzzo, Western Italian Alps, in the ruins of a *villa rustica* belonging to the Roman imperial period and destroyed by a fire at the end of the III c. AD (Elia & Meirano, 2012; Elia et al., 2013). Costigliole Saluzzo is located at the mouth of Varaita Valley, some 5 km East of the UHP Brossasco-Isasca Unit (BIU), tectonically sandwiched between the HP San Chiaffredo and Rocca Solei Units of Southern Dora-Maira Massif (Compagnoni et al., 2012; Castelli et al., 2013, with refs.). The hand-mills, up to 34-39 cm in diameter, were carved from Coe-bearing, Ctd+Grt±Gln-talcschists, and from Ctd+Grt-Phe schists.

The Coe-bearing Ctd+Grt±Gln-talcschists (samples US773, LA15) consist of Tlc, Grt, Ctd, Qtz ± Gln, late MgFe-Chl and accessory Rt, Ap and Opm. Peculiar bluish-green, strongly pleochroic, Ctd is abundant and partially replaced by a greenish MgFe-Chl. Grt occurs as strongly zoned porphyroclasts with a reddish core and a colourless rim. Ctd inclusions occur in the Grt core, and relict Coe, partially inverted to Qtz, is preserved in the Grt rim. A slightly-zoned, bluish to colourless Gln is particularly abundant in sample LA15, and it seems in equilibrium with both Ctd and Grt.

The Ctd+Grt-Phe schists (sample LA13) consist of Phe, Qtz, Grt, Ctd, former Gln, minor late Chl and Bt, and accessory Rt and Opm. Light-blue to light-green Ctd is widespread in the matrix, where it is aligned to the main foliation defined by Phe, and it is locally included in Grt porphyroclasts. Lozenge-shaped and/or elongated, fine-grained Wm+Bt+Chl aggregates, likely represent the pseudomorphic replacements of former Gln.

Field occurrence of the Ctd+Grt±Gln-talcschists is still unknown. The site of the *villa rustica* and the presence of Coe relics suggest a possible provenience of these rocks from the UHP BIU. However, similar talcschists have never been reported from this Unit. This finding opens two challenging hypotheses, both under investigations: (i) the occurrence of still unrecognized, peculiar "whiteschist" within the BIU; (ii) the existence of a second, still unmapped, UHP Unit in the Southern Dora-Maira Massif.

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Lawsonite-bearing eclogite from Yuka terrane, the North Qaidam, NW China

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The North Qaidam UHP metamorphic belt lies at the northeast margin of Tibet and is a typical Paleozoic continental deep subduction-collision belt. It extends about 400 km along NW-SE direction and is bounded by the North Qilian block to the north, the Qaidam basin to the south, the Altun Tagh to the west and a small fault to the east. It mainly consists of para- and ortho-gneiss, schist and minor amphibolite, marble, eclogite and garnet peridotite. Coesite-bearing eclogites and pelitic gneiss and diamond-bearing garnet peridotite occur as lenses or interlayers in these gneisses mainly exposed, from southeast to northwest, at four places of Dulan, Xitieshan, Luliangshan and Yuka. The Yuka eclogite-gneiss terrane is located at the western segment of this UHP belt. Previous studies found two kinds of eclogite, phengite eclogite and massive bi-mineralic eclogite in this area. Petrological study suggested clockwise PT path for both eclogite and pelitic gneiss, and P–T conditions of T=650-690°C, P=3.0-3.4 GPa were estimated for peak stage of the eclogites (Chen et al., 2005), which are well consistent with the finding of coesite in garnet (Zhang et al., 2009). Geochemical and high-precision isotope geochronological studies suggest that the protolith of the Yuka eclogites has within-plate basalt (WPB) affinity and formed at 800-850 Ma in the setting of rift or mantle plume association with the breakup of Rodinia supercontinent, and experienced UHP metamorphism at 431-437 Ma (Chen et al., 2009; Song et al., 2010).

In this paper we document a new finding of lawsonite-bearing eclogite. The eclogite occurs as lentoid body within pelitic gneiss lying at the western segment of the Yuka terrane. It is mainly composed of amphibole (60-65 vol%), garnet (15-20 vol%), zoisite (15-20 vol%) and quartz (5 vol%). Garnets in this rock occur as euhedral coarse porphyroblasts with grain size ranging from 1.0 to 2.0 mm in diameter; mostly they have dirty inclusion-rich cores and clean inclusion-poor rims. Inclusions in garnet core are mainly clinozoisite, quartz, amphibole and epidote, and in garnet rim are few zoisite and paragonite occur. Omphacites were found only as relics in some amphiboles, and are mostly surrounded by a symplectite of diopside+albite. Zoisites occur as oriented prismatic crystals with varying length sizes from 1 to 5 mm. As outstanding findings some polyphase assemblages of zoisite/clinozoisite+ quartz+amphibole which show a rectangular shape, and polycrystalline assemblges of zoisite/clinozoisite with rhombus shape were found in some garnets. The unique rectangular and rhombus shapes and the high content of clinozoisite very much resemble pseudomorphs after lawsonite (Tsujimori et al., 2006; Castelli et al., 1998; Usui et al., 2006). Amphibole as part of the mineral assemblage of the pseudomorphs is a little different from previous studies, a formation reaction of lawsonite + omphacite = epidote/ zoisite + quartz + amphibole + fluid (Liu et al., 2013) is suggested. Electron microprobe analyses reveal that omphacites in this eclogite have a Jd-content ranging from 30% to 34%. Garnets are mainly almandine and show obvious prograde growth zonation: from core towards rim the Xsps decreases from about 4% to <1%, Xprp increases from ca 10% to 14%, Xgro decreases from 33% to 23%, and Xalm increases from 55% to 63%. Geochemical analyses indicate MORB affinities depleted in LREEs (light rear earth elements) and LILEs (large ion lithophile elements) for that eclogite with a resulting flat chondrite-normalized REE and depleted mantle-normalized trace elements patterns.

Based on bulk composition of the eclogite, mineral chemistry analyses and isoline maps of Xgro and Xprp in garnet, together with Grt-Omp Fe^{2+}-Mg exchange geothermometer data (Powell, 1985; Ravna et al., 2000; Ellis et al., 1979) and Perple_X pseudosection calculations (Connolly 2005), T=540-550°C, P=1.6-1.8GPa and T=560-565°C, P=2.2-2.3GPa were derived for pre-peak and peak metamorphic stages respectively, which is consistent with the lawsonite stability field but distinct from other two eclogites in this area.

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Contrasting crust-mantle interaction in the continental subduction channel: evidence from orogenic peridotite/pyroxenite in the North Qaidam orogen, northern Tibet

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A combined study of zircon U-Pb ages, trace elements, mineral inclusions and O-Hf isotopes as well as rock-forming mineral O isotopes was carried out for orogenic peridotite/pyroxenite and host gneiss in the North Qaidam orogen, northern Tibet. The results reveal contrasting crust-mantle interactions in the continental subduction channel.

Three distinct zircon domains are recognized in the garnet lherzolite/pyroxenite: (1) middle/high-luminescent cores, grains or rims, exhibiting weak zoning or no zoning, variable Th/U ratios, low REE contents, flat REE patterns with relative lack of negative Eu anomalies, containing inclusions of Ol, Cpx, Opx and Gra, and yielding U-Pb ages of 417±4 to 426±3 Ma; (2) low-luminescent rims, exhibiting weak zoning, planar zoning or no zoning, low Th/U ratios <0.1, high REE contents, steep REE patterns with negative Eu anomalies, containing calcite inclusion as well as multiphase solid inclusions of Cal+Kfs and Qtz+Kfs+Pl, and yielding U-Pb ages of 404±3 to 405±8 Ma; (3) low-luminescent rims, exhibiting no zoning, low Th/U ratios <0.1, high REE contents, steep REE patterns with negative Eu anomalies, and yielding U-Pb age of 368±3 Ma. These zircon domains show variable Hf isotope compositions with large differences between different samples, but narrow $\delta^{18}O$ values of 5.4 to 6.6‰. Nevertheless, their Hf-O isotope compositions are similar to the UHP metamorphic rocks with continental affinity in the North Qaidam orogen. In addition, anatexis of the UHP metamorphic rocks with the same time as the zircon growth in the orogenic peridotite/pyroxenite has also been recognized in the orogen. All these data suggest that these orogenic peridotie/pyroxenite underwent multiple stages of metasomatism by fluids derived from dehydration/anatexis of the deeply subducted continental crust in the exhumation and postcollisional stages.

Rock-forming minerals from garnet lherzolite and dunite exhibit $\delta^{18}O$ values of 4.6 to 5.5‰ for Ol, 3.0 to 5.7‰ for Grt, 4.6 to 5.6‰ for Cpx, and 4.5 to 5.6‰ for Opx. Minerals from garnet pyroxenite show relatively higher $\delta^{18}O$ values of 5.7 to 5.9‰ for Grt, 5.6 to 6.0‰ for Cpx, and 7.8‰ for Opx. Most of these samples exhibit O-isotope disequilibrium between coexisting minerals. It appears that these ultramafic rocks would have interacted with both low-$\delta^{18}O$ and high-$\delta^{18}O$ fluids under high-T conditions. However, the deeply subducted continental crust cannot have served as the source of low-$\delta^{18}O$ fluids in the orogenic peridotite because its high $\delta^{18}O$ values. Instead, the low-$\delta^{18}O$ fluids are suggested to derive from dehydration of the subducted oceanic crust that had undergone high-T alteration by seawater. Therefore, the orogenic peridotite/pyroxenite record the crust-mantle interactions with fluids derived from both the deeply subducted oceanic and continental crusts in the continental subduction channel.

Linking halogen (F, Cl) and HFSE mobilization during deep crust-mantle interaction: Evidence from Ti-clinohumite-bearing veins in the Dabie orogenic peridotite

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Crust-mantle interaction in the subduction factory is critical for the transport of soluble slab-derived elements to the mantle wedge and generation of subduction-related magmas. More and more evidences indicate that high field strength elements (HFSE) are mobile in subduction zones (Katayama et al., 2003; Kessel et al., 2005; Gao et al., 2007; Zhang et al., 2011). Solubility experiments have shown that HFSE can be efficiently mobilized by halogen-rich (F and Cl) fluids and melts (Keppler et al., 1993; Rapp et al., 2010; Migdisov et al., 2011). HFSE complexation with polymerized halogens has been thus proposed as an efficient mechanism to enhance HFSE mobility and transport in subduction zone settings (Manning, 2004), implying that there may be a potential link between HFSE and halogens mobilization. However, to date, direct mineralogical and petrological observations related to this link are still lacking.

Several garnet peridotites are commonly associated with coesite-bearing gneisses in the Dabie-Sulu UHP metamorphic belt. Most of them were initially derived from the mantle wedge above the subducting slab (Zhang et al., 2009), and were scrapped by the exhumed continental crust along the slab-mantle interface (Zheng, 2012; Chen et al., 2013). These garnet peridotites currently contain considerable amounts of zircon and Ti-rich phases, thus providing a unique opportunity to directly investigate HFSE transfer from crust into deep mantle.

The investigated samples are fresh garnet harzburgites collected from the Maowu mafic–ultramafic body in the Dabie UHP metamorphic belt. Veins with variable amounts of orthopyroxene, garnet and Ti-clinohumite as well as considerable amounts of apatite and zircon occasionally crosscut the wall harzburgite. Platium group element (PGE) concentrations and Os isotopic composition imply that the Maowu harzburgite was originated from the subcontinental lithospheric mantle (SCLM) beneath North China Craton. Mineral textures and chemistry indicate that both orthopyroxene and Ti-clinohumite in the veins are produced by the metasomatic reaction between olivine and Si-Ti-bearing agent. The P-T conditions of 5.5-6.4 GPa and ~800 ^{o}C were estimated for the matrix mineral assemblages in the Ti-clinohumite-bearing veins. Zircon grains only occur in the veins and show equilibrated texture with other matrix minerals, with very low Th/U (<0.1) ratios. Secondary Ion Mass Spectrum (SIMS) *in-situ* zircon dating in a thin section scale yields tight U-Pb ages of 225.4±3.7 Ma, indicating that the harzburgite experienced Triassic UHP metasomatism by a fluid. Compared with the wall harzburgite, the Ti-clinohumite-rich veins are enriched in SiO_2, Al_2O_3, TiO_2, P_2O_5, LREE, LILE and also display positive Nb, Ta and Zr anomalies, with variable suprachrondritic Nb/Ta ratios (19-42). They have higher F and Cl concentrations than the wall harzburgite. These data demonstrate that the Maowu harzburgite was metasomatised by the incoming fluid rich in SiO_2, Al_2O_3, P_2O_5, LREE, LILE, HFSE, F and Cl. Such halogen-rich fluid may be derived from subducted supracrustal rocks at UHP conditions and could enhance HFSE mobilization in subduction zone settings. The whole-rock F and P_2O_5 concentrations in all samples correlate positively with the HFSE concentrations, corresponding to several experimental results that HFSE solubility is dependent on F concentration in hydrous fluids (Rapp et al., 2010; Migdisov et al., 2011). Precipitation of apatite during deep crust-mantle interaction would rapidly reduce F concentration in the fluid, resulting in precipitation of HFSE-rich minerals (e.g. zircon and Ti-clinohumite). That may be the reason for the common association of apatite with zircon and Ti-clinohumite in orogenic garnet peridotites (Katayama et al., 2003; Zhang et al., 2005, 2011; Yang et al., 2009; Zheng et al., 2014).

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Garnet geochemistry records the action of metamorphic fluids in ultrahigh-pressure dioritic gneiss from the Sulu orogen

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Fluids play an important role in subduction-zone metamorphism. It can catalyze mineral reaction, enhance trace element mobility, and facilitate crust-mantle interaction at the slab-mantle interface in subduction channels. Therefore, it is important to elucidate the source and composition of subduction-zone fluids, the timing and P-T conditions of fluid action, and the geochemical and geodynamic consequences for the fluid-rock interaction in both oceanic and continental subduction zones. Metamorphic growth of garnet in various types of HP and UHP rocks can be linked to breakdown of hydrous minerals at different metamorphic stages. Therefore, garnet geochemistry can record the action of metamorphic fluids during subduction-zone metamorphism.

A combined study of major and trace elements, water contents and oxygen isotope composition was carried out for metamorphic garnet in ultrahigh-pressure dioritic gneiss from the Sulu orogen. The results provide insights into the action of metamorphic fluids on garnet overgrowth under subduction-zone conditions. Garnet grains show a core-rim structure and the two types of domains exhibit distinct geochemical compositions. The cores have high contents of almandine (52.4-65.3 mol.%) and spessartine (4.2-19.4 mol.%), and low $\delta^{18}O$ values of 5.0 ± 0.2‰. The rims have low spessartine contents (1.0-3.4 mol.%), high grossular contents (28.7-36.1 mol.%) and high $\delta^{18}O$ values of 6.1 ± 0.3‰. Furthermore, the rims show much lower contents of Li and HREE, and considerably higher contents of Sc, V and Ga than the cores. In addition, the cores exhibit very low contents of structural hydroxyl in 32 ± 10 to 48 ± 20 ppm H_2O, whereas the rims show much higher contents of structural hydroxyl in 112 ± 16 ppm to 171 ± 34 ppm H_2O. Although the boundary between core and rim is highly irregular, the zoning in water contents, element and oxygen isotope compositions are all spatially correlated with each other. Taken together, the geochemical compositions of garnet cores and rims would primarily dictated by two types of metamorphic fluids with distinctive compositions. Some garnet subgrains, bounded by fractures, show the two types of domains with distinct water contents. This difference indicates insignificant exchange of structural hydroxyl by diffusion during growth of the rims over the cores. Mineral-pair O isotope thermometry yields consistent temperatures of ~560 °C for the quartz-garnet rim and quartz-titanite, and titanite U-Pb dating yields a metamorphic age of 226 ± 6 Ma. Thus, the growth of garnet rims is linked to the exhumation of deeply subducted continental crust in response to the action of metamorphic fluids, and the compositions of garnet cores and rims are primarily controlled by the composition of attending fluids. As such, garnet provides a good mineralogical record of the fluid action during subduction-zone metamorphism.

Densification of subducted felsic crust: Omphacite-bearing orthogneisses in the Western Gneiss Complex, Sunnfjord, Norway

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Geodynamic models for the behaviour of continental margins during collision and subduction require realistic information on rock density and rheology as they evolve during the subduction-eduction cycle. In the Western Gneiss Complex (WGC), a giant mid-late Silurian HP-UHP terrain in the southern Scandinavian Caledonides, the predominant exposed lithology is granitoid orthogneiss. Preservation of peak Scandian HP or UHP mineral parageneses is rare due to pervasive amphibolite-facies overprinting and partial melting. Where exhumation-related ductile deformation is weak there is widespread evidence for the formation of phengite in orthogneisses (Engvik et al., 2000; Hacker et al., 2010) but the extent to which plagioclase transformed to denser jadeitic pyroxene (to be expected under the pressures calculated from metabasic eclogites in the WGC) is not yet well known.

In the southern part of the WGC P-T conditions recorded in eclogites are in the quartz-stable, HP range with temperatures significantly lower (550^{o}-$700^{o}C$) than the better-known UHP rocks north of Nordfjord. In the Dalsfjord area in Sunnfjord, omphacite-bearing dioritic to granodioritic orthogneisses of the Gjölanger Unit have been found to outcrop continuously over an area ~$6km^2$ and possibly considerably larger (Cuthbert 1985, Skår, 1997). They can be shown to have evolved from a Mesoproterozoic two-pyroxene, garnet-free, charnockitic precursor by transformation of feldspar to domains of czo + ky + qz ±pg ±phe and mafic domains to omp + grt + rt (altered to symplectites of amp + plag ±biotite). Peak P-T conditions are estimated to be 2.3GPa at ~$650^{o}C$. The gneisses are L>S tectonites with a strong omphacite aggregate linear shape fabric. Syn-tectonic veinlets consist of coarse quartz, omphacite, phengite, rutile and carbonate.

Transformation of anhydrous charnockite to a hydrous eclogite-facies mineral assemblage involves a significant increase in density. The change from massive charnockite to a strongly-lineated omphacite gneiss also suggests a change in rheology. If similar rocks were originally widespread in the WGC, both such changes are likely to have influenced mechanical behaviour of the crust during Scandian subduction and eduction. Such transformations require a pervasive influx of aqueous fluid, but no local source of fluid is evident. Hence transport of fluid over several kilometers is implied, possibly from metasedimentary cover rocks or previously hydrated, overlying subduction-zone mantle.

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Timescales of (U)HP metamorphism and melt crystallization: zircon U-Pb and trace-element results from the D'Entrecasteaux Islands, Papua New Guinea

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Ultrahigh-pressure (UHP) terranes record the deep subduction and subsequent exhumation of crustal rocks. To more clearly understand these processes, the relative timing of metamorphism, deformation, and partial melting, and the relationship of the UHP eclogites to their host rocks must be well constrained. Southeastern Papua New Guinea (PNG) exposes domal structures comprised of (U)HP eclogites and migmatitic host gneiss across three islands, including from west to east, Goodenough, Fergusson, and Normanby Islands. The PNG (U)HP terrane is unique in that it lies within an active rift basin, preserves abundant evidence for partial melting, and has not been overprinted by later tectonic activity. Moreover, the PNG terrane records a rapid exhumation history with UHP metamorphism occurring by ca. 5.6 Ma (zircon from the only known coesite-bearing eclogite), and Ar-Ar thermochronology indicates final extension-driven exhumation to temperatures < 300 ºC by ca. 1.8 Ma. To further constrain the evolution of the Pliocene PNG (U)HP terrane and compare exhumation histories among the domes, zircons were analyzed by U-Pb isotope dilution thermal ionization mass spectrometry (ID-TIMS) geochronology from a variety of eclogites, host orthogneiss, leucosomes, and dikes. Eclogite collected to the northeast of the coesite-locality within the Mailolo Dome (Fergusson Island), yield zircon dates of ca. 4.3 Ma, and to the east in the Oitabu Dome (Fergusson Island), an eclogite yields zircons that crystallized at ca. 4.6 Ma. To the west of these domes, within Goodenough Dome (Goodenough Island), eclogites yield much younger dates of ca. 2.8–2.6 Ma. Trace elements were measured from dissolved zircon by TIMS-TEA, and trace-element transects across additional grains were analyzed by *in situ* LA-ICP-MS from the eclogites. Nearly all analyses have flat HREE slopes (Lu/Gd < 3.0) and no negative Eu anomalies (Eu/Eu* > 0.75), consistent with zircon that (re-) crystallized during eclogite-facies metamorphism. Trace element distribution coefficients for zircon and garnet from the eclogites reveal similar equilibrium patterns documented in other HP rocks, further supporting that the zircons crystallized at HP, garnet-stable conditions. Zircons reveal melt-present deformation on Mailolo Dome, with crystallization of strongly deformed foliation-parallel leucosomes from ca. 3.5–3.0 Ma and weakly deformed cross-cutting dikes at ca. 2.4 Ma. In comparison, Goodenough Dome foliation-parallel leucosomes reveal melt crystallization from ca. 3.8–2.7 Ma and cross-cutting dikes from ca. 2.7–2.3 Ma, which is seemingly at odds with the ca. 2.8–2.6 Ma eclogite dates. Finally, in the south, Normanby Dome records host orthogneiss development by ca. 5.6–5.0 Ma and emplacement of deformed granodiorite sills by ca. 4.1 Ma. Zircons from late, non-deformed felsic and mafic dikes across all domes yield synchronous crystallization ages of ca. 1.8 Ma. The ID-TIMS dates from eclogite on Mailolo Dome and host gneiss on Normanby Dome underwent coeval peak metamorphism at ca. 5.6–4.6 Ma. Subsequent exhumation and cooling of the (U)HP rocks in the PNG terrane began first in the east, within Normanby Dome, followed by Goodenough Dome ~1 m.y. later in the west, and finally rocks exposed in the central Mailolo Dome cooled ~2 m.y. after Normanby exhumation. All domes reveal final extension-driven exhumation by ca. 1.8 Ma.

Geochronological, geochemical, and Nd–Hf isotopic studies of the Qinling Complex, central China: Implications for the evolutionary history of the North Qinling Orogenic Belt

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The Qinling Complex of central China is thought to be the oldest rock unit and the inner core of the North Qinling Orogenic Belt (NQOB). Therefore, the Qinling Complex is the key to understanding the pre-Paleozoic evolution of the NQOB. The complex, which consists of metagraywackes and marbles, underwent regional amphibolite-facies metamorphism. In this study, we constrained the formation age of the Qinling Complex to the period between the late Mesoproterozoic and the early Neoproterozoic (ca. 1062–962 Ma), rather than the Paleoproterozoic as previously thought. The LA-ICP-MS data show two major metamorphic ages (ca. 499 Ma and ca. 420–400 Ma) for the Qinling Complex. The former age is consistent with the peak metamorphic age of the high- and ultra-high pressure (HP–UHP) rocks in the Qinling Complex, indicating that both the HP–UHP rocks and their country rocks experienced intensive regional metamorphism during the Ordovician. The latter age may constrain the time of partial melting in the NQOB, between the late Silurian and early Devonian. The Qinling Complex is mostly affiliated with subduction–accretion processes along an active continental margin, and should contain detritus deposited in a forearc basin.

The available data indicate that the NQOB was an independent micro-continent at least prior to the Neoproterozoic, and included a portion of the Grenville orogenic belt during the period 1.2–0.8 Ga. The NQOB has experienced a unique geological history, which is obviously different from that of the North China Craton (NCC) and the Yangtze Craton during the Precambrian. The Neoproterozoic granitoids that intruded the Qinling Complex can be interpreted as the products of assembly of the supercontinent Rodinia. The NQOB was separated from Rodinia at ca. 830–740 Ma. Subsequently, the NQOB moved closer to the northern margin of the NCC, and the initial accretion or collision with the NCC occurred from the late Cambrian to the early Ordovician.

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Geological Evolution of Hispaniola

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Hispaniola is a segment of an Early Cretaceous to mid-Eocene intra-oceanic island arc system that has been dissected and exhumed by an ongoing, highly oblique collision of the arc with the southern margin of the North American continent.

The island arc was formed over a southwest-dipping subduction zone that geochronological studies on high-pressure metamorphic studies suggest began sometime prior to 120Ma. The subduction complex of this arc is exposed in the north-east part of the island (Samaná and Rio San Juan areas), its fore-arc basement in the western and south-western Cordillera Septentrional and overlying fore-arc basin sediments in the Cordillera Oriental. The magmatic arc and back arc underlies the Cordillera Central. The early magmatism consisted of a bi-modal suite of rocks with island arc tholeiite (IAT) characteristics. At about 110Ma, the locus of the magmatism shifted to the southwest of the earlier magmatism and became calc-alkaline in character. This change also coincided with deformation within the arc that thrust mantle rocks northeastward over the early arc rocks to form a mylonite belt.

Arc volcanism ceased in the mid Eocene, when the arc began its highly oblique collision with the southern margin of North America. This ongoing collision has resulted in uplifted ranges that expose the Cretaceous sequences, separated by Paleogene to Neogene pull-apart and ramp-valley sedimentary basins that reflect the present physical geography of the island. The shortening of the back-arc basin formed the Hispaniola fold and thrust belt. Neogene oblique thrusting emplaced part of the ~90 Ma Caribbean Large Igneous Province (CLIP) onto the southern part of the Hispaniola Arc edifice to form the Pres'quile du Sur-Bahoruco massifs of the southern part of the island.

Granulite facies overprint in HP-UHPM rocks in the Moldanubian Zone (Bohemian Massif); was it a continuous process or separate metamorphic event?

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Recent results of petrological studies on HP-UHPM rocks in the Moldanubian Zone of the Bohemian Massif, mainly on compositional zoning and solid phase inclusions in garnet from various lithologies enabled the establishing of a prograde history of the rocks which underwent subduction and subsequent granulite facies metamorphism during Variscan Orogeny (Faryad et al., 2013, Perraki and Faryad, 2014). It was shown that the HP-UHP metamorphism and their amphibolite-granulite facies overprint were two separate processes that occurred in the Moldanubian Zone. In this contribution we present further evidence indicating that the granulite facies metamorphism occurred after the HP-UHP rocks had already been exhumed to different levels of the middle or upper crust. A medium-temperature eclogite that is part of a series of tectonic blocks and lenses within the amphibolite facies Monotonous unit contains preserved eclogite facies assemblage with prograde zoning of garnet and omphacite that is partly replaced by a symplectite of diopside + plagioclase + amphibole. Garnet and omphacite equilibria and pseudosection calculations indicate that the HP metamorphism occurred at relatively low temperature conditions, reaching about 650 °C and 2.0 GPa. The striking feature of the rocks is the presence of garnet porphyroblasts with fractures filled by granulite facies assemblages. They are represented by olivine, spinel, and Ca-rich plagioclase which occur as a symplectite forming two central, olivine-rich and marginal, plagioclase-rich zones. The olivine- spinel equilibria indicate temperatures of about 900 °C. The overall textures, principally the preservation of eclogite facies assemblages support that the granulite facies overprint was a short-lived process as it was also documented earlier from the Moldanubian Zone (O´Brien and Vrána, 1995). The new results allow constraining a geodynamic model suggesting exhumation of HP-UHP rock along the subduction channel with most of the granulite facies equilibration occurring due to heating by mantle derived magma in the middle and upper crust.

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Granulite facies equilibration of HP-UHPM rocks in the Moldanubian Zone; evidence for separate HT-UHT metamorphic event

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Felsic granulites in the Moldanubian Zone are typical for the presence of ternary feldspars, which are indicative for UHT conditions in quartz-feldspatic lithologies. Despite of such high-temperature equilibrium, garnet from some felsic granulites preserve prograde zoning that was formed during subduction an UHP metamorphism, recorded by the presence of coesite and microdiamond. Based on geochronological data, the HP-UHP metamorphism occurred around 370-360 Ma and granulite facies overprint show ages around 340 Ma. Trace element and REEs distribution in garnet show two phase growth suggesting its formation by two separate metamorphic events. Growth of new garnet and preservation of HP garnet with prograde zoning suggest that the granulite facies overprint was a short-time event, which occurred in the crustal levels, rather than a continuous heating during isothermal decompression from mantle depth. The evidences for such process were investigated in a coronitic metatroctolite that occurs at the contact with felsic granulite and migmatites. The coronae consist of core of orthopyroxene, with two or three zones: the innermost is characterized by calcic amphibole with minor spinel and relicts of clinopyroxene, followed by a symplectite of amphibole with spinel, sapphirine and accessory corundum and the outermost zone is formed by garnet and amphibole with relics of spinel. The orthopyroxene forms a monomineralic aggregate that may contain a cluster of serpentine in the core, suggesting its formation after olivine. Based on mineral textures and thermobarometric calculations, the troctolite was crystallized in the middle to lower crust and the coronae were formed during three different metamorphic stages. The first stage is related to a subsolidus reaction by formation of orthopyroxene around olivine. The amphibole formation in the second corona suggests the presence of a fluid that resulted in the replacement of primary igneous orthopyroxene and governed the reaction orthopyroxene + anorthite = amphibole + spinel. The last stage of corona formation with amphibole + spinel + sapphirine indicates granulite facies conditions. U-Pb data on zircon indicates Variscan ages for both the troctolite crystallization (~ 360 Ma) and granulite facies metamorphism and corona formation at ~340 Ma that fits well with the generally accepted age for granulite facies metamorphism. The intrusions of troctolite and other Variscan mafic and ultramafic massifs are interpreted as potential heat source for amphibolite - granulite facies metamorphism that led to partial reequilibration of earlier high- to ultrahigh-pressure metamorphic rocks in the Moldanubian Zone.

Following dolomite fate from HP to UHP conditions: the impure Cal-Dol marbles from Dora-Maira Massif (western Alps)

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Polymetamorphic impure Cal-Dol-marbles from the UHP (730°C at 4.0–4.5 GPa) Brossasco-Isasca Unit (BIU; Dora-Maira Massif) are promising rocks to investigate the poorly known fate of dolomite within the Earth's interior. Dolomite occurs as pre-kinematic porphyroclasts with curved, irregular or lobed margins. Under both CL and SEM, dolomite usually shows at least four stages of growth, coupled with chemical variations, and distinct included mineral assemblages, depending on bulk-rock composition: I) a pre-Alpine inner core; II) an HP prograde-Alpine outer core, concentrically overgrowing the inner core; III) an UHP inner rim asymmetrically overgrowing the partly resorbed core; IV) an UHP early-retrograde outer rim that asymmetrically overgrows the inner rim in sharp discontinuity.

A chemically simple marble consisting of Cal, Dol, Cpx, Ol, and retrograde Atg, Tr and Mg-Chl has been studied in detail. Alpine Cpx includes abundant primary, crystallographically oriented H_2O+chloride ± carbonate fluid inclusions, and local intergrowths of Dol+Cal. T/P-$X(CO_2)$ petrogenetic grids and pseudosections, and mixed-volatile P-T grids modelled in the CMS-H_2O-CO_2 system predict the first, and only, prograde (ca. 1.7 GPa, 550°C) growth of Dol in equilibrium with Cpx and Ol through the breakdown of Atg+Arg. In a fluid saturated system, the subsequent HP-UHP prograde and early retrograde P-T evolution is thermodynamically predicted in the Cpx+Fo+Dol+Arg stability field in equilibrium with a dominantly aqueous COH fluid ($0.0003<X(CO_2)<0.0008$). This implies that, though prograde growth of Dol II can be explained by the Atg dehydration, the growth of Dol III and Dol IV cannot have been induced by simple isochemical metamorphic reactions. In Dol, re-entrant irregular grain boundaries are interpreted as due to dissolution/precipitation episodes in saline aqueous fluids. They cannot be ascribed only to local fluid-assisted grain-boundary migration processes, since the presence of abundant crystallographically-oriented (i.e., primary) fluid inclusions in Alpine Cpx coexisting with Dol indicates migration of carbonate- and chloride-bearing aqueous fluids at least at the sample scale.

Kinetics of Dol dissolution in aqueous fluids is poorly known, and experimental and thermodynamic data under HP conditions are still lacking. However, data on calcite indicate that dissolution at HP during subduction is enhanced by following a prograde increase in both P and T, by high salinity in aqueous fluids, and/or low pH conditions. In a closed system, variations in one or more of these parameters should promote carbonate dissolution and/or precipitation processes. In the studied marble, the prograde P-T path and the occurrence of free high-saline fluids represent favourable conditions i) for the inferred dissolution-precipitation processes of the stable dolomite in a closed system; ii) for possible migration of the dissolved carbonate, if the system would have been open during subduction.

Exhumation of the Papuan New Guinea (U)HP terrane: Constraints from low temperature thermochronology

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The world's youngest (U)HP terrane is located in the D'Entrecasteaux Islands (DEI) of eastern Papua New Guinea (PNG) (Monetelone et al., 2007; Baldwin et al., 2008). This UHP terrane has been exhumed from depths of ~90 km since ~8 Ma (Baldwin et al., 2008). The DEI comprise metamorphic core complexes and gneiss domes with cores of amphibolite and eclogite-facies gneisses, as well as Pleistocene granitoid intrusions (Hill et al., 1992, Little et al., 2007, 2011). The high-grade core zone of the domes are juxtaposed against an upper plate that includes gabbro and ultramafics that represent dismembered ophiolites (i.e., Papuan Ultramafic Belt (Monteleone et al., 2001), or Solomon Sea lithosphere (Gaina and Müller, 2007).

The DEI lie to the west of the active seafloor spreading rift tip of the westward-propagating Woodlark Basin. Seafloor spreading there has been propagating westward into heterogeneous crust of the Woodlark Rift since at least ~6 Ma. The Woodlark Basin formed due to seafloor spreading between the Australian plate and the counterclockwise rotating Woodlark microplate (e.g., Taylor et al., 1999; Wallace et al, 2004). The northern margin of the Woodlark basin is defined by the Woodlark Rise and the southern conjugate margin by the Pocklington Rise.

Subducted sediments, basalts, and volcanogenic detritus from the Australian continental margin were protoliths for UHP rocks (Zirakparvar et al., 2012). These were subducted at a north dipping subduction zone, the remnant of which is now marked by the Pocklington Trough. The former subduction thrust is marked in the DEI by a carapace shear zone that separates the core zone from the overthrust ophiolitic rocks. The mechanisms of UHP exhumation are debated, but exhumation has occurred along this former subduction zone and there is an density inversion with relatively low density (U)HP rocks structurally beneath high density obducted ophiolites (Martinez et al., 2001). Thus buoyancy, likely enhanced by partial melting during exhumation (Little et al., 2011; Gordon et al., 2012) is important, with normal faulting on shear zones during the final stages of exhumation. The trans-mantle diapir model (Little et al., 2011, Ellis et al., 2011) has (U)HP exhumation occurring dominantly via buoyancy forces, with the weak, low viscosity body localizing rifting in the Woodlark rift with complex feedback between upward movement of the diapir and rifting (Ellis et al., 2011). The domes of the DEI would thus reflect the largely uneroded form of diapir(s). The rotating microplate model (Webb et al., 2008) explains (U)HP exhumation via counterclockwise rotation of the upper plate (Woodlark Plate) facilitating subduction inversion along the former subduction thrust. Similarities between the tectonic scenario during the Eocene, for the Western Alps, led Malusà et al. (2011) to suggest a similar mechanism for (U)HP exhumation in eastern PNG, that is, motion of the upper plate away from the trench permits (U)HP exhumation.

Low temperature thermochronology provides constraints on the late-stage thermal and exhumation histories in the DEI and along the conjugate rift margins of the Woodlark Basin. We present apatite and zircon fission track (AFT and ZFT), and apatite and zircon (U-Th)/He (AHe and ZHe) data. AFT ages generally decrease from ~8 Ma at Misima Island in the east, to between ~1.5 and 0.5 Ma in the DEI. AHe minimum ages also decrease to the west, from ~6 Ma at Misima to between 2.0 and 0.3 Ma within the DEI. On Goodenough Island, the western-most and highest-standing DEI, AFT and AHe ages are the youngest. Within the general westward-younging trend there is some local variation indicating younger more-local events follow the dominant westward propagating rift control. ZHe ages from Normanby and Fergusson Islands range from 1.7 to 1.3 Ma. ZFT ages are only from Goodenough Island and range from 1.6 to 1 Ma. For some samples we measured confined track-length distributions (CTLD) using ^{252}Cf implantation. Track length data generally indicates rapid cooling (means ≥~14 microns), except on Goodenough Island. There, core zone and upper elevation samples (>800 m) have AFT ages up to ~1.5 Ma with CTLDs (means of 10-13 µm) indicative of residence within a PAZ, or reheating before final cooling/exhumation at ~0.75 Ma. Inverse thermal models do not constrain very well the timing of initial cooling into the PAZ, and in these cases we rely on higher temperature thermochronology data (e.g., ZFT, K-feldspar $^{40}Ar/^{39}Ar$). Carapace zone and lower elevation samples, including those on the coast of on Goodenough Island tend to be younger (<1 Ma) and where available, have longer mean lengths (~13 µm). Inverse models generally indicate a simple rapid cooling history for these samples, although some minor partial annealing is permissible. The final phase of rapid cooling, with or without partial annealing is <1 Ma, typically ≤0.75 Ma. Thermochronologic data from Goodenough Island is also being used to constrain thermokinematic models (PeCube) in order to test the relative roles of buoyancy and normal faulting as well as rates and timing of exhumation of these elogite-bearing domes (Bermudez et al., 2014).

Overall, systematic westward-younging of thermochronologic ages is correlated with westward propagation of rifting ahead of the seafloor spreading rift tip. As samples from the DEI lie on this trend, extensional gneiss dome and core complex formation there are most likely also controlled by rifting. Thus rifting ultimately controls exhumation as it effectively removes the upper plate lid, along the former subduction thrust. That, plus buoyancy of subducted material, density inversion and late-stage normal faulting all play a role in Late Miocene –recent UHP exhumation.

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Metamorphic evolution of high-pressure–low-temperature rocks from the northern section of the Guatemala Suture Zone: *PT*t paths and tectonic implications

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The Guatemala Suture Zone (GSZ), the western end of the boundary between the North American and Caribbean plates, is a highly tectonized geotectonic unit that underwent major compressional events prior to its present history as a largely strike slip system. Metamorphic complexes occur both north and south of the boundary. The northern section consists of (a) a serpentinite-matrix mélange with tectonic blocks of high-pressure–low-temperature (HP–LT) eclogites, minor blueschists, amphibolites and vein-related rocks, (b) a continental terrane that contains high pressure-high temperature (HP-HT) eclogites, (c) a low-grade disrupted volcanosedimentary sequence, and (d) large ultramafic fragments from the base of a Cretaceous island arc sequence. Hitherto, the history of this northern section of the GSZ was interpreted as a straightforward sequence of subduction-exhumation-collision and obduction. However, Sm–Nd, U–Pb and Ar–Ar ages from a range of rock types combined with petrographic and thermobarometric studies on garnet-bearing metabasites in the mélange indicates a more complicated evolution. Each mélange lithology records a different *P-T* path. The mélange eclogites, for example, document a polymetamorphic history consisting of HP-LT metamorphism at 130–125 Ma and ~60 km depth, early exhumation at 117–116 Ma to ~35 km, subsequent amphibolite facies metamorphism and, finally, exhumation at ~85 Ma. In contrast, jadeitite and mica rocks within the mélange yield crystallization and exhumation ages of ~ 95 Ma and ~77–53 Ma. In further contrast, continental eclogites show a still younger HP-HT metamorphic peak at 77–75 Ma at ~80 km depth, and exhumation ages of ~76–66 Ma. These complex *PT*t paths indicate discreet, multiple or continuous tectonic events for each rock type rather than a simple, common subduction/exhumation/obduction history for all rock types. The high *P-T* conditions of oldest eclogites within the mélange suggest an early evolution in an early Cretaceous subduction channel. Their subsequent record at lower *P* but higher *T* may reflect an increase in the thermal gradient caused by continental subduction. In contrast, the multiple ages from jadeitites and mica rocks suggests continuous subduction and fluid infiltration into the mantle. Finally, the metamorphic peak recorded in continental eclogites may document the deepest level of continental subduction following a major arc-continent collision as well as marking the beginning of exhumation of elements from the subduction channel.

α-quartz in UH*P* rocks: irrelevant or crucial?

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The role of monocrystalline α-quartz in UH*P* rocks containing coesite ± diamond is often ascribed to prograde and/or retrograde H*P* metamorphic conditions, and generally considered irrelevant to the UH*P* metamorphic evolution. However, recent Raman microspectroscopic studies reported incipient amorphization of α-quartz in UH*P* eclogites from Antarctica (Palmeri et al., 2009), leading to the evidence that the mechanisms of SiO_2 polymorphic transformations are not fully known.

Raman microspectroscopy was applied to over 60 quartz in UH*P* garnet, and to matrix quartz. The investigated samples come from two western Alpine metamorphic complexes and include Dora-Maira (DM) pyrope-bearing whiteschists, and Lago di Cignana (LdC) garnetite nodules in quartzites, where the diamond grade was attained based on petrographic and/or thermodynamic studies. From DM samples, we collected spectra of α-quartz non associated with coesite, although the latter is present in the same sample, and in LdC samples, we analyzed α-quartz and coesite in the same spessartine garnet growth zone at a distance of less than 10 μm from each other. Fifteen α-quartz inclusions in pyrope and two matrix α-quartz from DM show unquestionable evidence for lattice disordering and incipient amorphization (band position 485-490 cm^{-1} and 604 cm^{-1}). Amorphized α-quartz (i.e., presence of diaplectic glass with defect structure) is associated with crystalline α-quartz. These spectral data are notably different from those of LdC, that show crystalline α-quartz inclusions with variable degrees of compressive stress effects (upshift of 464 cm^{-1} band to 470 cm^{-1}), indicative of formation by coesite inversion. At the contact with quartz inclusion, the surface of host-spessartine is also under tensile stress (hardening of A modes suggestive of symmetry lowering).

Our study indicates that: 1) metastable H*P* α-quartz transitions occur in rocks that experienced peak lithostatic pressures exceeding 4 GPa, and 2) in a single garnet, more than 1 GPa pressure difference can be preserved to the 10-μm scale for crystalline silica polymorphs. Careful analysis of Raman data shows that *α*-quartz is able to record transient short-time pressure events different from lithostatic pressure regimes. Consequently, the thermodynamic vs. the kinetic control in silica polymorphic transformations has to be reconsidered.

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Composite silicate and carbonate multiphase solid inclusions in metamorphic garnet from ultrahigh-pressure eclogite in the Dabie orogen

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Composite multiphase solid (MS) inclusions composed of silicate and carbonate minerals are identified for the first time in metamorphic garnet from UHP eclogite in the Dabie orogen. These inclusions are morphologically euhedral to subhedral, and some show relatively regular shapes approaching the negative crystal shape of the host garnet. They are usually surrounded with radial cracks in the host garnet. The inclusions are primarily composed of variable proportions of carbonate and silicate minerals such as calcite, quartz, K-feldspar and plagioclase, with occasional occurrences of magnetite, zircon and barite. Based on the proportions of carbonate and silicate phases, they are categorized into two groups.

Group-I is carbonate-dominated with variable proportions of silicate minerals, whereas Group-II is silicate-dominated with small proportions of carbonates. LA-ICPMS trace element analyses yield remarkable differences between the two groups of MS inclusions. Group-I inclusions exhibit remarkably lower REE contents than Group-II inclusions, with significant LREE enrichment and large LREE/HREE fractionation in the chondrite-normalized REE diagram. In contrast, Group-II inclusions show rather flat REE patterns with insignificant LREE/HREE fractionation. In the primitive mantle-normalized spidergram, Group-I inclusions exhibit positive anomalies of Zr and Hf, whereas Group-II inclusions show negative anomalies of Zr and Hf. Nevertheless, the both groups exhibit positive anomalies of Ba, U, Pb and Sr but negative anomalies of Nb and Ta, resembling the composition of common continental crust. Nevertheless, Group-I inclusions have higher Ba and U contents than Group-II inclusions.

Combined with petrographic observations, the two groups of MS inclusions are interpreted as having crystallized from coexisting silicate and carbonate melts in a deep subduction zone. The differences in trace element composition are primarily ascribable to the proportions of carbonate and silicate minerals in the MS inclusions. The positive Zr and Hf anomalies in Group-I inclusions are attributable to dissolution of zircon into the UHP carbonate melts. As such, the carbonate melts are capable of dissolving both melt-mobile and melt-immobile incompatible trace elements for geochemical transfer at the slab-mantle interface in deep subduction channel. The silicate melts are derived from the breakdown of hydrous minerals such as paragonite and phengite (Gao et al., 2012), whereas the occurrence of carbonate phases indicates the involvement of sedimentary carbonate in the continental subduction-zone metamorphism. The coexistence of silicate and carbonate melts in the eclogitic garnet provides insights into the nature of hydrous melts in the subduction factory.

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A review of serpentinite mélanges of Cuba. Correlations along the NE leading edge of the Caribbean plate and geodynamic implications

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Serpentinite mélanges containing exotic blocks of HP-rocks (eclogite, garnet amphibolite, blueschist, greenschist, pelitic schist, gneiss) occur all along Cuba in a variety of geologic settings. In western Cuba, olistoliths of serpentinite mélanges occur within syn-orogenic sedimentary-matrix mélanges (also containing olistholiths of ophiolitic and volcanic arc rocks) related to arc-continent collision of latest Cretaceous age. K-Ar ages indicate however that the high-P blocks formed and exhumed much earlier, during the mid Cretaceous (ca. 110±10 Ma). Similar ages and petrologic characteristics (oscillatory zoning, clockwise P-T paths dominated by near-isothermal decompression) allow correlating these fragments of mélange with those of central Cuba (from Havana to Holguín regions, ca. 800 km apart), which occur as discrete bodies disseminated within dismembered low-P ophiolitic complexes or as separate tectonic slices. The oldest age related to the subduction stage obtained so far in high-P blocks of west-central Cuba is 124.0 ± 2.9 Ma (Lu-Hf Grt of eclogite), which compares well with suprasubduction magmatism in west (oldest age 129.5 ± Ma; Ar/Ar low pressure calcic amphibole) and central (oldest age 132.9±1.4 Ma, SHRIMP zircon in trondhjemitic gneiss; Rojas-Agramonte et al., 2011) Cuba. Published K-Ar and Ar/Ar data indicate that the mélanges were exhumed close to the Earth's surface by ca. 110 Ma. On the other hand, the earliest products of subduction in eastern Cuba serpentinite mélanges are MORB-derived garnet amphibolites that show counter-clockwise P-T paths and partial melting at 700-750 ºC and 1.5 GPa, 115-120 Ma (SHRIMP zircon), indicating a very hot-subduction scenario interpreted as the result of subduction of a mid-ocean spreading center at ca. 120 Ma. Published Ar/Ar data indicate slow exhumation to near surface depths during the late Cretaceous. These relations, and other elements of the geological evolution of Cuba, indicate that serpentinite mélanges in eastern and west-central Cuba are not correlated and that they formed at different subduction zones. While ages and petrological evolution of eastern Cuba mélanges are comparable with those of the Rio San Juan mélange, Dominican Republic (Krebs et al. 2008, Escuder-Viruete et al., 2013), suggesting onset of SW-dipping subduction of the Proto-Caribbean (Atlantic) at 130-120 Ma, the western-central Cuba mélanges can be correlated with mélanges from Guatemala, which formed during late Jurassic/early Cretaceous NE-dipping subduction of Farallon (Pacific) (Brueckner et al., 2009). The implications are 1) complex Cordilleran and Caribbean subduction tectonics affected the NW branch of the leading edge of the Caribbean plate during the early Cretaceous, 2) Jurassic-Cretaceous Cordilleran complexes are expected to occur in the basement of the Cretaceous Caribbean arc to the West of the Cauto fault, and 3) truly newly formed Cretaceous Caribbean volcanic-arc lithosphere occurs only to the East of the Cauto fault (eastern Cuba and beyond).

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Île Dumet (Brittany, France) and its glaucophane eclogite: the little sister of Île de Groix

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Blueschist-facies rocks are scarce within the Variscan orogen. Two main occurrences are known at "Île de Groix" and "Bois-de-Céné" (Armorican Massif, NW France). Another glaucophane occurrence was recorded in 1988 [1] on the 0.09-km^2 uninhabited island called "Île Dumet", which lies off the coast of southern Brittany, ~65 km SE of Île de Groix and ~60 km NW of Bois-de-Céné. However, this finding went unnoticed, since it has not been taken into account in any geodynamical modelling of the Variscan orogen and is not mentioned on the latest edition of the geological map of France. An orthogneiss occurs on the SW half of the island; the original granitoid had intruded micaschists in the NE half where numerous 1 to 10 m long boudins/pods of mafic rocks occur. These pods are strongly retrogressed into plagioclase-bearing amphibolite, but a few of them contain relics of glaucophane-bearing eclogite; these high-*P* rocks also occur as numerous loose blocks along the NE coast of the island, suggesting that the best preserved eclogites lie offshore in that direction.

Sample ID9 contains Grt+Cpx+Qtz+clinoamphibole+clinozoisite+Phg+Ru. The prograde metamorphic evolution includes garnets zoned to pyrope-richer rims ($Pyr_{3\text{-}13}$) and clinopyroxenes zoned to jadeite-richer rims ($Jd_{30\text{-}45}$). However, colour-zoned clinoamphiboles reveal retrograde zoning from glaucophane through alumino-barroisite and alumino-kataphorite towards alumino-taramite; also the Fe/Mg ratio in the clinoamphibole increases gradually towards adjacent Fe-rich garnet. This trend is similar to the nyböite to alumino-taramite trends observed in the Liset eclogite in the "Norwegian coesite-eclogite province" [2] and in the Jianchang eclogite in the Chinese "Su-Lu coesite-eclogite province" [3]. All these three trends of decreasing f_{Al} factor ($Al^{VI}/(Al^{VI}+Al^{IV})$) [2] in clinoamphibole are due to decreasing P and/or increasing T prior to the growth of plagioclase.

Île Dumet represents a new blueschist-facies occurrence between Île de Groix (Brittany) and Bois-de-Céné (Vendée) [e.g. 4]. All three occurrences occupy the centres of wide synforms [e.g. 5] whose concentric units are, from rims to core (i.e. from base to top): (a) a high-*T* migmatitic basement, (b) Lower Palaeozoic metasediments and acid metavolcanites (called “porphyroids”), and (c) blueschist-facies metapelites and metabasites derived from a pre-Variscan oceanic crust.

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Pressure–temperature–time–deformation history of the Western Gneiss Region, north and south of the Møre-Trøndelag shear zone: implications from U-Pb and trace-element zircon results

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The Western Gneiss Region (WGR) of Norway is cut by the Møre-Trøndelag strike-slip fault zone; ultrahigh-pressure (UHP) rocks have been identified south of the fault zone but not to the north of it. South of the fault zone, UHP and HP eclogite as well as amphibolite (some of which may be retrogressed eclogite) occur as lenses in migmatitic gneiss. North of the fault, mafic rocks also occur as lenses in migmatite gneiss, and in one location—the Roan Peninsula, which exposes the deepest structural level of the northern WGR—mafic rocks interpreted as HP granulite (garnet-cpx-opx + decompression-related sapphirine, corundum) locally contain a relict garnet-cpx-rutile assemblage that may represent former eclogite-facies conditions. In order to understand the differences and/or similarities between the P–T–t–d paths of the WGR to the north and south of the Møre-Trøndelag shear zone, samples of the mafic blocks and migmatitic host gneiss were collected from both domains, and zircons from these samples were analyzed by split-stream laser-ablation inductively coupled plasma mass spectrometry (LASS). From the UHP domain, eclogites from this study and previous work record metamorphism from ca. 425 to 400 Ma (Carswell et al. 2003; Root et al. 2004; Kylander-Clark et al. 2007, 2008; Walsh et al. 2007; Krogh et al. 2011). Different textural types of leucosome within and cross-cutting the host gneiss to the eclogites yield U-Pb zircon dates as old as 410–406 Ma (Gordon et al. 2013). Trace-element analyses obtained simultaneously with U-Pb dates indicate crystallization of zircon under garnet-present conditions in the majority of the leucosomes. In the northern WGR, zircons from mafic pods (one garnet-cpx-opx granulite and one garnet amphibolite) yield ages of ca. 415 and 408 Ma, respectively, and the zircon trace-element patterns and zircon/garnet distribution coefficients suggest that the zircons crystallized at high-pressures, under garnet-stable, plagioclase-unstable conditions. Different melt generations, ranging from foliation-parallel leucosomes to cross-cutting deformed dikes, from the same outcrop as the garnet amphibolite yield a tight cluster of crystallization zircon dates from ca. 409 to 405 Ma, respectively, with zircon trace-element patterns indicating crystallization under plagioclase-stable conditions (<16 kbar). The new LASS results from the northern WGR amphibolite suggest a potential HP history for this domain prior to the granulite-facies overprint. Moreover, the new zircon results combined with previous geochronologic results indicate a similar timing for metamorphism and melt crystallization across the entire WGR, both to the north and south of the Møre-Trøndelag shear zone. Thus, the rocks were subducted and taken to HP conditions during the late stages of collision between Laurentia and Baltica. The presence of early, coeval, abundant leucosomes in both domains suggest that the rheologic weakening associated with the different melt generations across the entire WGR aided in exhumation of U/HP rocks beginning at ca. 410–400 Ma.

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Formation of multiple HP veins in UHP eclogites (Hualiangting, Dabie, China): fluid source, element transfer, and closed-system metamorphic veining

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Multiple associated high-pressure (HP) metamorphic veins and their host ultra high-pressure (UHP) eclogites at the Hualiangting area (Dabie terrane, eastern China) are investigated to constrain the provenance of vein-forming fluids, UHP fluid-rock interaction, and vein crystallization in a geochemically closed system as well as element behaviors during the formation of vein system in deep subduction zone. HP veins in the Hualiangting eclogite have highly various mineral assemblages in different spatial locations, and can be classified as omphacite-epidote (Omp-Ep) vein, epidote-quartz (Ep-Qz) vein, and epidote-kyanite-quartz (Ep-Ky-Qz) vein from vein-eclogite boundary to vein interior. The eclogite profile adjacent to the multiple veins shows systematic decrease in the abundances of coesite-bearing epidote, kyanite, and quartz, indicating intensive UHP fluid-rock interaction between eclogite and vein-forming fluids. Mass-balance calculations indicate that the UHP fluid-rock interaction leaded to a strong depletion of Sr and Pb (up to -90 %), and moderate depletion of Th (up to -50 %), U (up to -80%), light-rare-earth elements (LREEs) (up to 40-60 %), and transition metal elements (TMEs) (Cr, V, Sc, Co, and Ni) (up to -40 %) as well as a low degree of depletion of heavy-rare-earth elements (HREEs) (< -25 %) in the eclogite adjacent to the vein.

In-situ Sr isotopic analyses on epidote in both eclogites and veins indicate that the fluids responsible for all types of veins were originated from eclogites themselves rather than surrounding gneisses (i.e., “internal” fluids). Petrological study and phase equilibrium modeling reflect that vein-forming fluids were mainly produced by UHP lawsonite breakdown in host eclogites at the P-T conditions of 2.7-3.0 GPa and 660-720 °C. Therefore, the formation of multiple HP veins and relevant dissolution-transport-precipitation in eclogite-vein system were isolated from a large-scale external fluid infiltration (i.e., in a geochemically closed system). Systemic compositional variation of HP veins from eclogite-vein boundary to vein interior, including gradual decrease of sparingly-soluble elements (e.g., Mg, Ti, TMEs and HREEs) and Eu/Eu* value and continuous increase of fluid-mobile elements (e.g., Cs, Rb, LREE, Th, and U), reflecting that the multiple veins were the products of different stages of crystallization from the peak UHP fluid. This study indicates that vein formation involves multi-stage evolutions of UHP fluid and that both fluid dissolution and mineral precipitation would lead to significant trace element fractionation in eclogite-vein system.

Fluid infiltration in an interlayered blueschist-greenschist sequence (Coastal Cordillera, Chile)

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Blueschists and greenschists interlayered at the dm to cm scale occur in a fossil accretionary prism in the Coastal Cordillera of Chile (Hyppolito et al., 2014). Three distinct processes are commonly invoked to explain these apparent metamorphic heterogeneities within single units: 1) Equilibration at distinct P-T conditions and late-stage tectonic juxtaposition, 2) chemical differences in the protolith, and 3) variable degrees of retrograde fluid infiltration during exhumation. It is important to distinguish between these processes because each explanation provides distinct information about the tectonometamorphic history of the unit and constraints about element transport during the metamorphism.

The blueschists and greenschists represent metavolcanic rocks with oceanic affinities based on predominantly OIB-type REE patterns and immobile trace element ratios. Their close spatial association and the lack of structural breaks in between the layers argue against a large-scale tectonic transport of rocks with different metamorphic facies. The presence of glaucophane relicts as cores in zoned amphiboles in both rock types is evidence for a pervasive high-pressure metamorphic stage, constrained to about 10 kbar at ~400°C (Willner, 2005). During exhumation, a retrograde greenschist-facies overprint stabilized winchitic/actinolitic amphibole + phengite + chlorite + albite ± K-feldspar at 4±1 kbar. Greenschists have a higher modal abundance of chlorite and lower amounts of glaucophane compared to blueschists. Gradational contacts and the persistence of glaucophane in both rock types point to a selective fluid infiltration process. We used several adjacent blueschist-greenschist pairs with similar REE geochemistry, reflecting similar protoliths, to evaluate fluid-induced metasomatic changes. Key features include addition of water and depletion of Si and Na in greenschists relative to blueschists, mobilization and non-systematic behavior of most major elements and transition metals, and concurrent mobilization trends for K, Ba, Rb and Cs. Thermodynamic calculations show that the differences in modal mineralogy can be explained by distinct bulk rock major element compositions in case of H_2O-saturated conditions. However, similar modal variations can result from variable water contents at H_2O-undersaturated conditions. The amount of fluid that percolated through the layers is ultimately responsible for the distinct visual appearance, either indirectly by affecting the major element composition or directly by affecting the degree of H_2O-undersaturation. Both parameters must be carefully evaluated to decipher the origin of interlayered metamorphic rocks.

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High pressure water-fluxed melting of felsic orthogneisses: the Eger complex, the Bohemian Massif

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The Eger crystalline complex in the Bohemian Massif is dominated by high-grade anatectic rocks as orthogneisses, migmatites, granites and felsic granulites. They represent felsic orogenic lower crust that was rapidly exhumed at rate of 1.1-2.5 mm/year during the Variscan orogeny at around 340 Ma along the Saxothuringian suture zone. Peak metamorphic conditions for these anatectic gneisses and granulites were estimated at ca. 650-720°C and 15-30 kbar. The rocks reveal textural variations from stromatic migmatite, inhomogeneous diatexite to isotropic granitic gneiss and granite reflecting different degree of migmatization. Field relationships suggest that these rocks represent a continuous textural sequence and are all derived from the same protolith, biotite-muscovite granite. In this study, we aim to understand timing, conditions, type and consequences of the high pressure partial melting in a subduction setting.

The orthogneisses and migmatites reveal textural signs of migmatization and mineral assemblage of Qtz + Kfs + Pl + Mu + Grt ± Bt ± Ky. Phengite has between 3.1 and 3.6 Si (p.f.u.) and its content in the migmatites varies between 5 to 25vol%. The presence of phengite in the main foliation indicates its growth along the prograde path, but phengite remains stable also during partial melting and on retrograde path. In contrast, granulites do not present migmatite textures and consist of an anhydrous assemblage Qtz + Kfs + Pl + Grt + Ky. The textural and mineralogical differences are interpreted as a result of heterogeneous hydration and consequently also of variable degree of melting at high pressure. We suggest that these rocks underwent localized water-fluxed melting at high pressure, with the felsic granulites representing a part of the system that was not hydrated at high pressure, therefore remained dry and did not undergo apparent melting.

Resulting high pressure melts are granitic in composition, no further melting occurred during decompression in mid-crustal levels. Moreover, the in situ produced melt caused brittle failure of the rocks, a mechanism that has not been previously described. We postulate that the brittle failure was triggered by high melt pressures coupled with the volume increase during the melting reaction together with increased pore pressure due to pervasive melt migration. Melt induced brittle failure caused extensive weakening that has assisted the rapid ascent of these lower crustal rocks.

Petrologic characterization of the blueschists and eclogites of the northern part of Acatlan Complex, Mexico: New thermobarometric data and their implication for the metamorphic evolution of southern Mexico

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The Acatlan Complex is a metamorphic basement that is crucial for the understanding of the evolution of the southern part of Mexico during the Paleozoic era. Some authors suggest that the tectonic evolution of the Acatlan Complex is related with the convergence and the subsequent collision between Laurencia and Gondwana, others suggest that is related with the subduction in the western margin of Pangea during the Devonic-Carboniferous period, giving as a result the formation of a HP metamorphic belt (Keppie et al., 2010; Galaz et al., 2009).

The northern part of the Acatlan Complex have a special geological interest because there are two juxtaposed units with different metamorphic grade, the Suite Piaxtla-Mimulco (high pressure) unit and the Zumpango-Coatlaco-Salada (Low Pressure-Medium Pressure) unit. Both have been interpreted as a subduction channel. The studied metamorphic sequence mainly comprises greenschists and pelitic schists with some metred sized blocks of blueschists and strongly retrogressed eclogites

The blueschists have a mineral assemblage consisting of Na-amphibole, albite, chlorite, phengite, zoisite, titanite, garnet, ilmenite, titanomagnetite partially replaced by a mineral assemblage actinolite-tremolite, albite, titanite. The Na-amphibole displays a zonation with an early Na-rich core overgrown by a Na-Ca rich rim, suggesting partial re-equilibration in greenschists facies. The eclogites present a relict mineral assemblage garnet, rutile, partially replaced by a mineral assemblage albite, white mica and chlorite. The major and trace element analysis of the studied blocks (discrimination diagrams) for the tectonic setting suggests a MORB-type signature.

This work presents the preliminary results of the petrography, mineral chemistry and geochemistry of the studied region. The structural, textural, and mineralogical characteristics are described for different lithotypes also thermo-barometric data are presented and their geological implications are discussed. This study provides new petrological data that contributes to the understanding of the tectonic evolution of southern Mexico.

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A comprehensive ion microprobe study on zircon from jadeitites and related rocks from the Rio San Juan Complex, Dominican Republic

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The Rio San Juan Complex consists of subduction-related schists and serpentinite mélanges that host different types of metamorphic blocks (e.g. blueschist, eclogite, orthogneiss) and a variety of quartz-free and quartz-bearing jadeitites and related jadeite-rich rocks. Most of these rocks occur as loose blocks; however, quartz-bearing jadeitites may also form concordant layers or veins in lawsonite blueschist, a rare association worldwide that allows direct study of jadeitite-blueschist relationships.

Proposed mechanisms for jadeitite formation include crystallization of jadeitite from a HP fluid and metasomatic replacement of a suitable protolith. To evaluate these concepts, we conducted a study on the geochronology, geochemistry and oxygen isotopes of zircon in two settings; (1) from a jadeitite and also an albite-rich jadeite rock found as loose blocks within the mélange, and (2) from a quartz-bearing jadeitite layer and its host blueschist.

Loose blocks: Zircons from both the jadeitite and albite-rich jadeite rock show faint to pronounced oscillatory zoning and are often rimmed by irregularly shaped CL-bright domains of variable thickness. Although distinguishable by CL, these zircon rims are almost identical to the core domains in age (SHRIMP U/Pb: jadeitite, 115.0 ±0.9Ma; jadeite-albite rock, 113.4 ±1.3Ma), with respect to the $\delta^{18}O$ values (IMS-1280: jadeitite, $\delta^{18}O(Zrn)$ = 5.1 ±0.6‰; 2 SD, VSMOW; albite-jadeite rock, $\delta^{18}O(Zrn)$ = 4.7 ±0.8‰) and REE patterns.

Blueschist-hosted jadeitite layer: Zircon grains separated from the jadeitite layer show either an irregular to pronounced oscillatory zoning pattern or no obvious zoning at all. CL-dark zircon domains can be differentiated from CL-bright domains, are in general oscillatory zoned and exhibit an age of 117.1 ±0.9 Ma and a $\delta^{18}O$ value of 5.4 ±0.4‰. In contrast to the loose-block samples above, in the jadeitite layer the CL-bright zircon domains differ significantly from the CL-dark zircon domains in terms of age (77.6 ±1.3Ma), $\delta^{18}O$ value (6.3 ±0.8‰) and REE patterns. Zircon grains from the jadeitite-hosting blueschist form a texturally homogeneous population of oscillatory and patchy zoned grains. These zircons are slightly younger (113.6 ±1.1Ma) than the CL-dark zircon domains of the jadeitite layer, but show, within error, an identical value of $\delta^{18}O$ (5.6 ±0.6‰).

The measured $\delta^{18}O$ values and other geochemical characteristics of zircon from the loose jadeitite and albite-jadeite rocks, the blueschist zircons and the CL-dark zircon domains from the jadeitite layer are all similar to values and patterns obtained from igneous zircon of the oceanic crust ($\delta^{18}O(Zrn)$ = 5.2 ±0.5‰; Grimes et al., 2011). Thus, these zircons are best interpreted to be igneous in origin, either as remnants of a metasomatically altered protolith or as xenocrysts. The CL-bright zircon domains from the jadeitite layer show geochemical features of metamorphic overgrowth and/or replacement and might either have formed contemporaneously with the jadeite in the layer or represent a different metamorphic event.

Grimes, C.B., Ushikubo, T., John, B.E., Valley, J.W. (2011) Uniformly mantle-like $\delta^{18}O$ in zircons from oceanic plagiogranites and gabbros. Contributions to Mineralogy and Petrology 161:13-33.

Lawsonite-blueschist in the Hakoishi sub-unit, Kurosegawa belt, Kyushu, Japan, as a remnant of late Paleozoic Mariana type subduction, part 1: Geology and Tectonics.

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Blueschist and eclogite can give insight to understand the geo-tectonic processes taken place in the active margins, such as reconstructing the tectonic history of the relevant areas, water budget/supplier to surrounding mantle, and etc. However, common post-peak deformation and associated hydration reactions during the exhumation stage can easily obliterate most of physic-chemical information recorded in these rocks at the deeper part of the subduction zone.

We recently found lawsonite-blueschists (LBS) free from these post-peak events from the Hakoishi sub-unit in the Kurosegawa belt, Kyushu, in the outer belt of Southwest Japan. Therefore, LBS in question roles as an open window to understand physic-chemical processes developed at moderate depth of the past subduction zone. Actually our group has already reported P-wave velocity of LBS under its inferred peak *P-T* conditions (Fujimoto et al., 2010). In this conference, we will introduce geological and mineralogical outline of studied LBS and will discuss the geo-tectonic significance by two associated papers.

The main constituents of the Hakoishi sub-unit, extending in an east-west trending narrow lenticular area of ca. 10 x 1 km^2, are metabasites and metachert along with minor amounts of metagabbro and metapelite. The original igneous textures of hyaloclastite and pillow lava/breccia, and slumping folding structures with a few cm thickness in metachert are well preserved through the area, and the development of the penetrative foliation is limited only in some metabasites in the western part. Serpentinite is mainly distributed at the southern margin of the Hakoishi sub-unit but is scarce inside of the sub-unit. Therefore, we consider that the Hakoishi sub-unit is mainly derived from constituents of layer 1 and layer 2 of a past subducting oceanic crust and then exhumed as a coherent block. All of these rocks record the LBS facies metamorphism, representing by the occurrence of lawsonite, sodic amphibole, sodic pyroxene and/or albite in both metabasites and metachert. Metagabbro associated with jadeite but without quartz is also reported (Saito and Miyazaki, 2006). The westward progressive mineral assemblage variation is detected of which detail will be shown in associated abstract.

Late Paleozoic phengite K-Ar ages (299-245 Ma) were obtained from phengite separates from Lws-bg. metapelites in the Hakoishi sub-unit. These ages are brand new in the Kurosegawa belt, Kyushu. These chronological and metamorphic facies characters coincide well with those of LBS of the Renge belt in the inner belt of Southwest Japan. Our new findings support the idea that the Kurosegawa belt was tectonic outlier from the Inner Zone beyond the present Median Tectonic Line (Isozaki and Itaya, 1991).

Fujimoto, Y., Kono, Y., Hirajima, T., Ishikawa, M., Arima, M. (2010) Physics of the Earth and Planetary Interiors. 183:219-228.

Isozaki, Y., Itaya, T. (1991) Journal of the Geological Society of Japan, 97:431-450*

Saito, M., Miyazaki, K. (2006) Bulletin of Geological Survey of Japan, 57:169-176*

* (in Japanese with English abstract).

High Pressure Metamorphism and Exhumation of Cretaceous eclogites within the Austroalpine nappes, Eastern Alps

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Eclogites in the Austroalpine nappes were formed in the Early Cretaceous in a SE-directed intracontinental subduction zone within the Apulian plate as result of oblique shortening combined with slab-pull of the Neotethyan oceanic slab (Handy et al. 2010). These Cretaceous eclogites define a W-E striking high pressure wedge from the southern Ötztal – Texel area towards the Koralpe-Pohorje area. This high-pressure wedge currently defines the boundary between Alcapa and the South Alpine Adriatic indenter. Eclogites located in this wedge appear as lenses and layers in mainly metapsammitic to metapelitic host rocks and are strongly transformed into secondary amphibolites after the pressure peak. Within this high pressure wedge a continuous transition from paragonite-amphibolites to eclogites is observed from N to S, indicating a metamorphic field gradient of ~10-14°/km, crossing the epidote-amphibolite-facies. In the W the wedge is characterized by steeply dipping isoclinal folds in contrast to the E with an almost flat-lying highly strained mylonitic shear zone showing an inverse metamorphic gradient. Metamorphic P-peak conditions show an increasing trend from ~580°/1.3GPa in the Texel area to ~700°/2.4GPa in the Koralpe and possibly >3.0GPa in the Pohorje (Janak et al., 2004). This increase of T and P to the E as well as the inversion of the metamorphic gradient in the Koralpe may indicate a different post-peak tectonic evolution. Coeval WNW-directed exhumation from deep parts of the wedge is assumed for the whole wedge with exhumation rates of 5-10cm/yr during the Early to Late Cretaceous. Final exhumation in the W in a convergent regime was probably related to N-directed indentation tectonics of the South Alpine Adriatic indenter, which led to steep dipping fold structures in HP rocks after exhumation by ca. 40-50 km to rather shallow levels. In the E, however, exhumation of deeper parts (ca. 80-100 km) in an extensional regime with dominant N-S stretch was replaced by E-directed extrusion tectonics in the Miocene.

Handy, M.R., Schmid, S.M., Bousquet, R., Kissling, E., Bernoulli, D. (2010) Reconsiling plate-tectonic reconstructions of Alpine Tethys with the geological-geophysical record of spreading and subduction in the Alps. Earth-Science Reviews, 102:121-158.

Janak, M., Froitzheim, N., Luptak, B., Vrabec, M., Krogh Ravna, E.J. (2004) First evidence for ultrahigh-pressure metamorphism of eclogites in Pohorje, Slovenia. Tectonics 23; doi:10.1029/2004TC001641.

Relictic eclogite facies metamorphism in amphibolites of the Chilean Patagonia (Diego de Almagro Island): First report and implications for the dynamics of the Early Cretaceous subduction zone at the Pacific margin of South America

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The Diego de Almagro Metamorphic Complex (DAMC), located at the Chilean Patagonia in the remote Diego de Almagro Island (51º 30' S), is related to a paired metamorphic system formed during Early Cretaceous subduction at the southwestern margin of Gondwana and is characterized by the occurrence of the deep portions of a fossil accretionary wedge bearing blueschist, greenschist, amphibolite, garnet-mica schist, and meta-ultramafic rocks (Hervé and Fanning 2003; Olivares et al., 2003; Willner et al., 2004; Hyppolito, 2007). Here we describe for the first time the presence of retrograded eclogitic rocks with N-MORB signature that occur as loose blocks and metric lenses within amphibolitic rocks. Mineral chemistry, textural relations and thermobarometric calculations using pseudosections reveal minimum pressures of ca. 1.50−1.65 GPa and temperatures of 610−650 ºC at peak conditions (mineral assemblage *CaAmp-Omp-Ph-Grt-Ep-Rt-Qz±NaAmp*), ensued by decompression and development of the amphibolite-facies overprinting mineral assemblage *Di-Ab-CaAmp-Ep-Qz-Ttn*. Ar-Ar dating of phengite from a sample of retrograded eclogitic rock yielded a plateau age of 122.1±0.3 Ma. The occurrence of proto-mylonitic *fabric* in strongly retrograded samples suggests the involvement of shear zones during part of the exhumation history. Comparison with published PTt paths of blueschist and amphibolite rocks from the Diego de Almagro Island suggests tectonic mixing during exhumation of rock complexes formed at different time and location within the subduction system. The eclogitic rocks described here constitute the only occurrence reported so far of fragments of oceanic crust subducted down ca. 50 km depth in the Patagonian accretionary complexes. We propose these rocks represent oceanic crust remnants derived from the subduction channel formed at the southwestern Pacific margin of South America during the Cretaceous.

Hervé, F., Fanning, M.C. (2003) Early Cretaceus subduction of continental crust at the Diego de Almagro archipelago, southern Chile. Episodes 26:285-289.

Olivares, B., Cembrano, J., Hervé, F., López, G., Prior, D. (2003) Geometria y cinemática de La Zona de Cizalle Seno Arcabuz, Andes patagónicos, Chile. Revista Geológica de Chile 30:39-52.

Willner, A.P., Hervé, F., Thomson, S.N., Massonne, H.J. (2004) Converging PT-paths of Mesozoic HP−LT metamorphic units (Diego de Almagro Island, Southern Chile, 51º 30' S): Evidence for juxtaposition during late shortening of an active continental margin. Mineralogy and Petrology 81:43-84.

Hyppolito, T. (2010) Thermobarometry, tectono-metamorphic history, and geochemistry of blueschists, eclogitic rocks and associated lithotypes of Diego de Almagro Island, Chilean Patagonia. Master Thesis, Universidade de São Paulo, 173 pp. Available at http://www.tese.usp.br.

Deformation microstructures of olivine in the presence of fluid and implications for seismic anisotropy and shear localization

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The Lindås Nappe, Bergen Arc, is located in western Norway and displays two high-grade metamorphic structures. A Precambrian granulite facies foliation is transected by Caledonian fluid-induced eclogite-facies shear zones and pseudotachylytes. To understand how a superimposed tectonic event may influence olivine fabric and change seismic anisotropy, two lenses of spinel lherzolite were studied by SEM and EBSD techniques. The granulite foliation of the surrounding anorthosite complex is displayed in ultramafic lenses as a modal variation in olivine, pyroxenes and spinel, and the Caledonian eclogite-facies structure in the surrounding anorthosite gabbro is represented by thin (<1 cm) garnet-bearing ultramylonite zones.

The olivine fabrics in the spinel bearing assemblage were E-type and B-type and a combination of A- and B-type LPOs. There was a change in olivine fabric from a combination of A- and B-type LPOs in the spinel bearing assemblage to B- and E-type LPOs in the garnet lherzolite mylonite zones (Jung et al., 2014). FTIR analyses reveal that the water content of olivine in mylonite is much higher (~600 ppm H/Si) than that in spinel lherzolite (~350 ppm H/Si), indicating that water caused the difference in olivine fabric. Fabric strength of olivine gets weaker as the grain size reduced, and as a result calculated seismic properties for the two deformation stages reveal that P- and S-velocity anisotropies are significantly weaker in the mylonite. Microtextures and LPO data indicate that the deformation mechanism changed from dominant dislocation creep in spinel lherzolite to dislocation creep accompanied by grain-boundary sliding in mylonite. Shear localization in the mylonite appears to be originated from the grain size reduction through (1) enhanced dynamic recrystallization of olivine in the presence of water and (2) Zener pinning of clinopyroxene, or (3) by ultracomminution during the pseudotachylyte stage (Jung et al., 2014).

Jung, S., Jung, H., Austrheim, H. (2014) Characterization of olivine fabrics and mylonite in the presence of fluid and implications for seismic anisotropy and shear localization. Earth Planets Space 66:46.

Role of saline fluids in sub-arc mantle and subducting slab

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Saline fluid inclusions are found from sub-arc mantle peridotite xenoliths: 3.7 wt% NaCl in Ichinomegata lherzolites, Northeast Japan arc (Kumagai et al., 2014) and 5.1 wt% NaCl in Pinatubo harzburgites, Luzon arc (Kawamoto et al., 2013). These indicate that aqueous fluids in mantle wedge can contain certain amounts of Cl. Such saline fluids are also found in jadeitites of serpentinite mélanges located in Southwest Japan (Mori, Shigeno, Kawamoto, Nishiyama in this conference). We suggested that separation of slab-derived supercritical fluids into aqueous fluids and melts plays an important role in elemental transfer from subducting slab to the mantle wedge (Kawamoto et al., 2012). It is, therefore, important to determine the effect of Cl on the trace element partitioning between aqueous fluids and melts. Synchrotron radiation X-ray fluorescence (XRF) analysis is conducted to know Rb, Sr, and Pb partitioning between aqueous fluids and melts simultaneously at high-temperature and high-pressure conditions. There is a positive correlation between partition coefficients and pressure, as well as salinity (Kawamoto et al., 2014). Two slab-derived components, melt and fluid components, are suggested to explain trace element characteristics of arc-basalts in the Mariana arc (Pearce et al., 2005). The fluid component is characterized by enrichment of alkali, alkali earth elements, and Pb. Such features can be explained if the fluid component is a saline fluid, because alkali earth elements and Pb are much less mobile with Cl-free fluids than Cl-rich fluids (Kawamoto et al., 2014). We suggest that slab-derived components have compositional features consistent with a saline fluid and a melt, which can be formed through a separation of a slab-derived supercritical fluid (Kawamoto et al., 2012, 2014). Slab-derived supercritical fluids contain Cl, and separated aqueous fluids inherit much of the Cl and some of the large-ion lithophile elements.

Kawamoto T., Kanzaki M., Mibe K., Matsukage K.N., Ono S. (2012) Separation of supercritical slab-fluids to form aqueous fluid and melt components in subduction zone magmatism. Proceedings of the National Academy of Sciences, U. S. A., 109:18695‑18700, pnas.org/content/109/46/18695

Kawamoto T., Yoshikawa M., Kumagai Y., Mirabueno M.H.T., Okuno M., Kobayashi T. (2013) Mantle wedge infiltrated with saline fluids from dehydration and decarbonation of subducting slab. Proceedings of the National Academy of Sciences, U. S. A., 110:9663-9668, pnas.org/content/110/24/9663

Kawamoto T., Mibe K., Bureau H., Reguer S., Mocuta C., Kubsky S., Thiaudière D., Ono S., Kogiso T. (2014) Large ion lithophile elements delivered by saline fluids to the sub-arc mantle, Earth, Planets and Space 66, 61, earth-planets-space.com/content/66/1/61

Kumagai Y., Kawamoto T., Yamamoto J. (2014) Evolution of carbon dioxide bearing saline fluids in the mantle wedge beneath the Northeast Japan arc, Contributions to Mineralogy and Petrology 168:1056, http://link.springer.com/article/10.1007%2Fs00410-014-1056-9

Pearce J.A., Stern R.J., Bloomer S.H., Fryer P. (2005) Geochemical mapping of the Mariana arc-basin system: Implications for the nature and distribution of subduction components. Geochemistry, Geophysics, Geosystems, 6, Q07006, onlinelibrary.wiley.com/doi/10.1029/2004GC000895/full

Lattice preferred orientation of olivine and chlorite in chlorite peridotites from Almklovdalen in the Western Gneiss Region, southwest Norway, and implications for seismic anisotropy

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Chlorite peridotites from Almklovdalen in southwest Norway were studied to understand the deformation processes and seismic anisotropy in the upper mantle. The lattice preferred orientation (LPO) of olivine and chlorite was determined using electron backscattered diffraction (EBSD)/scanning electron microscopy. A sample with abundant garnet showed [100] axes of olivine aligned sub-parallel to lineation, and [010] axes aligned subnormal to foliation: A-type LPO. Samples rich in chlorite showed different olivine LPOs. Two samples showed [001] axes aligned sub-parallel to lineation, and [010] axes aligned subnormal to foliation: B-type LPO. Two other samples showed [100] axes aligned sub-parallel to lineation, and [001] axes aligned subnormal to foliation: E-type LPO. Chlorite showed a strong LPO characterized by [001] axes aligned subnormal to foliation with a weak girdle subnormal to lineation. Fourier transform infrared (FTIR) spectroscopy of the specimens revealed that the olivines with A-type LPO contain a small amount (170 ppm H/Si) of water. In contrast, the olivines with B-type LPOs contain a large amount (340 ppm H/Si) of water (Kim and Jung, 2014).

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 sample with a mixture of 25% of olivine and 75% of chlorite can produce a Vp anisotropy of 14.2% and a maximum Vs anisotropy of 22.9%. Because chlorite has a wide stability field at high pressure and high temperature in the subduction zone, the strong LPO of chlorite can be a source of the observed trench-normal or trench-parallel seismic anisotropy in the mantle wedge as well as in subducting slabs depending on the dipping angle of slab in a subduction zone where chlorite is stable (Kim and Jung, 2014).

Kim, D., Jung, H. (2014) Deformation microstructures of olivine and chlorite in chlorite peridotites from Almklovdalen in the Western Gneiss Region, southwest Norway, and implications for seismic anisotropy. International Geology Review. DOI: 10.1080/00206814.2014.936054

New discoveries of the UHP rocks in the Seve Nappe Complex (Swedish Caledonides) and their under-pressure–driven exhumation

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The Seve Nappe Complex (SNC) is an allochthonous unit of the Scandinavian Caledonides where several UHP rocks including gneisses and eclogites have been recently discovered (e.g. Janák et al., 2013; Klonowska et al., 2014; Majka et al., 2014a). These discoveries shed a new light on the subduction system and exhumation of the HP-UHP rocks within this orogenic belt. Detailed field studies, followed by comprehensive analytical investigations led to the first discovery of diamonds within gneisses in the Swedish Caledonides (Majka et al., 2014a, and this meeting) as well as new UHP eclogites and pyroxenites (this study).

The SNC, the highest metamorphic grade unit of the Middle Allochthon, is formed mostly by gneisses, mica schists and quartzites, whereas eclogites, peridotites and migmatites occur only locally. New UHP rocks, a phengite eclogite and garnet pyroxenite, were found in northern Jämtland by the lake Stor Jougdan, 25km southeast from the UHP Friningen eclogite (Janák et al., 2013) and 3km south from the (U)HP Tjeliken eclogite (Majka et al., 2014b). Phengite eclogite is fine grained, with Omp, Grt and Amp as major minerals. Abundant quartz inclusions are found within garnet porphyroblasts, with less common Omp, Zo, Ep, Rt, Ttn, K-Fsp, Pl, Ap and Zrn. Phengite (Si=3.33-3.46) is usually enclosed in omphacite (X_{Na}=27-38%). The chemical composition of garnet varies between $Alm_{44\text{-}49}Prp_{25\text{-}28}Grs_{22\text{-}28}Sps_1$ in the cores to $Alm_{48\text{-}49}Prp_{23\text{-}24}Grs_{27\text{-}29}Sps_1$ in the rims. Garnet pyroxenite veins were found within one of the garnet peridotite body that is located c. 1.5km to the east of the phengite eclogite. Equigranular pyroxenite is composed of Opx (X_{Mg}=92-93%), Grt ($Prp_{67\text{-}70}Alm_{16\text{-}18}Grs_{11\text{-}14}Sps_1$), Cpx ($X_{Mg}$=93-96%) and minor Ol ($X_{Mg}$=93-96%) and it is surrounded by Amp at the contact with peridotite. Conventional geothermobarometry and thermodynamic modelling applied to both eclogite and pyroxenite indicate peak metamorphic conditions of 3.0-4.4 GPa and 750-910ºC for the former and 2.3-4.6 GPa and 840-960ºC for the latter. Eclogite shows peak-P assemblage Grt+Omp+Ph+Coe(?)+Rt, whereas pyroxenite Grt+Opx+Cpx+Ol.

These discoveries challenged us to reconsider existing exhumation model for deeply subducted continental rocks with incorporated mantle lithosphere peridotites. We introduced new under-pressure–driven exhumation mechanism, the so-called ‘vacuum cleaner’ (Majka et al., 2014a). We proposed that continental margin rocks were subducted in an arc-continent collision setting and their exhumation, together with peridotites of Baltican affinity (Brueckner et al., 2004) from the lower plate, was facilitated by local pressure reduction resulting from extraction of the fore-arc lithospheric block.

Brueckner et al. (2004) Journal of Petrology 45:415–437. Janák et al. (2013) Gondwana Research 23:865–879. Majka et al. (2014a) Geology, doi: 10.1130/G36108.1. Majka et al. (2014b) in Corfu et al., eds. Geological Society of London, Special Publications 390:369-384. Klonowska et al. (2014) in Corfu et al., eds. Geological Society of London, Special Publications 390:321–336.

A multi-isotopic and trace elemental approach to provenance Caribbean greenstone artefacts in an essentially non-destructive way: Implications for pre- and post-colonial exchange and mobility networks

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Throughout the circum Caribbean in pre-colonial times, so called "greenstones" were used to manufacture a wide range of artefacts, including figurines, spiritual items and jewellery, as well as more utilitarian objects like axes. Whilst the metamorphic complexes serving as raw materials have restricted occurrences (Schertl et al., 2012), the greenstone artefacts are found throughout the circum Caribbean region establishing that greenstone objects have been exchanged and transported over variable distances from 100's m to 100's km. These pattern of exchange are of great archaeological interest, as they provide information about former trading and mobility networks between different island populations, inter-group actions, and how pre- and post- colonial societies were organized and operated (Garcia-Casco et al., 2013; Hofman et al., 2010, 2014). Preceding Caribbean archaeological studies did not fully exploit the provenance of lithic objects. Therefore provenance studies of lithic materials are underutilized in the Caribbean (Hofman et al., 2008).

The objectives of this ongoing research are: i) to test the application of a prototype of a portable laser device (Glaus et al., 2012) to macroscopically sample lithic artefacts in a non-destructive way; ii) to develop and apply essentially non-destructive analytical methods using sub nanogram amounts of strontium, neodymium and lead (Koornneef et al., 2014) allowing to analyse precious artefacts; iii) to apply multi-isotopic and trace elemental analyses to provenance greenstone artefacts; iv) to assess if the manufacture and usage of particular tools were related to specific physical properties depending on the rock type; and v) to determine pre-colonial exchange and mobility networks and their transition following the arrival of Columbus in 1492. To meet these objectives, a combined approach of petrographic and geochemical analyses of lithic objects is carried out.

Ongoing work is characterising the mineralogy, major and trace element and isotopic compositions of the principle metamorphic complexes in the Greater Antilles to provide the database with which to determine artefact provenance. Sampling of artefacts in European and Caribbean museum collections will be carried out using the portable laser device. Preliminary analyses of sources and artefacts of the Dominican Republic and the Lesser Antilles have been conducted. Further investigation of sources, assemblages, and conjoining of data is pending in order to draw overarching conclusions regarding the whole circum Caribbean.

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Slab mantle dehydration in Kamchatka – does the water flux directly influence the dynamics of subduction zones?

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The Kamchatkan subduction zone provides a unique natural laboratory to study large-scale subduction zone processes. In Kamchatka, the subduction of old Pacific oceanic lithosphere induces three distinct volcanic zones that occur with increasing slab depth and increasing distance to the trench, and all three are currently active. The Eastern Volcanic Front (EVF) runs along the entire eastern coast of the Kamchatkan peninsula and the Sredinny range (SR) largely covers the entire western part of it. Between those two volcanic chains lies the Central Kamchatkan Depression (CKD) that is characterized by an asymmetric graben structure and volcanic activity in its northern part only. The CKD narrows abruptly towards the southern tip of the Kamchatkan peninsula, where the EVF and the SR come together. The erupted rocks from the three volcanic chains have contrasting trace element characteristics. For example, in the EVF arc lavas B/Nb and $\delta^{11}B$ show decreasing values with increasing slab depth typical for many subduction zones and attributed to continuous dehydration of the downgoing slab. This trend is reversed in the CKD where B/Nb and $\delta^{11}B$ values increase drastically. In the third volcanic chain (SR) B/Nb and $\delta^{11}B$ are at low values again. This across arc geochemical trend has been interpreted as the result of slab mantle dehydration enabled by a specific thermal structure of the downgoing plate that is influenced in this region by the subduction of the Emperor seamount chain and the plate edge beneath northern Kamchatka.

In this contribution we present thermodynamic-geochemical models for three across arc thermal profiles at different along-arc positions in Kamchatka. The northernmost profile cuts across the volcanoes in the CKD, the intermediate profile is across the CKD where no volcanoes occur and the southernmost profile transects south of the CKD where no extensional structures are observed. All three thermodynamic-geochemical models can reproduce the observed B and $\delta^{11}B$ trends observed in the EVF. This trend reflects increasing dehydration of the slab crust with increasing slab depth. In the northernmost transect our model indicates intense slab mantle dehydration vertically beneath the CKD that results in a reversal of the expected B/Nb and $\delta^{11}B$ trends in arc volcanic rocks as it is observed in natural samples. In the intermediate transect slab mantle dehydration also occurs beneath the CKD, although the geochemical model results cannot be verified due to the lack of volcanic activity in the CKD in this region. In both cases dehydration reactions and fluid-rock interaction in the slab mantle lead to an increase of water content in the core of the subducted slab mantle, followed by a pronounced water liberation at the tip of the antigorite-out reaction. Although water contained in the slab mantle is liberated during the antigorite-our reaction large fractions of it are recycled into the deeper mantle. However, in the southernmost profile the thermal structure prohibits significant slab mantle dehydration and water possibly bound in serpentinites in the subducted slab is almost completely recycled into the deeper mantle.

These results of our thermodynamic-geochemical models raise some important questions regarding the large-scale dynamics in subduction zones. First, the coincidence of the position of intense slab mantle dehydration, the occurrence of the CKD and the volcanic centers therein vertically above the dehydration sites together with our geochemical observations suggest that slab mantle dehydration is responsible for the existence of the CKD volcanoes in Kamchatka. Second, the decreasing dehydration intensity from north to south together with the decreasing width of the extensional CKD structure suggests a connection between the lateral variation of slab mantle dehydration and the large-scale tectonics in the Kamchatkan peninsula.

Good news from the garnet front – trace element zoning patterns reflect reaction paths rather than kinetic effects

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Garnet is one of the most versatile minerals in petrology and geochronology. It is stable over a large pressure and temperature range – largely independent of rock type – and thus occurs in many metamorphic environments. Garnet has a wide range of chemical compositions and its major and trace element composition well reflects the pressure (P), temperature (T) and chemical conditions (X) as well as the element transport kinetic properties of the host rock during growth. Hence, compositional growth zonations in garnet contain information about many important geochemical, mineralogical and petrological properties of metamorphic rocks. However, detailed interpretation of complex zoning patterns in metamorphic garnet was hindered mainly by the lack of knowledge about the various contributions of kinetic and equilibrium effects to the trace element incorporation into the garnet surface.

In this contribution we combine thermodynamic equilibrium calculations together with mass balanced trace element distribution among coexisting phases with diffusion models that simulate kinetically controlled element transport in a reacting host rock. Comparison of the model results with natural garnets enables detailed interpretation of commonly observed major and trace element patterns in high-pressure (HP) and ultra-high pressure (UHP) garnet porphyroblast in terms of reaction paths and physico-chemical properties of the host rock.

The comparison of our numerical models with a series of well-investigated (U)HP samples shows that the kinetic influence on rare earth element incorporation into garnet is limited in most rocks at the early stages of garnet growth and increases with increasing grade of rock transformation. We show that REE zoning patterns can be used to distinguish between cold (lawsonite-stable) and warm (epidote-stable) prograde reaction paths. REE liberation along a warm P-T trajectory occurs in three distinct breakdown reactions involving chlorite, epidote and amphibole. All three reactions result in distinct heavy (HREE) and medium (MREE) REE growth patterns in garnet reflecting the contrasting partition of REE among garnet and the reacting mineral matrix. In contrast, REE liberation along a cold trajectory is predominantly controlled by the breakdown of amphibole, which produces a pronounced incorporation of both HREE and MREE in the rims of the growing garnet distinct from that along hot reaction paths. Chromium concentration variations in garnet are also an excellent source of information about the reaction path. Cr is largely immobile at the onset of garnet growth and becomes mobile at eclogite-facies conditions. The Cr distribution in garnet cores from different UHP samples clearly reflects the prograde transformation of magmatic clinopyroxene into garnet+omphacite. The formation of garnet from omphacite at UHP conditions is indicated by concentric Cr (and REE) enrichments in the outermost rims of the garnet porphyroblasts.

We would like to emphasise that detailed investigation and interpretation of trace element patterns in metamorphic garnet gives important insight into the reaction path of the host rock, which in turn has crucial implications for the interpretation of geochronological data from (U)HP garnets.

Polyphase inclusions in kyanite from Ky-bearing Kumdy-Kol eclogite and HP veins: evidence for partial HP-UHP melting

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Study of polyphase inclusions in high pressure minerals (e.g. garnet, clinopyroxene and many others) provides important information about metamorphic conditions as well as mineral-forming media at UHP metamorphism (Korsakov & Hermann, 2006; Gao et al., 2012). In this paper we present the results of our ongoing research study of kyanite-bearing eclogites from the Kumdy-Kol block (Kokchetav massif, Northern Kazakhstan). The Kumdy-Kol microdiamond deposit is a type locality for metamorphic diamonds (Schertl & Sobolev, 2013). There are different UHPM lithologies within this block, including diamond-bearing and diamond-free varieties (Sobolev & Shatsky, 1990, Shatsky et al., 1995, Lavrova et al., 1999). We focused our study on kyanite-bearing eclogite, which are exposed at outcrop along the shore line of Kumdy-Kol lake. Gneisses and kyanite-micaschists are the country rocks for eclogite. This outcrop located about 300 m to the East from the Kumdy-Kol microdiamond deposit, but despite the spatial proximity to the mine, no diamonds were found at this outcrop in country rocks. The eclogite bodies are highly variable in size and range from 10 cm up to 5-6 m in diameter. The relics of primary eclogitic assemblages occur in the core of relatively large eclogite boudins, which are surrounded by thick shell of retrograde amphibolites. The compositional layering is quite common for eclogites from this outcrop. Garnet-rich and clinopyroxene rich layers are alternated within the eclogite boudins. While the garnet-rich layers are composed by fresh garnet grains, the clinopyroxene-rich layers are almost completely replaced by plagioclase-diopside symplectite, which on its turn is partly replaced by amphibole. There are different veins, which crosscut the eclogite: quartz-rich probably UHPM veins with some clinopyroxene and allanite, kyanite-biotite-quartz-plagioclase veins and epidote veins. The kyanite-bearing veins could form as results of partial melting of eclogite or country rock. Polyphase inclusions consisting of biotite+plagioclase, similar to previously described to Bt-Kfs-symplectite like inclusions in K-bearing clinopyroxene (Korsakov & Hermann, 2006), were found in kyanite crystals from these veins, further supporting their magmatic origin. In addition to these veins, kyanite crystals were found in clinopyroxene-rich layers. In clinopyroxene-rich layers kyanite porphyroblasts are surrounded by spinel-plagioclase symplectite, formed during the retrograde stage. Coexistence of kyanite porphyroblasts with biotite-quartz-plagioclase matrix may indicate that partial melting occurs at HP/UHPM conditions. This study was supported by grants of RFBR (13-05-00367-a) and MD-1260.2013.5.

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New insights into the early Caledonian subduction in the High Arctic

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The Vestgötabreen Complex occurring within Oscar II Land of west-central Svalbard is a type locality for high pressure-low temperature (HP-LT) metamorphic rocks in the archipelago. For more than 40 years, this complex was interpreted as separate, exotic occurrence. However, recently a new blueschist locality was discovered within Nordenskiöld Land (Kośmińska et al., 2014), which is situated c.60km south from Oscar II Land. It shows that HP-LT metamorphism was more widespread along the west coast of Svalbard, than previously suspected, and the Vestgötabreen Complex should not be treated as an exotic outcrop anymore. This new discovery requires re-interpretation of an evolutionary model for HP rocks from Svalbard.

HP-LT rocks belonging to the Vestgötabreen Complex were metamorphosed c. 470-480Ma, during early stage of the Caledonian Orogeny (e.g. Dallmeyer et al., 1990; Bernard-Griffith et al., 1993). This complex is divided into two structural units. The Lower Unit (LU) comprises mostly metapelites, phyllites and calc-silicate rocks with scattered boudins of serpentinites, metabasalts and metacarbonates, whereas the Upper Unit (UU) consists mainly of phengite-garnet schists which are hosting lenses of eclogites and blueschists. The pressure-temperature (P-T) estimates performed for carpholite-bearing schists from the LU indicate peak conditions at c. 16kbar and 330-450°C (Agard et al., 2005). Conventional geothermobarometry calculations yielded P-T conditions at c. 18-24kbar and 580-640°C for eclogites from the UU (Hirajima et al., 1988).

Here, we report new P-T estimates for blueschists and garnet-bearing schists from the UU. Blueschists are composed mainly of Gl, Grt, Ph and Ctd with minor amount of Q, Rt, Ap, Ep, Pa, Cal and Hem. Garnet-bearing schists consist of Ph, Grt and Gl, accessory minerals are represented by Q, Rt, Ab, Hem, Ap and Cal. Garnet from blueschists shows changes in chemical composition from $Alm_{60-66}Prp_{9-20}Grs_{19-24}Sps_{1-3}$ in the core to $Alm_{56-58}Prp_{22-25}Grs_{18-19}Sps_{0-1}$ in the rim, whereas in phengite-garnet schists its composition varies from $Alm_{73-78}Prp_{9-22}Grs_{5-14}Sps_{1-3}$ in the core to $Alm_{68-73}Prp_{22-28}Grs_{3-6}Sps_{0-1}$ in the rim. Phase equilibrium modeling yielded peak conditions at c. 19-21kbar and 500-520°C, similar for both rocks. This indicates quite low geothermal gradient around 7-8°C/km. These results are in agreement with previous studies and with P-T estimates for aforementioned blueschists from Nordenskiöld Land.

These recent results indicate that vast parts of the west coast of Svalbard were subjected to HP-LT metamorphism already in Paleozoic. Plate reconstructions show that during the Caledonian Orogeny SW-Svalbard may have built one composite terrane with the Pearya Terrane (N-Ellesmere Island) (Mazur et al., 2009; Kośmińska et al., 2014). In turn, this composite terrane could have been dismembered by strike-slip sinistral movements at the later stage of the Caledonian Orogeny. It is currently challenging to determine the exact location of this terrane during the early Caledonian Orogeny. However, recently Schieffer et al. (2014) have shown a seismic data from east Greenland which suggest the existence of a fossil eastward dipping subduction zone of eclogitized crustal material overlain by serpentinized mantle. The composite SW Svalbard-Pearya Terrane could have been located on the northern continuation of that fossil subduction zone.

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Internally flawless microdiamonds: FIB TEM study

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North Bohemian microdiamonds (Kotková et al., 2011) occur as inclusions in garnet, kyanite and zircon reaching only 5 - 30 µm in size. Previous SEM study showed that acid garnet-kyanite-feldspar-quartz UHP rock (sample A) contains exclusively octahedral (oct) microdiamonds with well-developed smooth faces enclosed in kyanite and garnet, whereas cubooctahedral (cuboct) microdiamonds with rough surface occur within garnet and zircon of the intermediate garnet-clinopyroxene-feldspar-quartz UHP rock (sample B) (Jakubová et al., 2014). 100-200 Å thin films prepared from up to 10 µm sized microdiamonds by the ion thinning method were studied using transmission electron microscopy (TEM) in order to characterize diamond-forming media potentially preserved as inclusions within diamond and to examine the inclusion-host interface. Striking feature of all microdiamonds analyzed is absence of any inclusions in their interior: this distinguishes them from inclusion-rich microdiamonds from other locations (Dobrzhinetskaya, 2012). The diamonds also lack any deformation-related dislocations: only dislocations related to Dia growth such as low-angle grain boundaries and long curved dislocations radiating from the diamond core were observed. Diamonds enclosed in anisotropic kyanite are an exception, containing numerous straight dislocation lines which reflect Ky deformation via a dislocation glide mechanism upon cooling and suggesting short residence at high temperatures. The Grt-Dia and Ky-Dia interface is closed, but there is a gap between zircon and microdiamond: this is related to different elastic properties of the phases and corresponds to the "overpressure" in diamond in Grt and Ky and "underpressure" in diamond in Zrn determined previously using micro-Raman. Nevertheless, elongated and triangular gaps are present at both cuboct Dia-Zrn and cuboct Dia-Grt interface, which shows a zig zag pattern due to development of new (111) faces identified by HREM analysis. The gaps are filled with amorphous, commonly porous material. EDX spectra demonstrated presence of Ca + Fe, Ca + Cl (next to a graphite grain between Dia and Grt, sample B) and Ca +K + Al + Cl and Ca + S ± K (Dia-Zrn, sample B). An amorphous filling of a single oval inclusion close to the oct Dia-Ky interface contains Ca, Mg ± Zn, Cl and S, and Mg, Ca, Fe, Co, Ni, Cl and S (sample A). Our study has important implications for microdiamond growth and resorption: (i) absence of inclusions requires rather high growth rate preventing their incorporation; (ii) perfect crystal shape with smooth surfaces (oct Dia) reflects low driving force for Dia growth, and (iii) morphology and rough surface of cuboct Dia are likely related to high driving force i.e. fluid/melt supersaturation during Dia growth, as well as later resorption by Ca-Cl and Ca-S-dominated fluid/melt upon cooling. Such a resorption requires hight temperatures thus we propose that the dissolving agent represents the residual fluid after diamond crystallization. In gemological terms, the north Bohemian diamonds are internally flawless, which - along with their colourless nature – would make them a highly valued and priced diamonds if not for the low carat weight.

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Crust-mantle interaction in continental subduction channel: Evidence from extremely ^{18}O-depleted zircon from orogenic peridotite in the Sulu orogen

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Orogenic peridotite is one of common components in many UHP metamorphic terranes in collisional orogens. They can provide important information about the composition and evolution of mantle wedge above subduction zones, crust-mantle and fluid-rock interactions and chemical geodynamics at convergent plate boundaries. A combined SIMS and LA-(MC)-ICPMS study of U-Pb ages, trace elements, O and Hf isotopes was carried out for zircons from peridotite and its host gneiss in the Sulu orogen. This peridotite occurs as a block within the UHP gneiss, and has an assemblage of Ol + Opx + Spl + Chr + Amp + Srp ± Chl ± Dol ± Zrn. The majority of zircons from the peridotite show core-(mantle)-rim structure in CL images. Relict zircon domains of magmatic origin exhibit oscillatory or blurred oscillatory zoning, older U-Pb ages than the Triassic, high Th/U ratios, and steep MREE-HREE patterns. They contain mineral inclusions of Ap, Qz and Pl that are absent in the constituent minerals of peridotite. Their U-Pb ages, trace element and Hf-O isotope compositions are similar to those for protolith zircons from UHP metamorphic rocks in the Dabie-Sulu orogenic belt. Thus, these relict magmatic zircons would be physically transported into the peridotite by metasomatic fluids derived from dehydration of the deeply subducted continental crust. In contrast, newly grown zircon domains of metasomatic origin have U-Pb ages of 220±2 to 231±4 Ma, nearly synchronous with but slightly later than the UHP metamorphism in the middle Triassic. They exhibit weak zoning or no zoning, relatively low Th/U ratios (<0.1), low HREE contents, steep MREE-HREE patterns, negative Eu anomalies, and low $\delta^{18}O$ values of -11.3 to 0.9‰. Thus these zircons would have grown from metasomatic fluids during the exhumation of deeply subducted continental crust. The infiltration of metasomatic fluids into the peridotite is also indicated by the occurrence of hydrous minerals such as amphibole, serpentine and chlorite. Therefore, the peridotite underwent metasomatism by aqueous solutions derived from the dehydration of deeply subducted continental crust in the early stage of exhumation. It is this crustally derived fluid that would have brought not only such chemical components as Zr and Si but also tiny zircon grains from the deeply subducted crustal rocks into the peridotite at the slab-mantle interface in the continental subduction channel. As such, the orogenic peridotite records the crust-mantle interaction at the deep continental subduction zone via the mechanism of both the chemical transport of dissolved elements and the physical transport of tiny mineral grains. The fluid-peridotite reaction would be operated as a basic mechanism for the crust-mantle interaction at the deep continental subduction zone.

A common HP metamorphic evolution of interlayered eclogites and metasediments from the 'UHP unit' of the Tianshan metamorphic belt in China

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Petrological and mineralogical data of interlayered eclogite, marble and quartz-mica schist from a drill core are used to constrain the metamorphic evolution of metavolcanic and intercalated metasediments in the Tianshan (ultra-)high-pressure/low-temperature metamorphic belt, NW China. The eclogite mainly consists of varying amounts of garnet, omphacite, quartz and zoisite, the marble of calcite (>95 vol.%) with minor zoisite and phengite, and the schist of quartz, mica and minor calcite, chlorite, albite and garnet. Using garnet isopleths thermobarometry (e.g., Gaidies et al., 2006) and pseudosection calculations (Perple_X, Connolly, 1990) for the eclogite and quartz-mica schist reveal a common metamorphic evolution under HP condition of both rock types that is also consistent with the T estimates for the marble using conventional thermometry. The uniform P–T paths of the interlayered eclogite and quartz-mica schist, as well as compatible temperature data of the marble, document that the whole rock suite constitutes a coherent HP unit during peak metamorphic conditions and exhumation. Thus protoliths of the eclogite and associated sediments are believed to have undergone the same metamorphic evolution (e.g., Gross et al., 2008). In addition, the present HP rocks (collected from the northern part) do not support the recently proposed tectonic scheme that the Tianshan metamorphic belt consists of a northern "coherent UHP unit" and a southern "coherent HP unit" (Lü et al., 2012).

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Multiple subduction-exhumation processes in the subduction channel: Evidence from P–T evolution of an oceanic eclogite with polymetamorphism and multistage mineral growth

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High-pressure metamorphic eclogites record metamorphic processes at mantle depth in subduction zone, and the reconstruction of pressure-temperature (P–T) path of such rocks provides an opportunity to understand the metamorphic history, driving force, as well as the tectonic process. Here, we present petrological and thermodynamic data from an eclogite from the Chinese Tianshan ultrahigh/high-pressure metamorphic belt to study the P–T evolutions and dynamic processes of subducted oceanic crust. Petrological evidences suggest that the eclogite experienced polymetamorphism and multistage mineral growth. Textual discontinuity and compositional variations of two-stage garnet and epidote record the multistage metamorphism. In addition, omphacite shows three generations with chemical linear changes during P–T evolutions. The cyclic glaucophane and barroisite replacements (chronological transition of Gln_1→Brs_1→Gln_2→Brs_2) indicate that the eclogite may undergo a multiple subduction-exhumation process. The metamorphic evolution of this eclogite has been investigated using the petrological approach of pseudosections. Thermodynamic modeling based on effective bulk compositions shows that the eclogite have experienced a complicated P–T path consisting of prograde subduction, fast exhumation, subsequent cooling and re-subduction, and re-exhumation processes, producing multiple burial-exhumation cycles that are in accordance with the petrological observations. To our knowledge this is the first report of polymetamorphism in high-pressure eclogite from Southern Tianshan. The multiple subduction-exhumation process recorded in the eclogite is interpreted as a result of circulation pattern of metabasaltic blocks or slices carried by return flow in subduction channel (Gerya et al., 2002). Therefore, we propose that the exhumation mechanism of Tianshan high-pressure metamorphic belt is probably due to a subduction channel model, characterized by the chaotic juxtaposition of high- and ultrahigh-pressure rocks (Klemd et al., 2014).

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Multiple anatexis records of ultrahigh-pressure metamorphic rocks during exhumation of deeply subducted continental crust in the Sulu orogen

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A combined study of zircon U-Pb ages, trace elements and inclusions as well as petrology was carried out for migmatitic UHP gneiss from Weihai in the Sulu orogen. The results provided evidence for multiple partial melting of UHP metamorphic rocks during exhumation of deeply subducted continental crust. The metatexite sample is composed of plagioclase + quartz + muscovite + biotite, with minor millimeter size euhedral titanite porphyroblast. The melanosome sample is composed of plagioclase + quartz + muscovite + biotite with minor monazite and euhedral garnet porphyroblasts, and the leucosome sample is composed of plagioclase + quartz + muscovite, with minor titanite and epidote.

Zircon in the metatexite exhibits inherited cores of Neoproterozoic U-Pb ages and weakly oscillatory zoned rims. The rims yield a weighted mean U-Pb age of 212±4 Ma, exhibit steep HREE patterns and an average Ti-in-zircon temperature of 600°C, and contain few multiphase solid inclusions of K-feldspar + albite + quartz + apatite. The MS inclusions were also observed in titanite. These features indicate that both the zircon rims and titanite would crystallize from felsic melt.

Zircon in the melanosome exhibits patchy zoning with or without inherited cores. The patchy zoned domains yield a weighted mean U-Pb age of 223±2 Ma, exhibit flat MREE-HREE patterns with or without negative Eu anomalies and an average Ti-in-zircon temperature of 715°C, and contain eclogite-facies mineral inclusions such as garnet, omphacite and rutile. Multiphase inclusions are abundant in the patchy zoned zircon domains, monazite and garnet in this sample. They are mostly composed of muscovite + albite + K-feldspar + biotite + quartz + allanite ± chlorite ± xenotime ± water and occur as negative crystal shapes. In addition, fluid inclusions with negative crystal shape also occur in zircon and garnet and are composed of CO_2, CH_4 and water. Garnet has a composition of $Alm_{66-73}Pyr_{7-14}Spe_{5-21}Gro_{4-9}$, with spessartine inverse bell-shaped profile, typical of magmatic origin. Therefore, the patchy zoned zircon domains would grow from hydrous melt during anatexis, whereas garnet and monazite were peritectic minerals produced by melting reaction.

Zircon in the leucosome contains inherited cores of Neoproterozoic U-Pb ages, patchy zoned mantles and oscillatory zoned rims. The mantles and rims have weighted mean U-Pb ages of 227±5 Ma and 217±11 Ma, respectively. These two domains exhibit trace element characteristics and mineral inclusions similar to the patchy zoned zircon domains in the melanosome and the zircon rims in the metatexite, respectively. Therefore, the mantles would grow during the anatexis at eclogite-facies to granulite-facies transformation, whereas the rims would crystallize from anatectic melt later at amphibole-facies. As a consequence, zircon in these samples records multiple anatexis of the UHP gneiss during the exhumation of deeply subducted continental crust.

Eclogite from the Qianliyan Island in the Yellow Sea linking the units of Dabie-Sulu and the Korean peninsula

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The Qinling–Dabie–Sulu orogen extends broadly in E–W direction in central China and was formed by the northward subduction of the South China (Yangtze) Plate beneath the North China (Sino-Korean) Plate during the Triassic. At Qianliyan Island, about 80 km East of Qingdao in the northern part of the South Yellow Sea of China, lenses and layers of eclogite and two-mica epidote–plagioclase gneiss occur within granitic gneiss. The island is located in the Yellow Sea, directly between Quingdao, belonging to the Sulu UHP terrane of China, and the Hongseong HP metamorphic complex of South Korea.

From the eclogite, peak metamorphic conditions of 775ºC, 2.6 GPa were defined using compositions of garnet mantle zones, omphacite inclusions, and homogeneous phengite cores with high Si contents. On the basis of PT-calculations and petrographical studies, from the samples available no indication for reaching the coesite stability field was found. During exhumation, the eclogite underwent different stages of retrogression, i.e., at eclogite-facies (740-790ºC, 1.60-1.75 GPa,), epidote-amphibolite-facies (640-690ºC, 0.8-1.0 GPa), and, finally, at greenschist-facies conditions. Relics of omphacite and garnet in pyrite of the two-mica epidote–plagioclase gneiss, although obliterated in the rock matrix, prove this rock also to have experienced high-pressure (HP) metamorphic conditions; in addition these relics demonstrate the ability of pyrite to act as a container mineral and to protect its HP inclusions from retrogression. Similar HP metamorphic rocks occur at Sulu and Dabie in the west and at the Hongseong complex of South Korea in the east.

Whereas HP and UHP eclogites, marbles, gneisses and garnet peridotites of the Dabie and Sulu areas of the collision belt between South China (Yangtze) and North China (Sino-Korean) Plates have been intensely studied since the late 1980s, the extension of this belt towards the east/northeast, e.g. the South Korean Peninsula, is only poorly understood and/or has been discussed controversially for several years. Our recent studies on eclogites and related rocks from Qianliyan island enhance the probability for the existence of a large coherent HP (/UHP) metamorphic belt that extends from Qinlin via Dabie and Sulu towards the South Korean peninsula.

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Diamond-bearing nano-granitic inclusions in zircons from stromatic metatexite migmatites from the Sulu UHPM belt

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In the Dabie-Sulu UHP metamorphic belt, the gneisses from the Weihai region were partially melted to form stromatic metatexite migmatites. Previous U/Pb dating show that the crystallization ages of zircons from leucosomes range from 210 to 220 Ma, later than the ages of UHP metamorphism (*c.* 225-235 Ma) (Liu et al., 2010, 2012; Xu et al., 2013; Zong et al., 2010). The time interval between the two ages has been interpreted that the partial melting occurred in the exhumation process of gneisses (Liu et al., 2010, 2012; Xu et al., 2013; Zong et al., 2010). We have checked inclusions in zircons from the migmatites from the Weihai region by using Laser Raman spectroscopy, and identified nano-granitic inclusions predominantly consisting of quartz + albite + kokchetavite. In some nano-granitic inclusions, diamond and moissanite were also found. Diamond in nano-granitic inclusions suggests that the partial melting of gneisses started in the stability field of diamond, and diamond crystallized in the UHP stage. We received the zircon U-Pb ages using Nano-SIMS 1280. The zircons with diamond-bearing nano-granitic inclusions give U-Pb ages of 219 Ma, which are consistent with the U-Pb ages of the zircons from leuocosomes (210-220 Ma), indicating that the diamond-bearing nano-granitic inclusions were trapped and crystallized at relatively low pressures during the exhumation process. In addition, Ti contents of zircons were analyzed by using Nano-SIMS 1280, and Ti-in-zircon thermometer yields temperatures between 750 and 900 °C. At such condition of temperature, the pressure constrained by using the stability field of diamond was higher than 3.5 GPa for partial melting. Our study reveals that the gneisses reached their solidus P-T conditions during the subduction process rather than during the exhumation process. This, in turn, indicates that the exhumation of the Weihai UHP metamorphic slab probably was triggered by the partial melting of gneisses.

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Early Paleozoic Tectonic Evolution of the North Qinling Orogen, Central China：Constraints from HP/UHP metamorphism

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High-pressure/ultrahigh-pressure (HP/UHP) metamorphic zones mark the convergent lithospheric plate boundaries due to the paleo-oceanic crust subduction and continental collision, and record the geodynamic processes from subduction to exhumation of crustal materials (Simth,1988; Chopin, 1984, 2006; Carswell,1990; Maruyama et al., 1996; Ernst, 2001, 2006 ; Liou et al., 1998, 2006, 2009; Zheng , 2003, 2009 ; Powell et al., 2010, and their reference). The detailed studies of the type and space – time correlation, nature of the protolith and the ages of protolith, peak and retrograde metamorphism of the HP/UHP rocks can play a key role to understand the processes of the formation and evolution of orogenic belts. The North Qinling (NQ) Orogen is an important part of the Qinling Orogen, however, the formation and evolution of the region is still discussed controversially (Dong et al., 2011; Wang et al., 2011; Wu et al., 2013; etc). In this paper, we present a review for the recent studies of HP/UHP metamorphism of the North Qinling Orogen, aiming to constrain the tectonic evolution of the North Qinling orogen during the early Paleozoic time.

HP/UHP rocks mainly crop out in Guanpo area of the northern Qinling complex and the northern Qingyouhe - Songshugou - northern Zhaigen - northern Xixia area of the middle or southern Qinling complex, showing the characteristics of a planar distribution (Liu et al., 2013). All the NQ ortho-metamorphic HP/UHP rocks occur as lenses in the host gneisses, eclogite protoliths have similar geochemical feutures to continental basalt（Chen and Liu, 2011， Wang et al., 2013）and the protolith of the UHP felsic gneiss in the Songshugou area is typical for continental sendimentary rocks (Yang et al., 2002; Liu et al., 1996), indicating that these rocks might be the products of the continental (deep) subduction. The peak metamorphic ages of the HP/UHP rocks are ~500Ma by various dating method (SHIRMP, LA-ICPMS or SIMS), which suggest that these HP/UHP rocks from the North Qinling should have been formed by an identical tectonic event. The HP/UHP rocks, including the felsic gneiss located in the Songshugou, the retrograded eclogite from Qinyouhe and Zhaigen and the garnet amphibolite from the Xixa aera, have experienced their peak metamorphism at ~500 Ma, and were subsequently overprinted at medium - pressure granulite facies at ~450 Ma and at amphibolite facies at ~420 Ma, respectively, suggesting that these rocks have been subjected to an integrated tectonic process of continental (deep) subduction with two stages of exhumation (Liu et al., 2013). Moreover, the protolith ages of 843±7 Ma to 753±7 Ma for the HP/UHP rocks (Chen et al., 2011; Wang et al., 2011; Liu et al., 2013) indicate that they were formed by the (deep) subduction of the Neoproterozoic continental rocks. Integrated with previous studies, we present a tectonic evolution of North Qinling orogen in the early paleozoic: the Neoproterozoic continental crust of South Qinling was dragged by the Shangdan oceanic crust, and subducted northward to the southern margin of the North China Block. At ca. 500 Ma, the Shangdan ocean was closed and induced continental collision, then experienced two stages of exhumations at ~450 Ma and ~420 Ma, respectively.

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Polyphase solid inclusions in garnet: indicator of melt infiltration of earlier mineral inclusions

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Partial melting (anatexis) plays a key role in the geodynamic evolution of UHP/HP terranes. Evidence has accumulated that some UHP terranes have experienced partial melting during exhumation. Macroscopic evidence for melting events in regional UHP/HP metamorphic rocks includes granitic leucosomes and felsic veins in migmatites, S-type granites and mafic intrusions. Comparing to these remarking macroscopic evidence, microscopic evidence for partial melting is elusive due to melt crystallization and re-equilibration with surrounding minerals. Polyphase solid (PS) inclusions comprising quartz, K-feldspar, and/or other minerals are common in peak minerals (such as garnet and clinopyroxene) of UHP/HP rocks. Interpretations on the origin of PS inclusions have been controversial. These inclusions are recently interpreted as entrapped melts or supercritical fluids prior to, during or subsequent to peak metamorphism because these PS inclusions generally display features consistent with melting experiments on hydrous and carbonaceous minerals in garnet, such as intergrowth of various daughter minerals, radial wedge-like offshoots and negative crystal shapes. However, a primary entrapment is problematic with the random spatial distribution and the highly variable bulk composition of PS inclusions in host minerals, in addition to the coesite-like geometry of some PS inclusions. Therefore, the origin of PS inclusions still remains unclear and critical to resolve to reveal the anatexis in the continental subduction zone.

Here we report microstructural and geochemical evidence of partial melting and PS inclusions in garnets of a migmatitic quartz-garnet restite from the Ganjialing, Dabie Mountains, showing typical mineral assembly of quartz, K-feldspar, ± other minerals as isolated inclusions or thin films along rutile inclusions in garnet. These PS inclusions and films often display shapes that are compatible with those of euhedral coesite grains or the rutile grains in the center, in addition to wedge-like offshoots, neck-down textures and inclusion-garnet interfaces controlled by the crystallography of garnet. These observations exclude the possibility of primary melt entrapments for the PS inclusions. We proposed that these PS inclusions are reaction products between infiltrated melt and earlier mineral inclusions along fractures during early exhumation.

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Underpressure-driven exhumation of a diamond-bearing nappe: an example from the Seve Nappe Complex of the Scandinavian Caledonides

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When a continent collides with an island arc or other continent, continental crust of the subducted continent may be buried to depths exceeding 100 km and exposed to pressures which can cause formation of coesite and diamond. This process leads to substantial density increase in SiO_2-rich rocks and, in turn, to a reduction of the buoyancy of the subducted material, which should inhibit exhumation. Although the remaining buoyancy of the subducted crustal rocks with respect to the surrounding mantle rocks will still be positive and serve as a driving force for exhumation, another driving force is needed to cause the change from downward to upward motion. We report on the discovery of microdiamond in kyanite-garnet gneiss, from allochthonous metasediments of the Seve Nappe Complex in the Scandinavian Caledonides. Our discovery calls for general reconsideration of existing exhumation models of deeply subducted continental crust. We propose that the diamond-bearing rocks were subducted in an arc-continent collision setting and their exhumation was facilitated by local reduction of the horizontal compressive stress to a level below the lithostatic pressure, resulting from the downward extraction of the fore-arc lithospheric block.

First report of garnet whiteschists in the Central America-Caribbean region (Chuacús Metamorphic Complex, Central Guatemala)

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The Chuacús Metamorphic Complex, in Central Guatemala, is located between the Polochic and Motagua fault zones, in the current North America-Caribbean plate boundary. This Complex consists of HP polydeformed sequence constituted of quartz-feldspathic gneisses with eclogite-facies relics, amphibolites, garnet + kyanite pelitic schists and calc-silicates. Recent studies have shown that its tectonic evolution comprises at least two episodes of HP metamorphism during the Paleozoic and Cretaceous times respectively (Ortega-Gutiérrez et al., 2004; Solari et al., 2011). The latest episode records the convergent tectonics between North America´s basement and the Greater Antilles Arc (Martens et al., 2012).

In this study, we report the occurrence of garnet whiteschists in the Chuacús Metamorphic Complex, which represents the first finding in the Central America-Caribbean region. Garnet whiteschists occur as centimetre-size layers intercalated within garnet + phengite paragneisses and garnet + phengite ± chlorite ± kyanite pelitic schists. The observed mineral assemblage consist of garnet + phengite + kyanite + talc + quartz + rutile ± chlorite. Similar asseamblages have been predicted recently close to the quartz-coesite limit using thermodynamic modeling (Franz et al., 2013). Here we present the results of petrography and mineral chemistry, as well as, preliminary results of equilibrium assemblage calculations for garnet whiteschists, and P-T estimates for the related lithologies. We will discuss the results of this new finding by considering previously published data about HP metamorphism in the Chuacús Complex and its tectonic implications in the spatio-temporal framework of the Maya block-Central America-Caribbean region evolution.

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A Tertiary high-pressure (HP) interplay of an andalusite-bearing micaschist from the southern Pirin Mts., Pirin-Pangaion unit, SW Bulgaria

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The Rhodope Massif on the territory of Bulgaria is known for occurrences of eclogites (e.g. Kozhoukharova, 1980; Janak et al., 2011) but other HP rock types of crustal affinity, as reported from the Greek Rhodope, were not proven so far. A garnet-bearing schist rich in white mica was sampled from the Lukovitsa Formation near the Popovi-Livadi pass and investigated with the electron microprobe. Garnet grains of mm-size frequently show an inclusion-rich core which is relatively poor in Ca ($Alm_{0.67}Gr_{0.03}Py_{0.10}Sp_{0.20}$). After the corrosion of the core domain a clear garnet rim with significant zonation developed (inner rim: $Alm_{0.65}Gr_{0.25}Py_{0.05}Sp_{0.05}$, outer rim: $Alm_{0.72}Gr_{0.17}Py_{0.09}Sp_{0.02}$). After another corrosion event the outermost garnet rim ($Alm_{0.715}Gr_{0.09}Py_{0.125}Sp_{0.07}$) formed. At the same time and later, clusters of unoriented muscovite (Si around 3.1 per formula unit = pfu) and plagioclase and andalusite porphyroblasts crystallized. Earlier potassic white mica, occurring as core of oriented flakes, shows Si contents up to 3.3 pfu. On the basis of contoured P-T pseudosections (e.g. Massonne, 2013) calculated with PERPLE_X, the P-T evolution of the studied rock was reconstructed: (1) the garnet cores represent a low-P granulite or high-T amphibolite stage; (2) the overgrowing rim domain and the maximum Si contents in phengite reflect peak-P conditions of 16 kbar at 500°C and a subsequent exhumation at rising temperatures to reach P-T conditions of 10 kbar and 565°C; (3) a slight heating event at 6.5 kbar produced the outermost garnet rim; (4) unoriented muscovite and plagioclase porphyroblasts formed at this event or during the subsequent exhumation at decreasing temperatures. Analysed monazite can be subdivided in a high Y (> 1.5 wt.% Y_2O_3) and low Y (< 0.3 wt.% Y_2O_3) population. The high Y population, which probably formed before the HP garnet, yielded an age of 45.8 ± 5.8 (2σ) Ma. The low Y population with grains enclosed in the outermost garnet rim gave an age of 42.1 ± 5.2 Ma. In agreement with Liati (2005), the deduced HP metamorphism is an Early Eocene event related to the deep burial of rocks by continent-continent collision and their exhumation in an exhumation channel. The late low-P heating event including the very late formation of andalusite was caused by the nearby c. 33 Ma old Teshovo granite.

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Melting of eclogite at ultrahigh pressure (UHP) conditions: an experimental study

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Melting of the subducted oceanic crust at great depth is a topic addressed in manifold geoscientific works. Nevertheless, melting temperatures of metabasalt at UHP are poorly known including the compositions of initial melts formed. We have investigated a finely-ground powder of a fresh phengite-bearing eclogite with little amphibole and rutile (sample 15882; Massonne, 1991) from the Sesia zone, Italian Alps. Water in this material is broadly stored in phengite. Experiments with this powder in a small noble metal container at 4 GPa and constant temperature for one day or shorter time durations were undertaken in a piston-cylinder apparatus as reported by Massonne & Fockenberg (2012). The run products were investigated with the electron microprobe (EMP) on a polished section through this container. We were able to analyze the newly equilibrated phases, mainly clinopyroxene and garnet, despite grain sizes often below 5 μm. Small amounts of melt formed could also be detected with the EMP but a high-resolution electron microscope was additionally used for this purpose. The obtained bracket for the solidus was around 950°C. Another bracket at temperatures around 1250°C was produced at a pressure of 9 GPa in a calibrated Walker-type multi-anvil device. For comparison, a bracket at this pressure was also obtained for the metapelite KD37 studied previously by Massonne & Fockenberg (2012). Initial melts produced from eclogite are very rich in potassium as those generated from metapelites, but the studied metapelite KD37 shows a 100°C higher solidus temperature at 9 GPa. With rising temperatures the melts formed from eclogite become richer in Na and Ca by increasing decomposition of clinopyroxene. However at the maximum temperatures of our experiments, which are considerably above the solidus ($\Delta T = 350°C$ at 4 GPa, 250°C at 9 GPa), this phase is still significantly present in the restite assemblage together with abundant garnet. At such conditions but also at lower temperatures yet, when 20-30 % of the studied rock was molten, the obtained melt is quartz-monzonitic to monzodioritic in composition. In a subduction setting such melts could in principle intrude the overlying mantle wedge to fertilize it. However, the question arises if melts, generated from relatively dry metabasites, form in a modern subduction setting at all. If the temperatures near the upper boundary of the subducted slab do not exceed, for instance, 850°C at 4 GPa and 1000°C at 7 GPa, no melts from the eclogitized oceanic crust would form. Thus, it seems to us to be more likely that H_2O-rich fluids generated in this geodynamic setting are responsible for the fertilization of the mantle. In this fertilized region the melts relevant for magmatic arc systems would then be produced.

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Modeling eclogite mineral assemblages and fluid release history, North Qaidam UHP terrane, western China

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Gneiss-hosted eclogite in the southeastern North Qaidam terrane, near Dulan, commonly contains the assemblage Grt + Omp + Phe ± Ep + Qtz/Coe. A sample with high whole-rock CaO/FeO contains abundant zoisite porphyroblasts, samples with intermediate CaO/FeO contain less abundant epidote-group minerals, and a sample with the lowest CaO/FeO lacks epidote-group minerals. For these samples, Zr-in-Rt thermometry records 670-690°C, and phengite containing up to 3.56 Si p.f.u. in one sample records pressures up to 36 kbar.

Isochemical phase diagrams (pseudosections) for these eclogites predict stable mineral assemblages and maximum whole-rock water contents assuming fluid saturation. Garnet mode isopleths are generally subparallel to whole-rock H_2O contours, except along the boundary between Lws and Zo fields. For P-T paths crossing the Lws-Zo boundary at P<23 kbar, T<600°C, lawsonite breakdown to zoisite will produce significant (>1 wt%) release of H_2O at the boundary; H_2O released at the boundary increases with decreasing P and T. However, at higher temperatures, whole-rock H_2O content is already <1 wt%, so H_2O release is less significant at the boundary; most significant H_2O generation has already occurred within the Lws field as Grt grows and Lws breaks down. This is true not only for low CaO/FeO samples for which 23 kbar, 600°C is close to the maximum pressure predicted for zoisite, but also for high CaO/FeO samples for which a much larger Zo field is predicted, extending into the coesite stability field.

Garnet mode and whole-rock H_2O contours are steep in the Lws stability field, so fluid release is mainly sensitive to temperature in this region. In contrast, Grt and H_2O contours have a shallower slope at lower P, higher T conditions, where reactions involving Amph and Zo are responsible for H_2O release. At still higher P-T conditions, very little garnet growth or H_2O release is predicted within the Grt + Omp + Phe + Qtz/Coe field. As a consequence, relatively cool P-T paths passing ~23 kbar at T<600°C are predicted to continue significant Grt growth and H_2O release into UHP conditions, enhancing the potential to trap UHP mineral inclusions. In contrast, warmer P-T paths will end most significant Grt growth and H_2O release at pressures <20 kbar for low CaO/FeO samples, limiting the opportunity for garnet growth to trap UHP inclusions or record UHP compositions. In such samples, deformation may play a critical role in promoting UHP mineral growth and equilibration, especially if fracturing of garnet exposes prograde inclusions to reaction, causing a pulse of new Grt growth and fluid release. Fluid availability is also expected to control zircon growth/recrystallization, and therefore minor differences in bulk composition and P-T path should significantly impact which parts of the P-T path are dated by zircon U-Pb.

Comparing the Caledonian and Himalayan Collisional Orogens

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UHP terranes formed in association with continental collision provide insight into processes of deep subduction and exhumation of continental material. The Caledonides of Greenland and Scandinavia record the long-lived Paleozoic collision between Laurentia and Baltica and are often compared with the Himalayan orogen to provide a complete synthetic cross-section of an archetypical continental collisional belt. The Dabie-Sulu orogen provides a similar view of deep crustal processes. In both the Caledonides and Dabie-Sulu, geochronologic data documents a complex and long-lived history of subduction and exhumation. Early HP and UHP metamorphism in the Caledonides occurred during closure of intervening ocean basin(s) separating Laurentia and Baltica around 460 Ma. Continent-continent collision by 430 Ma resulted in subduction of Baltican lithosphere and crustal thickening in Laurentia. Widespread HP and UHP metamorphism in the Western Gneiss region of Norway and in North-East Greenland at 400 Ma records the culmination of Baltica subduction. Exhumation of deeply subducted Baltican crust and HP Laurentian crust between 400 and 360 Ma is accompanied by extension, basin development, and displacement on conjugate dextral and sinistral strike-slip faults across the orogen. UHP metamorphism of deeply subducted Laurentian crust in North-East Greenland at ca. 360 Ma records continued continental convergence. Dextral and sinistral strike-slip faults in North-East Greenland were active during and after UHP metamorphism and are interpreted to be crustal scale structures directly related to formation and exhumation of the North-East Greenland UHP terrane in an intracontinental setting. The timing of Caledonian UHP metamorphism at 360 Ma, approximately 60-70 m.y. following the initial Baltica-Laurentia collision, is consistent with present day intracratonic subduction beneath Tibet approximately 55 m.y. following the initial Himalayan collision. The geometry of conjugate strike-slip faults associated with formation and exhumation of UHP rocks in the Greenland Caledonides is similar to active faults in the Tibetan Plateau that can be interpreted as crustal scale faults associated with intracratonic subduction (Tapponnier et al., 2001). The 430-400 Ma mid-crustal migmatites and leucogranites lying beneath the syn-collisional extensional detachment system and associated basins formed at relatively shallow crustal levels and did not impact contractional deformation, subduction and eventual UHP metamorphism of relatively dry Laurentian crust. Similarly, Himalayan migmatites and leucogranites, upon which “channel flow” models are largely based, formed at shallow crustal levels beneath an active extensional system and simultaneous with large conjugate strike-slip faults on the Tibetan Plateau. Subduction of relatively dry continental material along steep crustal scale faults is likely occurring today in an intracratonic setting beneath the Tibetan Plateau. Comparison and interpretation of the 50-70 m.y. evolution of the Caledonides and Himalaya relies on robust geochronologic data sets that adequately link timing information with deformation and P-T paths for differing segments of the orogen.

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Evidence for existence of UHP sulfide melt in calc-silicate rocks from the Kokchetav massif (Northern Kazakhstan)

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The deepest subducted rocks from the Kokchetav massif were recrystallized within the diamond-stability field (P=6-7GPa, T=1000°C) and preserve the evidence for existence of different types of UHP melts/fluids (Hermann et al., 2006). Korsakov et al. (2006) and Hermann et al. (2006) suggested the presence of sulfide melts in the clinozoisite gneisses and dolomitic marbles based on findings of "decrepitated" inclusions of sulfides in garnets and reaction textures. However P-T conditions for existence of the sulfide melt remain poorly constrained. In this study we present preliminary results of our ongoing research on sulfide associations in calc-silicate rocks from the Kokchetav massif.

Calc-silicate rocks consist of Cal, Dol, Grt and K-Cpx. Zrn, Dia, Gr, All, Ph, Tit, Py, Po, Cpy, Sp were identified as accessory minerals. Po was found in matrix coexisting with All and as inclusions in All. Po and Py were detected in "decrepitated" polyphase inclusions. Some of these inclusions as well as some garnet porphyroblasts are surrounded by Cpx-Spl symplectite. According to Sobolev et al. (2006) Cpx-Spl symplectite was formed at 1.8 GPa and 900°C. Inclusions of ZnS and Po were also found coexisting with silicate polyphase inclusions in the cores of K-Cpx porphyroblasts with abundant Kfs-lamellae. Kfs-lamellae were not recrystallized in the parts containing sulfide inclusions. Silicate polyphase inclusions and sulfide inclusions in Cpx porphyroblast had similar size (nearly 7 µm) and negative crustal shape. Findings of the sulfide inclusions surrounded by Cpx-Spl symplectite and decrepitated features testify that these inclusions were captured at least at 1.8 GPa and 900°C. Coexistence of All with Po further supports that Po might exist at pressures more than 3 GPa (Hermann, 2002). According to Mikhno and Korsakov (2013), K-Cpx porphyroblasts with lamellae and polyphase silicate inclusions were crystallized prior or at peak metamorphic conditions (1000-1100°C and 6-7GPa). This implies that sulfides occurring in the core of K-Cpx existed near to the peak metamorphic conditions. At such conditions (T > 1000°C, P ~ 7GPa) sulfides are not soluble in silicate melt and present in system as immiscible sulfide melt (Litvin et al. 2005).

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Saline fluid inclusions in jadeitites from southwest Japan: Records of slab-derived fluid composition in subduction-zone channels

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Slab-derived fluids play important roles in mass transfer along subduction-zone channels between the subducting slab and mantle wedge (e.g., Bebout, 2013). Salinity of such slab-derived fluids probably affects solubility and fluid-rock partitioning of elements; therefore, it remains to be investigated in various rocks. Jadeitite, a rock composed mainly of jadeite (sodium pyroxene, $NaAlSi_2O_6$), occurs typically in serpentinite mélanges intercalated to high-pressure and low-temperature metamorphic belts. It is thought to be the product of direct precipitation from aqueous fluids and/or of fluid-induced metasomatism of a protolith (e.g., Harlow et al., 2007, Tsujimori & Harlow, 2012, and references therein). Fluid inclusions in jadeitite may record information about the fluid composition in subduction-zone channels. We determined major components and salinity of primary fluid inclusions in the jadeitites from eight localities in Japan: Omi-Itoigawa (Omi-Renge belt), Oya and Osa (Suo belt), Kochi (Kurosegawa belt), Mie and Tone (Nishisonogi metamorphic rocks), and Shimonita and Yorii (the origin unclear). In all of the samples, the fluid inclusions consist of a liquid phase and a gas bubble. Raman spectra show the presence of H_2O liquid and vapor with or without minor CH_4 gas. The freezing point of the liquid phase indicates high-salinity (up to 8 wt% NaCl equivalent) of the fluid inclusions. The high-salinity of the slab-fluids probably enhances the mobility of elements such as Pb in subduction-zone channels (Keppler, 1996). In addition, the salinity varies among the sample localities: for example, it is about 7.1 ± 0.1 wt% NaCl equivalent in the albite jadeitite from Oya and about 4.6 ± 1.2 wt% NaCl equivalent in quartz inclusions bearing jadeitite from Tone. Sisson et al. (2006) reported fluid inclusions with 2–8 wt% NaCl equivalent in albite jadeitite and those with 0–3 wt% NaCl equivalent in quartz-bearing jadeitite from Guatemala. Taken together, the salinity of slab-derived fluids possibly decreases with the depth in subduction-zone channels.

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Jadeite and jadeites from Turkey

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A wide variety of eclogite and blueschist facies rocks crop out in Turkey with documented metamorphic ages of Neoproterozoic, Triassic, Early and Late Cretaceous and Eocene. Among these high pressure metamorphic belts, the largest and best preserved is the Tavşanlı Zone, which includes both continental and oceanic sequences metamorphosed under blueschist and eclogite facies conditions during the Late Cretaceous (ca. 80 Ma). The metamorphism was related to subduction of a passive continental margin in an intra-oceanic subduction zone.

Jadeite and jadeites occur mainly within the metamorphosed continental sequences of the Tavşanlı Zone. At the base of the continental sequence, called the Orhaneli Unit, there is a micaschist series, over 1000 m in structural thickness. Clastic zircon ages indicate a Triassic and younger depositional age for the micaschists. In the western part of the Tavşanlı Zone, the micaschists contain regionally distributed jadeite, which coexists with chloritoid, glaucophane, lawsonite and quartz giving metamorphic P-T conditions of 24 kbar and 450° C. Metaaplitic veins of unknown age, a few tens of centimeters thick, cut the micaschists and are made up of quartz and jadeite. The micaschists also contain Ordovician metagranitic bodies, several hundred meters large, consisting mainly of jadeite and quartz.

Jadeite is rare in the oceanic crustal lithologies of the Tavşanlı Zone due to unfavorable rock composition. The bulk of the oceanic crustal rocks are represented by sodic amphibole and lawsonite assemblages. Jadeite is restricted to the few acidic metavolcanic rocks, which consist of quartz, jadeite and minor lawsonite. Jadeite in these rocks makes up over half of the rock.

The only "jade" occurrence in Anatolia is the purple jade from northwest Turkey. It is a fine-grained phonolite, metamorphosed in blueschist facies. Some of the primary magmatic minerals, including aegerine, and magmatic textures, including the outlines of former nepheline crystals, are preserved. The blueschist facies mineral assemblage is represented by jadeite, lawsonite and K-feldspar giving metamorphic P-T estimates of 8 kbar and 300° C. Jadeite usually makes over half of the rock and occurs both as individual grains and as overgrowths on the magmatic aegerine. The purple jade is found as loose blocks in the late Tertiary continental sedimentary rocks. The jade blocks, along with blocks of serpentinite, were brought to the basin by rock avalanches.

Petrofabrics of olivine and enstatite in mantle xenoliths in Shanwang, eastern China, near the convergent plate margin and implications for seismic anisotropy

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Since mantle peridotite xenoliths provide information about the deformation and metamorphic processes of the upper mantle lithosphere (Mercier & Nicolas, 1975), these rocks have been perceived as being crucial in interpreting both the geophysical and geochemical environments and the deformation mechanisms in the upper mantle. In particular, the seismic anisotropic layer is considered to be related to the presence of mainly olivine and orthopyroxene in the mantle, and therefore an understanding of the lattice-preferred orientations (LPOs) of these minerals in nature is important in distinguishing the deformation processes of the upper mantle (Nicolas & Christensen, 1987; Jung & Karato, 2001; Karato et al., 2008; Long & Silver, 2008). Therefore, deformation microstructures, including LPOs of olivine, enstatite, and diopside, in mantle xenoliths at Shanwang, eastern China, were studied to understand the deformation mechanism and seismic anisotropy of the upper mantle.

The Shanwang is located across the Tan–Lu fault zone, which was formed due to the collision between the Sino–Korean and South China cratons. All samples are spinel lherzolites and wehrlites, and LPOs of minerals were determined using electron backscattered diffraction (EBSD) with a scanning electron microscope. We found two types of LPOs of olivine: type–B in spinel lherzolites, and type–E in wehrlites. Enstatite showed two types of LPOs (type–BC and type–AC), and diopside showed four different types of LPOs. Observations of strong LPOs and numerous dislocations in olivine suggest that samples showing both type–B and –E LPOs were deformed in dislocation creep (Park & Jung, 2014). Seismic anisotropy was calculated using the LPO of minerals. The seismic anisotropy of P–wave was in the range of 2.2–11.6% for olivine, 1.2–2.3% for enstatite, and 2.1–6.4% for diopside. The maximum seismic anisotropy of the shear wave was in the range of 1.93–7.53% for olivine, 1.53–2.46% for enstatite, and 1.81–6.57% for diopside, respectively; therefore, the seismic anisotropy of olivine was stronger than that of enstatite and diopside.

Furthermore, the thickness of the anisotropic layer was calculated for four geodynamic models to understand the origin of seismic anisotropy under the study area by using delay time from shear wave splitting, and S–wave velocity & anisotropy from LPOs of minerals. We suggest that the seismic anisotropy under the study area can be most likely explained by two deformation modes that might have occurred at different times: one of deformed lherzolites with a type–B olivine LPO by lateral shear during/after the period of the Mesozoic continental collision between the Sino–Korean and South China cratons; and the other deformed the wehrlites with a type–E olivine LPO by horizontal extension during the period of change in absolute plate motion in relation to the westward–subducting Pacific plate (Park & Jung, 2014).

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Meta-ophiolite emplacement triggered by continental subduction, Syros Island, Cyclades (Greece)

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At convergent plate boundaries, meta-ophiolitic units are remnants of oceanic basins exposed at Earth's surface which commonly occur as highly deformed blueschist to eclogite facies mélanges. Meta-ophiolites are though to derive from either the upper plate (supra-subduction ophiolite), or the lower plate of the subduction zone. These two origins for meta-ophiolite imply that parts of PT, t path are shared or not by the meta-ophiolite and its footwall. To give insight on the meta-ophiolite origin and emplacement, we provide a highly detailed comparative petrological and structural study of a meta-ophiolite and its footwall located in the Cycladic Blueschists Unit (CBU).

We computed P–T pseudosections to monitor the evolution of the mineral assemblages with pressure and temperature for the analysed whole rock composition of our samples using THERMOCALC (tc 3.33 with the database 5.5; Powell et al., 1988 updated 1998; Holland & Powell, 1998, updated 2003) and the model chemical system MnNCKFMASHTO. Pseudosections coupled to micro textural observations helped drawing well-constrained PT path for both the meta-ophiolite and the margin.

We show that the ophiolite and the margin have been buried as two separated units. After an in-depth stacking, both the meta-ophiolite and the continental margin unit followed a common retrograde PT path across the blueschist/greenschist facies transition. We thus infer that the driving mechanism for meta-ophiolite emplacement and exhumation is the buoyancy of the continental crust that (i) locked the subduction zones triggering thrusts and (ii) enhances the exhumation of the stacked ophiolite and margin units.

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HP melanocratic rocks of the Anrakhai complex (Southern Kazakhstan): the general features of chemical and mineral composition

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Within the structure of Zheltavsky block basement (Southern Kazakhstan) metamorphic formations of different extent are present, representing the Anrakhai complex,. HP melanocratic rocks that were formed at the peak of eclogite facies conditions (the metamorphic age was estimated as 490 Ma) are of the greatest interest; the rocks are represented by eclogites and garnet clinopyroxenites, forming tectonic lenses within enclosing Grt-Ky-Kfs paragneisses; in some cases they form intercalations with each other.

According to the chemical compositions, both garnet clinopyroxenite (SiO_2=40-41 wt.%; ΣNa_2O+K_2O=0.6-1.1 wt.%) with the peak mineral assemblage of Grt ($Py_{22}Alm_{48}$)+Cpx (Di_{85})+Rt (P=17.5 kbar, T=830°C; Krogh Ravna, 2000; Gasparik, 1985) as well as eclogite (SiO_2 = 42-45 wt.%; ΣNa_2O+K_2O=1-2 wt.%) with the peak mineral assemblage of Grt (Alm_{63})+Cpx(Jd_{35})+Qtz+Rt (P=17.5 kbar, T=810°C) correspond to tholeiitic basalts, however the former has higher magnesium numbers ($MgO_{grt\text{-}cpx'ite}$=11.5 wt.%; MgO_{ecl}=8.5 wt.%). The observed distinctions between the two rocks indicate the existence of two different pre-metamorphic protoliths. The garnet grains of eclogites are characterized by a prograde growth zonation expressed by Prp increase from core to rim and Adr and Sps decrease in the same direction (Spear, 1993). Furthermore the mineral inclusion distribution is consistent with chemical zonation of the garnet grains; within the intermediate Fe-Ca zone inclusions of Hbl and Czo are present (assemblage of garnet amphibolites) andin the peripheral Fe-Mg part sporadic inclusions of Qtz, Rt, Omp occur (eclogite stage association). Transition from amphibolite facies to eclogite facies conditions can be expressed by the following balanced reaction: $1{,}67Fe^{3+} + 2{,}34Na + 2{,}34H_4SiO_4 + 0{,}75Czo + 1{,}33Hbl \rightarrow 0{,}66Grt + 6Cpx + 0{,}17Ca + 1{,}67Mg + 1{,}92AlO_2 + 5{,}2H_2O + 2{,}36H^+$, that reflects the process of eclogitization of the garnet amphibolite (considered to represent the protolith of eclogite). On the other hand the composition of mineral inclusions in garnet grains of garnet clinopyroxenites, represented by Di_{85} is similar to Di of the groundmass of the rock (Di_{83}) and indicates the formation of garnet during the regressive stage.

The presence of apatite within the groundmass of eclogite and garnet clinopyroxenite implies their protoliths rather to represent an ultramafic-mafic rock of intrusive character than a rock of volcanic origin. The absence of Pl in garnet clinopyroxenites as well as their high amounts of MgO might indicate clinopyroxenites to represent possible protoliths of the garnet clinopyroxenites, whereas the lower magnesium number and the higher amounts of alkalis of eclogites indicate gabbroic rocks (later transformed to garnet amphibolites) as protolith for these eclogites.

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The details of regressive metamorphism history of eclogites within the Anrakhai complex (Southern Kazakhstan) and some tectonic implications

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The Anrakhai metamorphic complex is a fragment of the Zheltavsky Precambrian basement (in Southern Kazakhstan) and represents a quite difficult conjunction of various rocks; in some cases relics of an HP event (eclogite facies) are present, namely in garnet clinopyroxenites, eclogites and surrounding Grt-Ky-Kfs paragneisses. High-pressure rocks are altered up to 90-95 Vol.% and mainly consist of mineral parageneses of lower metamorphic stages. Starting from peak metamorphic conditions eclogites (having the geochemical characteristics of crustal origin) passed the fields of HP and MP granulites and of amphibolite facies during an initial isothermal decompression (ITD), followed by isobaric cooling (IBC).

The earliest changes of eclogites lead to formation of a mineral assemblage of acid Pl (An_{10-13}) with Cpx (Di_{60}), indicating the transition from eclogite facies conditions to HP granulites (P=12.5 kbar, T=800°C; Newton et. al, 1982; Krogh Ravna, 2000). The appearance of Fe-Mg Cpx ($Cen_{30}Cfs_{23}$) in one assemblage with more basic Pl (An_{14-18}) reflects the decrease of pressure to MP granulites conditions (P=9.5–10 kbar, T=810°C; Newton et.al., 1982; Krogh Ravna, 2000) at approximately constant temperatures (about 800 °C). The following stage after MP granulite facies is expressed by the growth of amphibole-plagioclase symplectites at the expense of Fe-Mg Cpx and by amphibole-plagioclase coronas around garnet. Amphibole of the former assemblage matches to edenite composition and Pl composition varies from An_{20} to An_{26} (T=640°C, P=11 kbar; Kohn & Spear, 1990; Krogh Ravna, 2000) at amphibolite facies of higher pressure conditions. Amphibole rimming garnet is represented by pargasite as well as ferropargasite; the associated Pl is the most basic one observed (An_{30-36}) (T=550°C, P=10.5 kbar; Kohn & Spear, 1990; Krogh Ravna, 2000). Thus the formation of amphibole-plagioclase associations is related to the decrease of temperature at constant pressure (IBC). The eclogites of Anrakhai complex could be formed as a result of mid-crustal fragments (garnet amphibolites) subducted to the depths of the eclogite facies field; in doing so the uplift was slow enough to overcome the thermal relaxation effect for some time (O'Brien et.al., 2003). The presence of specific microstructures in retrogressed eclogites as well as geothermobarometry data indicate the completion of the main tectonic activity during uplift at depths corresponding to 10-11 kbar (30-35 km). After ITD gradual cooling took place.

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From Harry Hess to Today: Caribbean Serpentinites and HPLT Metamorphic Belts in the context of Caribbean Tectonic Evolution

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Since the pioneering of "subduction" by Harry Hess and Vening Meinesz, the Caribbean with its numerous arcs and sutures has long served as a laboratory for understanding subduction zone processes, 3D geometries, continuity and periodicities, and rates. From the 1950s through the 1970s, Hess's Princeton-based Caribbean Research Program provided much of the descriptive observation, petrography, geochemical lab analyses, field mapping, and early modeling of the arcs and sutures, all of which remain heavily relied upon today. Names like Maresch, Oxburgh, Bowen, Maxwell, Nagle, Donnelly, Pardo, Shagam, and many others guided by Hess's vision were the early architects of the Caribbean's tectonic building blocks. These blocks were in turn synthesized into more regional belts of HPLT and HTLP rocks by various workers, while marine geophysical surveys conducted largely by Lamont, Woods Hole, University of Texas and the US Navy filled out the Caribbean's regional tectonic structure. Theories for Caribbean tectonic evolution abounded through the 1970s, when the possibility of a Pacific origin for Caribbean lithosphere began to be appreciated. However, a final requirement for a kinematically robust model for Caribbean evolution came not from the Caribbean but from the Atlantic basins, in the form of an accurate framework of relative motion history between North and South America, based on the SEASAT and GEOSAT satellite altimetry. Once this framework was in place, the various geological parameters concerning regional evolution could be pigeon holed into their proper contexts, and a surprisingly simple and quantitatively accurate kinematic model for a Pacific-derived Caribbean Plate and its margins was borne. This framework today affords workers of HPLT metamorphic belts in Guatemala, Cuba, Margarita, Hispaniola, Jamaica, Nicaragua, Venezuela, and Colombia better constraints on subduction history than do places like California, the western Pacific, or even the Alps, which is one reason the Caribbean continues to play such an important role in studies of subduction.

This talk will review some of the arguments for the Caribbean's Pacific derivation, showing that the plate's oceanic interior derives from pre-mid Cretaceous Pacific lithosphere (Farallon?) that became engulfed between North and South America during the westward drift of the Americas from Africa. Northerly and southerly continuations of this Pacific lithosphere that did not fit between the American continents were subducted beneath Mexico and the northern Andes; thus the geometric insertion of Caribbean lithosphere between the Americas was effectively perfect. Mainly intra-oceanic island arcs were built upon the edges of this lithosphere during Caribbean-American relative migration. The Caribbean arc system progressively collided with and was accreted to the various segments of the American "Proto-Caribbean" rifted continental margins as dictated by the evolving plate boundary geometry, thus reversing or terminating the local subduction and progressively forming the circum-Caribbean suture belt with its wealth of HPLT metamorphic rocks. Eastward-younging diachronous Caribbean arc-American continent collision and interactions are recorded by (1) eastwardly-progressive conversion of Proto-Caribbean passive margins to arc-continent collision/suture zones, (2) staged termination of subduction-related arc magmatism in the Caribbean arcs, and (3) cessation of subduction and HPLT metamorphism at the various segments of the circum-Caribbean suture zone, among other things.

In addition to this regional overview of Caribbean tectonic evolution, this talk will identify some of the significant areas of remaining controversy that future research on HPLT complexes may be able to resolve. It will also place the island of Hispaniola in its regional context, portraying the significance of the Puerto Plata-Río San Juan-Samaná suture zone.

Internal P–T–t structure of subduction complexes — Insights from Lu–Hf geochronology on garnet and lawsonite (Halilbağı, Central Anatolia)

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The subduction complex near Halilbağı (Central Anatolia) is among the best sites to investigate deep-seated tectonic, petrologic, and geochemical processes taking place in subduction zones. The Halilbağı Unit comprises slices of lawsonite- and/or epidote-bearing blueschist and eclogite, as well as meta-chert and marble. The unit is overlain by an ophiolitic slab and underlain by a HP/LT metamorphosed carbonate platform. Previous studies of the Halilbağı Unit suggested tectonic blocks were metamorphosed under diverse peak conditions, but shared a common exhumation P–T path marked by syn-decompression cooling (Davis & Whitney, 2006; Çetinkaplan et al., 2008).

To better understand the internal structure and dynamics of this subduction complex, we carried out Lu–Hf geochronology on garnet (grt) and lawsonite (lws) from a variety of HP oceanic rocks, as well as the sub-ophiolitic metamorphic sole. Our results suggest that intra-oceanic subduction started at ~110 Ma (grt–amph isochron from a grt amphibolite). Less than 23 Myr later, the subduction interface was refrigerated enough to allow clockwise P–T loops (~87 Ma peak grt–matrix isochron for a lws+grt-bearing eclogitic blueschist) and syn-decompression cooling (~79 Ma retrograde lws–matrix isochron) of subducted oceanic rocks.

We will present further results for several HP metamorphic sub-facies (e.g., epidote (ep) eclogite, lws+ep blueschist, lws blueschist, lws eclogite). Such data may allow unravelling whether the co-occurrence of "warm" (i.e., ep-bearing), and "cold" (i.e., lws-bearing) HP rocks in the same locality results from (a) sampling of distinct levels of the subduction slab, (b) thermal maturation of the juvenile subduction zone, or (c) inaccurate P–T estimates. Novel natural constraints are thus expected on the dynamics of the Halilbağı Unit and of subduction complexes in general.

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EBSD-measured crystal preferred orientations of the Himalayan UHP eclogites

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Electron backscattered diffraction (EBSD) maps and crystallographic crystal preferred orientations (CPOs) of the Himalayan ultrahigh-pressure eclogites of the Kaghan Valley are presented. These eclogites are mainly composed of garnet and omphacite with minor epidote, phengite, quartz and accessory rutile and titanite, and secondary hornblende. The rocks exhibit strong CPOs in omphacite and rutile, random or complex fabric pattern in garnet and quartz. The retrograde phases constitute hornblende and titanite in which the former exhibits also a strong CPO fabric and the later does not.

The development of CPOs in omphacite in naturally deformed eclogites is controlled by multiple dislocation glide, grain-boundary migration and mass-transfer (Godard & Van Roermund, 1995). Therefore study of CPOs in eclogites provides information of the deformation regime. The most common types of CPOs in omphacite in eclogites are the S-type (flattening) fabrics, marked by a strong concentration of [010]-axes normal to the foliation and [001]-axes are perpendicular to [010], L-type (constriction) fabrics marked by relatively strong [001]-axes maximum parallel to lineation and a complete [010] girdle perpendicular to it (Abalos, 1997; Helmstaedt et al., 1972).

In the Himalayan eclogites, the CPOs in omphacite is strongest along [001]-axes and {011}-poles (L-type), suggesting intra-crystalline flow or dislocation glide along [001]{110} and [001](100) slip systems representing the subduction-related deformation rheology. Garnet exhibits complex or random fabrics. Hornblende exhibits identical CPOs to that of omphacite but those CPOs are developed due to homotaxial crystal growth/recrystallization during late-stage retrogression. We conclude that in the Himalayan eclogites deformation was mainly accommodated by omphacite representing a constrictive plastic strain regime and garnet behaved as rigid body as generally observed in most naturally deformed eclogites of the world.

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Lawsonite-blueschist from the western Himalaya (Ladakh, NW India): petrologic witness of cold subduction processes

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The Himalayan collisional orogen is relatively poor in high pressure metamorphics. Beside rare eclogite (Lombardo & Rolfo, 2000), few blueschist occur along the Yarlung-Tsangpo Suture (ITS), *i.e.* the suture marking the India-Asia collision. The petrographic features of blueschist-facies lithologies have been described in the western portion of the ITS in Swat, NW Pakistan and in Ladakh, NW India (*e.g.* Guillot et al., 2008 and references therein). Safe for a recent paper by Ao & Bhowmik (2014) on blueschist from the far eastern Himalaya, modern petrologic studies on the relatively more abundant blueschist from the western Himalaya are still lacking. There, the best occurrence of blueschist is that of the Shergol ophiolitic mélange, which outcrops over a distance of 250 km along the ITS and consists of several thrust slices sandwiched between the Nindam-Naktul-Dras nappe to the north, and the Lamayuru nappe to the south. Blueschist lithologies are heterogeneous and dominated by volcanoclastic sequences rich in mafic material with subordinate interbedding of metasediments. Prior to this study, P-T estimates based on conventional thermobarometry suggested T = 350-420°C and P = 9-11 kbar (Honegger et al., 1989).

West of the village of Tringo, blueschist facies metasediments are particularly abundant and suitable for petrologic modeling. They show the typical Lws-blueschist (LBS) facies assemblage Qtz + Phe + Lws + Na-Amp + Grt. Lws and strongly zoned Grt porphyroblasts overgrow the main foliation defined by high-celadonite Phe (Si > 3.80 a.p.f.u.). Preliminary petrologic results obtained from pseudosection calculations in the MnNKCFMASH model system constrain peak-P-T conditions to about 380-420°C, 20-21 kbar, *i.e.* at significantly higher P than previously estimated. The following exhumation still occurred in the LBS-facies field, allowing the preservation of Lws.

The reconstructed P-T evolution suggests that the Shergol blueschists are the result of cold subduction along a thermal gradient of ca. 5-6°C/km, and that such a low geothermal gradient was followed also during exhumation. This P-T evolution is consistent with a mature subduction zone system in an intra-oceanic subduction setting, as also suggested by Ao & Bhowmik (2014) for blueschist from the far eastern Himalaya.

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Lawsonite-blueschist in the Hakoishi sub-unit, Kurosegawa belt, Kyushu, Japan, as a remnant of late Paleozoic Mariana type subduction, part 2: Petrology and Mineralogy.

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The metamorphic zonal mapping for the metabasites in the Hakoishi sub-unit revealed that metamorphic reactions are well developed even in massive metabasites, which still preserve original igneous textures such as hyaloclastite and pillow lava, represented by replacement of plagioclase by lawsonite (Lws), pumpellyite (Pmp) and albite (Ab) (rarely jadeite), and of igneous augite by Na-pyroxene, Na-amphibole and chlorite (Chl). However, the development of epidote and actinolite was not detected. The wide occurrence of metamorphic pyroxenes in lower grade metabasite is clearly identified (e.g., Banno, 1998). Furthermore, following progressive mineral assemblage variation is identified in only 10 km horizontal distance from east to west with excess Chl, quartz (Qtz) and Ab;

Pmp + Na-amphibole (Zone1)
Lws + Pmp + Na-amphibole (Zone2)
Lws + Na-pyroxene + Na-amphibole (Zone3)

Jadeite content (X_{jd}) of Na-pyroxene (Di) gradually increases from Zone1 (X_{jd}=0.10-0.30) to Zone3 (X_{jd}=0.30-0.45). Glaucophane (Gln) component [$Y_{Al} = Al/(Al+Fe^{3+})$] of Na-amphibole also increases from Zone1 (Y_{Al}=0.15) to Zone3 (Y_{Al}=0.80). Modal amount of Pmp gradually decreases from Zone1 to Zone3 and that of Lws shows an opposite trend.

Petrogenetic grid in NCMASH system reveals that the observed mineral assemblages are stable from 0.45 GPa and <300 ℃ for Zone1 to 0.80 GPa and <350 ℃ for Zone3 and that the following mineral reactions are inferred to define the each zone boundary;

6 Pmp + 9 Chl + 19 Qtz + 34 Ab + 8 H_2O (Zone1) = 24 Lws + 17 Gln (Zone2)

6 Pmp + Gln + 10Qtz + 8 H_2O (Zone2) = 15 Lws + 9 Di + 2 Ab (Zone 3).

These data suggest that the studied rocks were formed under extremely low geothermal gradient of ca. 5°C/km.

The geological observation reported in the accompanying abstract by Hirajima et al. suggests that the Hakoishi sub-unit is a remnant of layer 1 and layer 2 of a past subducting oceanic crust with 10km length. Our petrological study suggests there is a pressure gap of ca. 0.3 GPa, corresponding with ca. 10 km depth. These data may suggest that the Hakoishi sub-unit could be formed by almost vertical subduction, such as Mariana type. The metamorphic reactions inferred from our observation are the hydration type. Actually H_2O content stored in hydrous minerals in lawsonite blueschist (LBS) increases from Zone1 (ca. 4.5 wt %) to Zone 3 (5.5-7.5 wt % H_2O). Our data clearly verify that the subducting LBS is a main water carrier into the mantle as suggested by Hacker et al. (2003).

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Jade artefacts from the Playa Grande site, Dominican Republic: mineralogical characterization and archeological implications

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Jadeitite (or jadeite jade), a rare hard and tough rock type composed mainly of the mineral jadeite, is now known from Ceramic Age sites on many islands in the Caribbean. It represents a prized lithic raw material for the manufacture of axes and adzes. Although initial provenance work in the early 2000's pointed to Guatemala as its likely source, new discoveries in Cuba and the Rio San Juan Complex (RSJC) in the northern Dominican Republic (DR) have made sourcing more equivocal. Jadeitite characterization is complex, and considerable mineralogical and geochemical intra-site variations are recognized, e.g., García-Casco et al. (2013). The known potential sources are serpentinite mélanges with a similarly variable inventory of metamorphic blocks. Very recent work in the northern DR has revealed the first evidence of local celt manufacture at the multi-component Late Ceramic Age coastal site of Playa Grande (AD 750 - 1600), from where the material appears to have been exchanged and distributed. The Playa Grande (PG) site is located only 20-30 km from the RSJC jadeitite source region recently described by Schertl et al. (2012). At PG, an unusually high percentage of the artefacts are celts, adzes and related tools, 35% of which appear to be jadeitite. Eleven celts and one adze were chosen for an on-going petrographical, mineralogical and geochemical analysis for direct comparison with the potential RSJC source material, where (Schertl et al., 2012) recognized: (1) a quartz-free jadeitite suite and (2) a heterogeneous quartz-bearing suite in which jadeitites can grade into jadeite, jadeite-lawsonite, and lawsonite quartzite. Suite (2) is particularly common in mélanges near the coast, whereas the quartz-free suite is found mainly 20-30 km inland in rugged hills representing the catchment area of the San Juan River. Nine of the twelve artefacts are jadeite-rich rocks. Seven of these are identical to or extremely similar in both mineralogy and petrography to jadeitites from the RSJC, with all but two corresponding best to the quartz-free suite of (Schertl et al., 2012). Two artefacts, composed essentially of jadeitite+lawsonite but lacking quartz, are rocks so far not known from the RSJC. One artefact is a silicified greenschist commonly associated with the jadeitite-bearing mélanges, while the other two are glaucophane-rich blueschists. Although the latter are common in the mélanges, the artefacts in detail contain an unusual omphacite+garnet+lawsonite association not yet described from the RSJC. These results show that most of the artefacts at PG most likely originated locally from the RSJC. Rather than exploiting easily accessible coastal outcrops, the PG inhabitants followed the San Juan River toward its source area and collected river cobble blanks. Jadeitites from the RSJC and the PG artefacts lack paragonite, a characteristic feature that may help in future provenance studies.

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High-pressure metamorphic rocks in serpentinite-hosted mélanges of the Dominican Republic: the role ofjadeitites

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New occurrences of jadeitite, jadeite quartzites, and jadeite-lawsonite quartzites have been recently discovered in the Rio San Juan Complex (RSJC) of the northern Dominican Republic. These rocks are found in serpentinite mélanges associated with a former intra-oceanic subduction zone. The mélanges contain blocks of various high-pressure (HP) metamorphic rock types such as blueschist, eclogite, jadeitite, orthogneiss, rare cymrite-bearing rocks, marble and metapelite. Comprehensive petrological studies on different types of eclogite and blueschist reveal a broad diversity of PTt-paths which are closely interrelated. In the early stages of the evolution of the subduction zone, PT-paths are both clockwise and anticlockwise with low ("hot") P/T-gradients; maximum PT-conditions derived from eclogites are about 800°C/2.5 GPa (a Lu-Hf-age on eclogite is 103.9 Ma). Omphacite-bearing blueschists document a continuous cooling and steepening of the PT-gradient; their recorded peak metamorphic conditions are 500-550°C/1.6-1.8 GPa at 80.3 Ma (Rb-Sr on Phe-Amp-WR). Very steep ("cold") P/T-gradients are derived from jadeite blueschists; Rb-Sr-ages (Phe-Amp-WR) of 62.1 Ma and Ar-Ar ages of 71.9 Ma date the peak metamorphic conditions of 360-380°C at about 17 kbar.

Jadeitites are known from only about 20 localities worldwide. They are thought to either crystallize directly from HP aqueous fluids or to form by metasomatic replacement of a suitable protolith such, for example, tonalite, trondhjemite or plagiogranite. A very unusual feature of the jadeitites of the RSJC compared to other jadeitites worldwide is their occurrence as layers and veins in jadeite-lawsonite blueschist and omphacite-garnet blueschist country rocks. The principal types of jadeite-bearing rocks observed in the RSJC can be categorized as (1) jadeitites *s.str.* (quartz-free, albite-bearing, >90 vol% jadeite), which have so far been found only as loose blocks/boulders in the mélange, and (2) jadeitites *s.str.* (quartz-bearing) and jadeite quartzites (JQ) which grade into jadeite-lawsonite quartzites (JLQ); while also occurring as loose blocks/boulders, these can also form concordant layers and discordant veins within blueschists. In addition, monomineralic omphacitite veins have also been found in such blueschists.

The unusual diversity of jadeite-bearing rocks in the RSJC, in context with their observed contact relationships with different blueschist country rocks, reflects their formation at different PT-conditions (350-500°C at minimum pressures of about 1.5 GPa and 500-600°C at ca. 1.1-1.5 GPa) over an extended time span of tens of millions of years in a continuously evolving subduction-zone environment. In addition, evidence for both crystallization directly from a HP aqueous fluid as well as formation by metasomatic replacement is found.

Evidence of Neoproterozoic continental subduction in Central Asian Orogenic Belt

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In the Central Asian Orogenic Belt, which is one of the largest accretionary terranes on the Earth, eclogite-bearing complexes occur in the Caledonian (Early Paleozoic), Hercynian (Middle-Late Paleozoic) and Baikalian (Neoproterozoic) orogens. The oldest eclogites are found in the North Muya dome, located in the Anamakit-Muya zone of the Baikal Muya accretionary fold belt within the Baikalian orogen. Eclogites occuring as lenses or layers intercalated with country rocks have a mineral isochrone age of 630 Ma (Shatsky et al., 2012). Zircons from two garnet-biotite gneisses and two garnet-biotite-muscovite schists were dated using the LA-ICP-MS technique. Hf-in-zircon isotopic analyses were performed using MC-LA-ICP-MS. Based on U-Pb isotope data and CL images zircon grains were divided into three groups: inherited, igneous and metamorphic zircons. Zircons with typical igneous textures and high Th/U ratios (from 0.78 to 0.25) are within 730-830 Ma time range. The metamorphic zircons (ages 650-630 Ma) have Th/U ratios varying from 0.02 to 0.004. The inherited zircons from garnet-biotite-muscovite schists concentrate in 1.9-2,6 Ga range. Zircons from this sample are characterized by the widest scatter of $\varepsilon_{Hf}(t)$ values (from +13.9 to -15.3) and T_{DM}^{C} model ages (0.82-3.86 Ga). Zircons from other samples have a much narrower ranges of ε_{Hf} (t) (+11.6 to -0.7) and T_{DM}^{C}(0.85-1.52 Ga). Most eclogites have $^{147}Sm/^{144}Nd$ ratio less than the chondritic value, suggesting their LREE-enriched geochemical characteristic. Nd and Sr isotopes show that eclogites display a bigger contribution of Archean component than exposed country rocks. The gneisses and schist exhibit a range of Nd isotopic composition with $\varepsilon_{Nd}(t)$ values ranging from -5 to +3 and $T_{Nd(DM)}$ from 1,61 to 1,05 Ga. The eclogites are characterized by the widest scatter of $\varepsilon_{Nd}(t)$ (from +6,9 to -16,8) and $T_{Nd(DM)}$ from 2,98 to 0,720 Ga. Sm-Nd model age data suggest that the eclogites protoliths were emplaced in Mesoarchean continental crust. Integration of zircon U-Pb dating with its Hf-isotope composition and Nd isotopes with the age spectra gives us the first evidence existing of Mesoarchean crust and Neoproterozoic continental subduction in Baykal-Muya belt of Central Asian Orogenic Belt. The eclogite-gneiss complex of the North Muya dome marks the transition from the oceanic subduction to the collision of island arcs with the continental blocks that separated from Rodinia or with the margin of the Siberian craton.

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Secondary fluid inclusions study the diamond-grade kyanite gneisses, Kokchetav massif: Evolution of fluid composition.

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Kokchetav HP/UHP rocks occur as slices and blocks in two structurally different units: (1) the Vendian to Cambrian megamelange belt and (2) the accretionary prism. The megamelange is subdivided into five terranes: Barchi-Kol, Kumdy-Kol, Sulu–Tyube, Enbek–Berlyk and Kulet [1-2]. The P-T conditions of Kumdy-Kol and Barchi-Kol terranes are 4 - 6 GPa, 1000°C [3]. Diamond-bearing kyanite gneisses from Barchi-Kol terrane were studied. These rocks consist of large kyanite and garnet porphyroblasts. The Ky porhyroblast has a zonal distribution of C and SiO_2 polymorphs: (i) graphite-rich core with inclusions of Qtz, Coe and small number of diamonds, and (ii) overgrowth with predominantly diamond crystals and rare graphite inclusions.

All secondary fluid inclusions (SI) from Ky porphyroblast have isometric form (up to 8 μm in size). They occur in graphite-rich core of porphyroblast and commonly consist of CO_2. In some CO_2 inclusions the diamond crystals were identified. Whereas SI in matrix quartz (up to 10 μm in size) are almost pure CH_4 with minor N_2, CO_2 and H_2O contents. The small size of the SI preclude classical fluid inclusions study and identification of composition of SI was performed by Raman spectroscopy. Raman bands for CO_2 inclusions in Ky occuring at 1281 cm^{-1} and 1386 cm^{-1} indicate high density of SI [4]. Strong luminescence in Ky crystals hides the H_2O range. Broad band at ~3450 cm^{-1} in Raman spectra of SI in quartz testify for presence of liquid H_2O [5]. The diamond formation in UHPM rocks is generally related with crystallization from COH fluid [6,7,8] by reaction: $CO_2+CH_4 \rightarrow 2H_2O+2C$. Our findings of different SI in Ky and Qtz may indicate for evolution of fluid composition. It is likely that graphite-rich core of Ky porphyroblast crystallized from reduced fluid whereas diamond crystallization occurs from moderately oxidized fluid. These observations are in a good agreement with experimental results [9].

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Long-lived decompression melting of UHPM rocks during continental subduction and exhumation in the N. Qaidam UHP belt

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Two stages of decompression melting of ultra-high pressure metamorphic (UHPM) rocks, which have lasted for ~45 Mys, syn- and post-UHPM, have been recognized the in the early Paleozoic North Qaidam UHPM belt on the northern margin of the Greater Tibetan Plateau.

In the first stage, adakitic (tonalitic-trondhjemitic) melts were produced by eclogite decompression during exhumation of subducted and metamorphosed oceanic/continental crust in response to continental collision. We present field evidence for partial melting of eclogite and its products, including adakitic melt, volumetrically significant plutons evolved from the melt, cumulate rocks precipitated from the melt, and associated granulitic residues. This “adakitic assemblage” records a clear progression from eclogite decompression and heating to partial melting, to melt fractionation and ascent/percolation in response to exhumation of the UHPM package. The garnetite and garnet-rich layers in the adakitic assemblage are of cumulate origin from the adakitic melt at high pressure, and accommodate much of the Nb-Ta-Ti. Zircon SHRIMP U-Pb dating shows that partial melting of the eclogite took place at ~ 435-410 Ma, which postdates the seafloor subduction (> 440 Ma) and temporally overlaps the UHPM (~ 440-425 Ma) (Song et al., 2014). Partial melting of UHPM felsic gneisses, as indicated by veinlets and dykes, also occurred in this stage.

The second stage of melting occurred at ~ 405-390 Ma, in which the concurrent plutons occur all along the UHPM belt (e.g, Wu et al., 2007; Wang et al., in press). The 393-390 Ma tonalitic plutons presents the melting of subducted continental lower crust at low pressure (<7 kbar). The 405-390 Ma two-mica granites, on the other hand, are products of decompression melting of the subducted upper crust. Decoupling exhumation between the subducted upper and lower crust are responsible for the generation of the two types of plutons.

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Age of peak metamorphism of eclogites from the Escambray Massif, Cuba

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Establishing the timing of HP/LT metamorphism during subduction and collision remains a major challenge. The Escambray metamorphic complex in Cuba represents a nappe stack that includes a greenschist-facies unit and two subduction-related HP/LT units composed of terrigenous metasedimentary rocks with eclogite lenses (16-25 kbar / 530-630°C) and MORB-type garnet amphibolites (12-14 kbar / 580-650°C), tectonically overlain by island-arc-related rocks with a LP/HT overprint. This contribution reviews and summarizes largely unpublished age data compiled in our working group (A. Baumann, M. Brix, F. Grafe, B. Idleman, M. Krebs, W.E. Hames, J. Pfänder, S. Sergeev, E. Scherer, S. Thomson).

A Mesozoic age for the Escambray protoliths is suggested by rare fossil findings, and post-collisional exhumation is indicated by pebbles of metamorphic rocks in conglomerates at about 45 Ma (Somin & Millan, 1981). U/Pb ages of 102 and 106 Ma on zircon interpreted to be metamorphic from an eclogite (Hatten et al., 1988) have been commonly used to constrain the age of HP/LT metamorphism in the Escambray. However, Ar-Ar ages for phengites in blueschists and eclogites range between 68 and 64 Ma. Fission-track ages range from 68-58 Ma (zircon) and 48-40 Ma (apatite). This constellation of ages suggests an unrealistically long residence time at depth of the HP/LT units during the collisional event. We have corroborated the earlier U/Pb results by U/Pb SHRIMP analysis as 104.7±1.6 Ma (concordant). However, other eclogites yield discordant U/Pb multi-grain results of 148±5 and 1142±210 Ma, and U/Pb SHRIMP spot analyses ranging from ~176 to ~105 Ma, probably reflecting various stages of lead loss.

Five garnet-bearing eclogite samples and one garnet amphibolite were selected for dating of the peak metamorphism of the Escambray HP/LT metamorphic units by the Lu/Hf method. The Lu/Hf ages for all eclogites cluster tightly between 69 and 71 Ma, with errors ranging from 0.6 to 1.6 Ma. A U/Pb age of 71±5 Ma on clearly metamorphic titanite from an associated schist corroborates these results. The garnet amphibolite yields 80.8 ± 2.4 Ma. Thus the available U/Pb ages on zircons in eclogites do not date the metamorphic overprint, but the age of the gabbroic protolith, variably reset by later re-equilibration processes.

The available age data from the Escambray Massif now yield a clearer picture. The two HP/LT units followed different P-T paths before amalgamation. The age of attainment of maximum subduction depth at ±70 Ma of the eclogite-bearing HP/LT unit correlates well with the cessation of magmatism in the related island arc and with regional reconstructions of the northern Caribbean, where the Cuban segment of the Great Caribbean Arc collided with parts of the Yucatán Peninsula (Stanek et al., 2009; García-Casco et al., 2008).

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Linking zircon ages to P−T paths through textural position and REE patterns: The eclogite-mafic granulite to intermediate granulite transition from the Blanský les, Bohemian Massif

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The eclogite-mafic granulite occurs as a rare boudin within a felsic kyanite-K-feldspar granulite in a low strain zone. Its boundary is marked by important metasomatism involving diffusional gain of potassium on a centimeter-scale, and probable infiltration of felsic melt on a larger scale, converting the eclogite-mafic granulite into intermediate ternary feldspar-bearing granulite. The peak P−T conditions of the eclogite based on inclusions in garnet are 18 kbar at an uncertain temperature, with matrix reequilibrated at 12 kbar and 950 °C. Four samples representing the transition from the eclogite-mafic granulite to the intermediate granulite were studied. In the eclogite, REE patterns in the garnet core show no Eu anomaly, compatible with crystallization in the absence of plagioclase and consistent with the inferred initial eclogite-facies conditions. Towards the rim of garnet LREE decrease and a weak negative Eu anomaly indicates passing into HP granulite-facies conditions with plagioclase present. The outermost rims of garnet next to ternary feldspar in the intermediate granulite show the lowest LREE and deepest Eu anomaly.

Zircon was analyzed by LASS (laser ablation–split-stream inductively coupled plasma–mass spectrometry) and shows U-Pb dates from 404 to 334 Ma. There is a trend of flattening of the slope of HREE from the old to the young dates with an apparent discontinuity, not clearly related to a discontinuity in the ages. The Eu anomaly is mostly negative, but some zircon in the eclogite has no Eu anomaly. The oldest dates are interpreted as crystallization of the protolith at > 404 Ma without garnet and with plagioclase, therefore as a shallow level mafic rock, likely a gabbro. The flat HREE patterns and negative Eu anomaly or its absence indicate (re)crystallization in presence of garnet, with or without plagioclase. A correlation between decreasing Yb/Gd with age indicates that the spread of dates is likely to be mainly a result of incomplete recrystallization of the protolith zircon along the P−T path, thus making interpretation of the dates difficult. However, some textures indicate crystallization of new zircon that may be linked to the P−T path. A zircon included in garnet and crystallized with omphacite gives c. 350 Ma that is interpreted as the minimum age of the eclogite facies metamorphism. A zircon grown partially along grain boundaries within the recrystallized opx-cpx-gar-plg matrix gives 338 Ma, interpreted as the age of exhumation to 12 kbar. Older dates and zircons with steep HREE patterns are clearly more abundant in the eclogite-mafic granulite, and dates older than c. 345 Ma and/or showing steep HREE patterns are very rare in the intermediate granulite. This points to the metasomatic processes that converted eclogite-mafic granulite to intermediate granulite facilitating zircon recrystallization.

Intermediate granulite produced by transformation of eclogite at a felsic granulite contact, in Blanský les, Bohemian Massif

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Layers or bodies of intermediate granulite on scales from a cm to a hundred metres occur commonly within the felsic granulite massifs of the Bohemian Massif. Their origin is enigmatic in that they commonly have complex microstructures that are difficult to interpret, and therefore even the sequence of crystallization of minerals is uncertain. At Kleť, in the Blanský les massif there is a revealing outcrop in a low strain zone in which it is clear that intermediate granulite can form by the interaction of felsic granulite with eclogite. The eclogite retains garnet from its eclogite heritage, the grains at least partially isolated from the matrix by a plagioclase corona. The original omphacite-dominated matrix of the eclogite now consists of recrystallised diopsidic clinopyroxene, orthopyroxene and plagioclase, with minor brown amphibole and quartz. The modification of the eclogite is dominated by addition of just K_2O and H_2O, rather than all the elements that would be involved if the process was one of pervasive melt infiltration. This suggests that the main process involved is diffusion, with the source being the felsic granulite, or local partial melt of the granulite. The diffusion occurred at about 950°C and 12 kbar, with the main observed effects being 1) the un-isolation and preferential destruction of the interior part of some of the garnet grains by large idiomorphic ternary feldspar, 2) textural modification of the matrix primarily involving the recrystallisation of clinopyroxene into large poikiloblasts containing inclusions of ternary plagioclase, and 3) conversion of low-K plagioclase in the matrix into ternary feldspar by incorporation of the diffused-in K_2O. The phase equilibria in the intermediate granulite are consistent with the chemical potential relationships that would be superimposed on the original eclogite by the felsic granulite at 950°C and 12 kbar.

Featured volatiles of the HP veins and their host rocks from the West Tianshan, China

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Understanding the exchange of volatiles in geochemical reservoirs and recycling in Earth's interior are one of the central issues of terrestrial geodynamics (e.g. Magenheim et al., 1995; Su et al., 2004; Wallace, 2005; Wood & Normand, 2008). The major volatiles in Earth's crust and upper mantle are H_2O, CO_2, S, F, and Cl (e.g. Philippot et al., 1998; Koleszar et al., 2007; Aiuppa et al., 2009; Rowe et al., 2009), but their partitioning between various phases and their mechanisms of transport in the crust and upper mantle still remain somewhat enigmatic despite decades of research. Studies of uplifted tracts of high-P/low-T metamorphic rocks of the Tianshan, China can provide detailed information regarding the extent of loss of volatile components during subduction zones. This study focuses on three high-pressure veins, and their host rocks. Two high-pressure veins occur within the blueschist, and one vein within the eclogite rock units. The host eclogite rock is composed of garnet, omphacite, amphibole, paragonite / phengite, quartz, rutile and minor titanite, albite, zircon, carbonate. The host blueschist rock is composed mainly of glaucophane, garnet, white micas, epidote, carbonate, rutile and minor titanite, albite, zircon, opaque phases whereas the vein shows a coarse grained, granoblastic heterogranular texture and consists of omphacite, quartz, carbonate and apatite. Between vein and host rocks a reaction zone is observed. The combination of whole rock studies with mineral of major element data as well as trace element data indicate that differences exist between the vein and its host rock: 1, higher Fe_2O_3 of the host rocks relative to the veins; 2, an enrichment of Li in the veins and the reaction zone compared to the host rocks, while the amounts of mainly large-ion lithophile elements and LREE are depleted relative to their concentrations in the host rocks; 3, F, CO_2 concentration in the blueschist host rocks is lower than those of vein, whereas Cl concentration of the host rocks is richer than Cl in the veins. F and Cl are common minor or trace constituents of micas, amphiboles, apatites in which they substitute for hydroxyl. Lower CO_2 concentration in the blueschist is interpreted by devolatilization, which is consistent to carbonates which were replaced or decomposed and liberate CO_2.

Omphacitites and Jadeitites from Alpine Corsica: two different types of jades

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Two different types of jade were found in the high-pressure (HP) terranes of Alpine Corsica (France). The first type occurs as veins (up to ca. 10 cm thick) in blueschist-facies (garnet-free; ca. 450 °C and 1.8 Gpa) Tethyan metagabbros, and mainly consists of omphacite, lawsonite and quartz (Vitale Brovarone 2013). The veins cut across a weak schistosity of the metagabbro defined by stretched igneous plagioclase (now dominant lawsonite) and clinopyroxene (now partially replaced by glaucophane) sites. The omphacite forms either prismatic of fan-shaped, fibrous crystals and aggregates. The second type occurs as large (ca. 30-50 cm thick) dykes cross cutting eclogite-facies metagabbros (glaucophane-garnet-omphacite, ca. 520°C and 2.3 GPa) and mainly consists of pure jadeite, quartz, blue amphibole, sphene, white mica and large zircons. The jadeite forms prismatic aggregates likely replacing former albitic plagioclase. The two rocks equilibrated at different metamorphic conditions (blueschist vs. eclogite) and originated from two different mechanisms. The blueschist omphacitite veins likely precipitated from a fluid at HP (Type-P by Tsujimori and Harlow, 2012), whereas the eclogitic jadeitites represent meta-plagiogranits (Type-R).

The omphacitites veins share some structural and mineralogical similarities with some Dominican jades (Schertl et al., 2012).

Jadeite in Corsica was first described in metagranitic rocks (Essene, 1968), whereas this is the first report of "ophiolitic" jadeitites in this HP complex. The genesis of the Corsican jadeitites is comparable with the Alpine jadeitites from the Monviso (Compagnoni et al., 2012). However, whereas the Alpine jades occur within serpentinites, the Corsican jadeitites described herein were found in metagabbros.

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Organic carbon fluxes in forearc subducting slabs

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At subduction zones, crustal rocks are recycled into the Earth's interior with profound implications for global elemental cycling. This process includes redistribution of carbon from the solid state (e.g. carbonates, graphite, diamond) to the fluid phase (e.g. CO_2, CH_4, HCO_3^-), which deeply participates in the global carbon cycle. In the subducting oceanic crust, C in the solid state mainly occurs as inorganic (i.e. carbonate minerals) and organic carbon (organic matter). The participation of carbonates in the deep C fluxes has been recently matter of experimental and field-based studies pointing to intense carbonate dissolution at high-pressure (HP) conditions (Frezzotti et al., 2011; Ague and Nicolescu, 2014; Facq et al., 2014). This feature in part questions previous, more conservative thermodynamic and experimental results (Kerrick and Connolly, 2001; Poli et al., 2009). Conversely, much less is known about the contribution of the organic carbon. The production of C compounds such as CH_4 and CO_2 from the transformation of organic matter during burial and diagenesis is well established. At higher P and T, however, little is known about the possible devolatilization of organic carbon during progressive graphitization. Whole rock budgets from the Catalina Schist point to the retention of most (>75%) organic carbon (Bebout 1995). Thermodynamic studies on the evolution of graphitic rocks have concluded that during prograde metamorphism, graphite-water is the dominant fO_2 buffer, and even little consumption of graphite would result in fO_2 buffering throughout metamorphism (Holloway, 1984; Connolly and Cesare, 1993; Connolly, 1995; Pattison, 2006). This points to very limited devolatilization of organic carbon. However, these studies are based on two crucial assumptions: i) absence of intense fluid-rock interaction, and ii) graphitic C to be pure graphite, with little information on disordered graphitic C, which typically occurs for temperature (T) <500-550 °C in forearc slabs.

Here we show that widespread, dramatic leaching of disordered organic carbon occurs at HP conditions by fluid-mediated processes. This process occurs not only along lithological boundaries (ideal locus of fluid-rock interaction), but also within the metasedimentary pile, possibly indicating networked fluid flows (Zack and John, 2007). We studied large metasedimentary sequences in the metamorphic terranes of Alpine Corsica, where pristine lawsonite-bearing eclogite and blueschist assemblages are extremely well preserved with limited retrograde overprint (Vitale Brovarone et al., 2013). We performed a detailed field survey and systematic P-T estimates in the country rocks at the regional scale. Our results show that the fluid-rock interactions responsible for the organic C leaching affected a significant amount of the HP-LT terranes of Corsica from a minimum P-T condition of ca. 360 °C and 1.6 GPa to at least 500-550 °C and 2.2 GPa (Vitale Brovarone et al., 2014). These conditions are well comparable with the estimated thermal regimes of active subducting slab in the forearc regions (Syracuse et al., 2010). At these conditions, organic C contained in oceanic sediments is structurally disordered (Beyssac et al., 2002). Mass balance calculations point to significant CO_2 fluxes produced by this fluid-induced bleaching, with implications for C transfer to the forearc wedge. A detailed spectroscopic analysis of the organic matter across the reaction zone points to the selective consumption of the less ordered C component (i.e. monometamorphic organic C) relative to a more ordered component (likely inherited detrital graphitic incorporated in the sediment prior to subduction, (Galy et al., 2008). This selective leaching therefore provide a constrained monitor for organic C devolatilization at subduction zones: this process can be extremely efficient for T below ca. 500-550 °C typical of the forearc regions of subducting slabs where the organic carbon is only partially graphitic, whereas less efficient at higher T in the subarc or postarc regions. The same principle can be applied to organic C incorporated in continental crust, with shallower C devolatilization and deeper C retention.

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Chromium-rich kyanite, magnesiostaurolite and corundum in ultrahigh-pressure eclogites from Pohorje Mountain (Slovenia, Eastern Alps) and Tromsø Nappe (Norway, Northern Scandinavian Caledonides)

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Chromian kyanite, magnesiostaurolite and ruby (corundum) were found in ultrahigh-pressure eclogites associated with metaultramafic rocks (garnet peridotites, serpentinites) from Pohorje Mountains (Eastern Alps) and the Tromso Nappe (Northern Scandinavian Caledonides). The eclogites are composed of primary Mg-rich garnet (48-63 mol% pyrope), omphacite (28 mol% jadeite), phengite (3.45 Si pfu) and kyanite with secondary amphibole (pargasite, magnesiohornblende) and zoisite which are abundant in strongly retrogressed rocks. The concentrations of Cr_2O_3 in kyanite (17.0 wt%), magnesiostaurolite (15.0 wt%) and corundum from this area (up to 12.4 wt%) are the highest Cr values ever reported for these minerals from natural samples.

The Cr-rich kyanite of turquoise-blue colour contains inclusions of chromite (Cr* = 0.74-0.78), Cr-rich magnesiostaurolite (6-15 wt% Cr_2O_3; X_{Mg} = 0.7-0.8), Cr-rich garnet (Cr_2O_3 = 2.0 wt%), omphacite (Cr_2O_3 = 0.5 wt%) and Cr-rich amphibole (Cr_2O_3 = 3.5 wt%). Kyanite is often surrounded by a corona composed of the assemblage Cr-bearing sapphirine (up to 5.5 wt% Cr_2O_3) + corundum + Al-spinel + plagioclase. Blue-green, Cr-rich magnesiostaurolite (5.4-8.5 wt% Cr_2O_3; X_{Mg} = 0.76-0.82) forming up to 500 µm large crystals is associated with Cr-kyanite, Cr-spinel and Cr-corundum (ruby) which are surrounded by pargasitic amphibole and zoisite.

Chromian kyanite, magnesiostaurolite and ruby formed through reactions involving primary chromite derived from a magmatic protolith characterized by high Cr, Mg, Al and low Si, during prograde metamorphism and formation of eclogite at HP-UHP conditions. Chromium enrichment in kyanite, magnesiostaurolite and corundum was controlled by simple substitution for Al in the octahedral sites ($Cr^{3+}Al_{-1}$), and the $Fe^{2+}Mg_{-1}$ and $Mg(OH)Al_{-1}O_{-1}$ substitution mechanisms in magnesiostaurolite. The highest Si content and near absence of tetrahedrally coordinated Al was observed in the most Cr-enriched magnesiostaurolite.

P-T-t evolution of high pressure rocks during an Ordovician arc-continent collision at the margin of Laurentia in Western Newfoundland (Canada)

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Sediments of the Humber margin of Laurentia (Fleur de Lys Supergroup) in western Newfoundland were metamorphosed and exhumed within an exhumation channel during collision with the peri-Laurentian Dashwoods microcontinent. We modelled the metamorphic evolutions for phengite-bearing samples of metabasic and metapelitic rocks in the system SiO_2-TiO_2-Al_2O_3-FeO-O_2-MnO-MgO-CaO-Na_2O-K_2O-H_2O through the calculation of P-T pseudosections with PERPLE_X. These pseudosections were contoured by various modal and chemical parameters of minerals and rocks.

Garnet mica-schist, the main rock type of the Fleur de Lys Supergroup, experienced heterogeneous peak pressure conditions at 16.5-18 kbar, 450-520°C or 10-12 kbar, 450-515 similar to conditions derived from intercalated garnet amphibolite. Eclogite lenses in the mica schist record the highest peak P-T conditions of 18-22 kbar at 570-630°C. The age of this peak was dated by two Rb-Sr mineral isochrons at 458±6 Ma and 459±7 Ma (both calculated with a revised decay constant for Rb, for consistency with U/Pb age data). Both rock types show a clockwise P-T path with a distinct stage of thermal relaxation, i.e. heating during early decompression. We conclude that the clastic sediments of the Humber margin were deeply buried during early collision as a result of southeastward subduction of the intervening oceanic Taconic seaway under the Dashwood microcontinent. The eclogite represents mafic rocks that were somewhat deeper subducted and emplaced within the metasediments during upward-directed forced flow in a subduction channel. The Rb-Sr age recorded by the eclogite is the earliest known age and indicates the initiation of collision. Different peak pressure metamorphic conditions within the Fleur de Lys Supergroup were also the result of forced flow active in the exhumation channel between the colliding plates.

Metamorphic conditions of blueschists in the Mt. Hibernia Schists, Jamaica

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A suite of samples collected from the Mt. Hibernia Schists in SE Jamaica includes metamorphosed P-MOR-type basalt, subvolcanic trondhjemitic intrusions, tuffs and tuffaceous clastic sedimentary rocks, which occur within an Early Cretaceous accretionary prism. Eight characteristic mineral assemblages can be defined within this sample suite involving glaucophane, and rare riebeckite/magnesioriebeckite, winchite, actinolite, pumpellyite, lawsonite, epidote, chlorite, titanite, phengite, albite and quartz. Augite is an important relict phase of the magmatic source rocks. Although four metamorphic facies (pumpellyite-actinolite, greenschist, lawsonite-blueschist, epidote blueschist) are represented, calculated multivariant reactions as well as PT pseudosections indicate similar peak conditions in all rocks at approximately 5.5-7.5 kbar and 270-320°C. In particular, it can be shown that the assemblage glaucophane-pumpellyite-chlorite only occurs in a restricted field along the lower PT-limit of the blueschist facies.

The occurrence of the amphibole winchite is enigmatic, because a miscibility gap between glaucophane and actinolite should exist at these PT-conditions. Although submicroscopic amphibole intergrowth cannot be completely ruled out at present, a case can also be made for metastable growth of winchite below the critical temperature of the gap.

Fabric development and calcic-to-sodic compositional zonation in amphibole are prograde. A calculated model pressure-temperature path based on continuous metamorphic reactions with evolving amphibole solid-solutions show a prograde pressure increase between 200°C/3kbar and the peak conditions. This path is explained either by subduction and involvement in an Early Cretaceous accretionary prism or by a collisional setting related to a major compressive strike-slip fault.

Coseismic UHP metamorphism recorded by eclogite breccias at Yangkou in the Chinese Su-Lu UHP metamorphic belt

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Eclogite pseudotachylytes and breccias from the collisional belts record earthquakes coeval with high-pressure metamorphism (Austrheim & Boundy, 1994; Austrheim et al., 1997; Lund & Austrheim, 2003; Austrheim & Andersen, 2004; John & Schenk, 2006; Angiboust et al., 2012). Recent seismological data show that areas in the deep crust where eclogites may be stable are seismically active (Fountain et al., 1994; Austrheim, 2013). Combined study of orogenic eclogites and deep seismicity may provide insights into the mechanism of intermediate depth earthquake. This approach is based on the popular hypothesis that the high-pressure rocks in orogenic belts are samples of deeply subducted slabs. Most of the existing studies of high-pressure pseudotachylytes, and eclogites in general, suggest that fluid plays a key role in driving high-pressure metamorphism (Austrheim, 1987; Jamtveit et al., 1990; Austrheim et al., 1997; Camacho et al., 2005; John & Schenk, 2006; Austrheim, 2013). Eclogites in fracture zones have been considered to have transformed from basic rocks as a result of fluid infiltration during seismic faulting at depths, while the host rocks away from faults are considered to remain untransformed for being beyond the reach of fluid. Despite the popularity of this hypothesis, abundant mineralogical and petrological evidence casts doubt about the deep subduction/exhumation history of the high-pressure rocks in orogenic belts.

A high- and ultrahigh-pressure (HP and UHP) metamorphic complex occurs on the beach of the Yangkou bay, northeast of the city of Qingdao, China. A block of coesite-bearing eclogite breccia and several eclogite facies cataclasite dykes and veins are recently identified (Yang et al., 2014a, 2014b). The breccia block is thrusted over a coesite-bearing coronitic eclogite, and is gradational to a foliated eclogite at the contact. The coronitic eclogite is characterized by garnet coronas between fine-grained high-pressure mineral aggregates forming pseudomorphs after plagioclase, ilmenite, biotite, and pyroxene in a gabbroic protolith. The breccia consists of fine-grained cataclastic eclogite fragments (garnet + omphacite + coesite/quartz ± phengite ± kyanite) and a coarser-grained matrix schist (garnet + quartz + phengite + kyanite). The foliated eclogite consists of intercalating bands of the cataclastic eclogite and a schist similar to the fragments and the matrix, respectively, in the breccia. The igneous fabric of the eclogitized gabbro is increasingly obliterated from the coronitic eclogite through the foliated eclogite to the breccia. The field context, the locally preserved igneous fabric in the breccia, the similar whole-rock compositions, as well as the complementary mineral assemblages in the fragments and the matrix with respect to the coronitic eclogite, suggest that the breccia was formed by cataclasis and segregation of minerals in a former coronitic eclogite in response to a sudden pressure release. Micropoikilitic amoeboid garnet containing numerous inclusions of omphacite and other high-pressure minerals and fine needles of kyanite are characteristic of eclogite-facies pseudotachylytes and suggests flash melting and rapid crystallization (Austrheim & Boundy, 1994). In the breccia and foliated eclogite, quartz + K-feldspar ± albite aggregates are included in garnet or form strings in the cataclasites. In some aggregates quartz grains are cemented by K-feldspar and a vesicular albite, also implying crystallization from melts in a rapid cooling and decompression process from the UHP condition. The previously reported intergranular coesite from Yangkou (Liou & Zhang, 1996; Ye et al., 1996; Wallis et al., 1997; Zhang & Liou, 1997) is found to occur only in the cataclasites in the breccia and the foliated eclogite. Given that coesite converts to quartz completely in a few years when being cooled and decompressed slowly, it is only possible for the intergranular coesite to survive via a rapid cooling and decompression event. The crystallization of albite from flash melt necessitates a decompression rate from the UHP to crustal conditions that is not compatible by the fastest known exhumation rate of subducted slabs but implies transient UHP metamorphism coeval with the seismic event (Yang et al., 2014a).

Cataclasite dykes and veins with eclogitic mineralogy cut through the variably eclogitized gabbro at Yangkou (Yang et al., 2014b). The dykes (5−15 cm wide) are bounded by mylonite/ultramylonite zones. The cataclasite veins (generally 2−4 cm wide) cutting through the foliation of the high-pressure host rock are free of mylonite boundary zones. The dykes and veins are dominated by eclogite fragments consisting of debris of omphacite, garnet, quartz, phengite, and kyanite, in a matrix of variable amounts of a schist rich in quartz, phengite, and kyanite. Garnet clasts in the fragments are welded and overgrown by more Ca-rich garnet containing different mineral inclusions than those in the garnet cores. The micropoikilitic texture of garnet is typical of eclogitic pseudotachylytes. Crack-sealing K-feldspar veinlets in the cataclasite dykes also imply frictional or shock induced melting of K-micas. The complimentary modal abundances in the cataclasite and the schist imply that the dykes formed by flow of the omphacite and garnet dominated cataclasites into the fractures during seismic faulting, while the lower density minerals (quartz, phengite, and kyanite) were largely left in the ultramylonite boundary zones. The dykes have the same composition as their host rocks, except for slightly lower Si and large ion lithophile elements and higher Mg, Ca, Cr, Co, and Ni. Chromite, probably spurted from the nearby ultramafic rock, is found as rare particles in the cataclasite fragments. This implies that material exchange occurred by mechanical mixing between the dykes and the ultramafic rock during seismic faulting. The Cr-rich eclogite minerals grown on the chromite are evidence for coseismic high-pressure crystallization. Short-lived crystal growth is implied by the fine grain sizes of the eclogite minerals and very limited element diffusion between the garnet clasts and their overgrowths. Thermobarometry shows that the dykes formed at much higher P-T conditions than their host rocks. The fact that the host rocks are more hydrated implies that the dyke formation was not related to fluid infiltration. Both stress and the temperature were only transiently high in the dykes, which have been metastable since they were formed. It appears, therefore, that seismic wave stress was the key factor inducing the high-pressure phase transformation in the dykes.

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Three-dimensional morphological observation of the small fluid inclusion using FIB-XCT technique.

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Fluid inclusions in high-grade rocks are occasionally small, in size up to several microns, and it is difficult to perform detailed studies. We carried out detailed morphological studies on a prograde-stage fluid inclusion, which is observed in a metamorphic quartz vein collected from the Sanbagawa metamorphic belt, southwest Japan (Yoshida and Hirajima, 2012). The studied fluid inclusion was composed of H_2O-NaCl aqueous liquid with the salinity of 7.7 mass%, and CH_4 gas. The inclusion was picked up by using focused ion beam (FIB) system. Then, it was investigated by synchrotron radiation-based high-resolution X-ray computed tomography (XCT) using a Fresnel zone plate at BL47XU in SPring-8. By using FIB-XCT technique, we can perform the detailed three-dimensional morphological study on tiny objects (<10μm) combined with other conventional analytical techniques such as Raman microscopy. XCT image of a reequilibrated fluid inclusion (~7μm in size) draws a faceted shape, which fairly corresponds to the interfacial relationship of α-quartz. This euhedral morphology also satisfies the crystal orientation of the host quartz. The volume fraction of the bubble/liquid determined by 3D-CT image was well in accordance with the values estimated by other methods.

Combining the Raman microscopy and *P-T-V-x* properties of the fluid, densities of liquid and gas phases were estimated separately. Based on the volume fraction and density of each liquid/gas phase, the bulk composition and density of the fluid inclusion were estimated. Since the studied inclusion is trapped during prograde stage and is thought to have experienced the entire decompression and cooling path of the host metamorphic rock, density of the fluid inclusion could have reequilibrated during the exhumation of the metamorphic terrain. The estimated isochore yields *P-T* conditions (ca. 300 ºC/ 0.26 GPa) comparable with the previous *P-T* estimates derived from the decompression and cooling path. This result is consistent with the indicated “density closure temperature” of the quartz (300 ºC: Küster and Stöckhert, 1997). Our result shows that FIB-XCT technique has a powerful potential to perform morphological observation on tiny fluid inclusions of a few microns.

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Deeply subducted crustal environments of sublithospheric diamonds from Sao-Luis (Brasil)

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Diamonds from Sao-Luis river alluvial deposits (Juina, Brazil), are known by their superdeep origin related to recycling of oceanic crust, basalts and pelagic sediments in the lower mantle. Syngenetic inclusions in 59 diamonds from Sao-Luis were represented by phases of superdeep paragenesis as it was described previously. The dominated inclusions are majoritic garnets, ferropericlases, CaSi- and CaSiTi-perovskites, MgSi-perovskites, TAPP, SiO_2 phases, kyanites, AlSi-phases, olivines and Fe-sulfides. Rare inclusions of clinopyroxenes, KFsp (K-hollandite?), CF, NAL, grossular, native iron, magnesite, $CaCO_3$+$CaMgSi_2O_6$ (composite inclusions) have been found in separate diamonds. All majoritic garnets we found are of metabasic affinity and in some cases associated with omphacitic clinopyroxenes.

The studied diamonds from Sao-Luis display wide variations of carbon isotopic compositions ($\delta^{13}C$) ranging from 2.7 to -25.3 ‰. The diamonds with inclusions of ferropericlase have very narrow range of $\delta^{13}C$ values from -2.1 to -7.7 ‰, which are closely similar to the “normal” mantle values. Diamonds with inclusions of majoritic garnet and CaSi- and CaSiTi-perovskites in many cases show marked differences from the expected “normal” mantle values of $\delta^{13}C$ values. Low $\delta^{13}C$ values (-10 to -25‰) have been observed exclusively in a series of superdeep diamonds with calcic-majorite garnets, Ca-silicates, aluminous silicates and SiO_2 from Sao-Luis.

The variations in $\delta^{13}C$ within individual diamonds may be attributed to either different source of carbon or fractionation effect during diamond growth. No correlation of carbon isotope composition and nitrogen content has been found in individual diamonds. It therefore appears that the cores and rims of the Sao-Luis diamonds precipitated from different fluids/melts with variable N/C ratios and/or under different growth conditions. The highly negative $\delta^{13}C$ values in the core (-20 to -25 ‰) potentially represent organic matter in sediments or altered basalts, and the lower $\delta^{13}C$ values may represent mixing trends towards “normal” mantle compositions (Schulze et al., 2004; Harte, 2011). In this study, we have also described a series of diamonds which show opposite trend of change carbon source from primordial mantle to subducted/crustal (either biotic or abiotic carbon).

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Synexhumation anatexis of ultrahigh-pressure metamorphic rocks: Evidence from migmatite and felsic vein in the North Qaidam orogen, northern Tibet

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A combined study of petrology, geochronology and geochemistry was carried out for migmatite and felsic vein from the North Qaidam UHP terrane, northern Tibet. The results demonstrate partial melting of UHP metamorphic rocks in the continental collision orogen during the early exhumation. Migmatized gneisses contain microstructures such as granitic/felsic aggregates, small dihedral angles at mineral junctions and feldspars with magmatic habits, indicating the former presence of felsic melts. Felsic veins inside both eclogite and gneiss exhibit typical magmatic textures such as large feldspar grains with straight crystal faces and granophyric intergrowth of quartz and feldspar, indicating vein crystallization from anatectic melts. These microscopic observations demonstrate anatexis of the UHP metabasite, metapelite and metagranite.

Felsic veins within eclogites are rich either in plagioclase with low normative orthoclase or rich in quartz. In either case, they have low trace element concentrations, with plagioclase-rich veins displaying significant positive Eu and Sr anomalies. Combined with cumulate structures, these veins are interpreted as cumulates precipitated from anatectic melts. Felsic veins hosted by gneisses exhibit similar composition to experimental melts in the An-Ab-Or triangle diagram. They have high trace element contents and parallel patterns to their host in the REE and spider diagrams, with slight positive Eu and Sr anomalies. Thus, they are interpreted as evolved anatectic melts with minor accumulates due to various extents of crystal fractionation. The felsic veins in both eclogite and gneiss exhibit roughly consistent trace element distribution patterns with enrichment of LILE and LREE, depletion of HFSE and HREE.

Anatectic zircon domains from the both felsic veins and migmatites yield U-Pb ages around 420 Ma, younger than peak UHP eclogtie-facies metamorphic event. Combining the petrological observations with metamorphic P-T paths and experimentally constrained melting curves, it is suggested that the anatexis of UHP metamorphic rocks was caused by phengite dehydration melting during the exhumation. Therefore, the UHP metamorphic rocks underwent dehydration melting to produce the anatectic melts with similar trace element patterns to, but different element contents from, magmatic melts that were finally evolved into one pulse of synexhumation granites in the UHP terrane.

New insight into the Earth's Transition Zone: In situ discovery of moissanite, native elements and metal alloys in diamond-bearing chromitites from the Luobusa ophiolites, Tibet

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We report a new *in-situ* discovery of super-reducing ultrahigh-pressure (SuR UHP) assemblages in the Luobusa chromitites, Tibet, and propose two models to explain the origin of the mineral assemblages. The Luobusa podiform chromitites with a thin dunite envelope occur in mantle harzburgite, which consist dominantly of Mg-chromite ((Mg/(Mg+Fe)=0.63-0.76; Cr/(Cr+Al)=0.77-0.84)) + forsterite (Fo_{96-98}) ± diopside. The most common inclusion in chromite is olivine. Olivine inclusion in chromite contains higher NiO than matrix olivine and is similar to kimberlitic olivine in Raman spectrum. Minute inclusions of diopside, Cr-Na-bearing pargasite, Cr-bearing chlorite, lizardite and antigorite are also found in chromite.

In-situ identification of diamond has been reported by Yang et al. (2014). The new *in-situ* identification of SuR UHP assemblages includes: (1) abundant blue moissanite crystals in olivine domains between disseminated chromite grains, which occur as interstitial phase or inclusions in olivine, (2) Fe-Ni alloys with or without Cr impurity (Cr_{0-2}-$Fe_{7-20}Ni_{78-93}$) and Mn-Fe-Cr alloys in chromitite, and (3) rare multiple inclusion pockets in chromite and olivine: such as native Fe and Si in chromite, and moissanite, Si-bearing chromite, wüstite and a few unknown phases in olivine.

Based on our new findings and the literature data (Yang et al., 2007, 2014, review see Liou et al., 2014), such as, (1) both diamond and moissanite separates have the distinct ^{13}C-depleted carbon isotopic compositions ($\delta^{13}C$ = -18 to -35 ‰ for diamond; -22 to -32‰ for moissanite) (Trumbull et al. 2009), (2) the former existence of inferred CF ($CaFeO_4$) structure (P > 12.5 GPa) based on the exsolution lamellae of coesite and pyroxene in chromite (Yamamoto et al. 2009), (3) the presence of SuR UHP mineral separates (Yang et al. 2004) and crustal impurity, and (4) the different ages of PGE sulfides and zircon (Shi et al. 2007; Yamamoto et al. 2013), we propose two tentative models to explain the origin of these UHP minerals.

Model I involves a deep origin and three-stage evolution. In stage 1, olivine, moissanite and some SuR UHP minerals were formed in a highly reducing environment at the top of the transition zone (TZ) or at the mantle depth of 300-400 km. The mantle source at the depths has been contaminated by previously subducted oceanic and continental crusts. Subsequently in stage 2, the chromitite migrated upward by convection and was emplaced into mantle harzburgite. Reaction between the chromitite and the host harzburgite took place. Finally in stage 3, the chromite and host rose to shallow level and underwent hydrothermal alteration. In the model, low-P hydrous phases are interpreted as altered phase after olivine or metastable preservation. Model II involves a deep subduction of the chromitite. In this model, the Luobusa chromitite was initially crystallized at shallow depths like normal chromitites in ophiolite. Subsequently in stage 2, the chromitites migrated downward through subduction or convection to a depth of 120-180 km, where the chromitite recrystallized and trapped some SuR UHP materials derived from the TZ. Finally in stage 3, the chromitites ascended to the crust level by upwelling or exhumation (?).

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Composition of deep continental subduction-zone fluids: the message from migmatic leucosomes and multiphase solid inclusions in UHP metamorphic rocks

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The composition of oceanic subduction-zone fluids was usually deduced from the composition of arc volcanics, whereas a direct study of HP blueschist- and eclogite-facies metamorphic rocks exhumed from subducted oceanic crust only provides information about the mass transfer at shallow depths of <80 km. In contrast, UHP eclogite-facies metamorphic rocks provide us with an excellent target to directly study subduction-zone fluids at subarc depths of >80 km. Migmatic leucosomes and multiphase solid inclusions (MSI) are common in UHP metamorphic terranes. In terms of their occurrence, composition and age, they are inferred to represent the crystallized products of anatectic melts during collisional orogeny. Geochemical analyses of them provide a proxy for the composition of anatectic melts under HP to UHP conditions. The results are delineated by plotting the calc-alkalinity index (MALI = $NaO+K_2O-CaO$ in weight percentage) against SiO_2 content and Si/Al ratios (molar SiO_2/Al_2O_3) against (Na+K)/Al ratios [molar $(Na_2O+K_2O)/Al_2O_3$].

Leucosomes inside UHP eclogites from North Qaidam (west-central China) exhibit large variations in composition, with SiO_2 = 57.49 to 78.38 wt%, Al_2O_3 = 12.46 to 20.60 wt%, MALI = –3.22 to 5.86 and A/CNK = 0.68 to 1.26, Si/Al = 2.39 to 5.34 and (Na+K)/Al = 0.22 to 0.77. Despite the variation from tonalitic to granodioritic to granitic, the composition of leucosomes is predominantly calcic. The leucosomes exhibit significant enrichment of LILE and LREE but depletion of Nb, Ta and HREE in the primitive mantle-normalized spidergrams. This generally resembles the distribution patterns of trace elements in common arc volcanics. Nevertheless, the leucosomes exhibit very large variations in trace element ratios, e.g., from 24 to 1950 for Sr/Nd and from 0.21 to 25 for Th/U.

Different sizes of felsic MSI in the garnet of UHP eclogites from the Dabie orogen (east-central China) exhibit very large variations in composition, with SiO_2 = 63.78 to 94.43 wt%, Al_2O_3 = 1.89 to 18.26 wt%, MALI = 0.19 to 15.21, A/CNK = 0.18 to 1.54, Si/Al = 2.86 to 42.40 and (Na+K)/Al = 0.48 to 3.30. While large MSI tend to exhibit high alkali contents, small MSI generally show high SiO_2 contents. The elevated SiO_2 contents but highly variable Al_2O_3 contents are attributable to the occurrence of almost single quartz phase in the MSI. This is particularly so for the small MSI that exhibit significantly higher Si/Al and (Na+K)/Al ratios than the experimentally defined fields for hydrous melts and supercritical fluids, suggesting their precipitation from fluids rich in silica and alkalis. Trace element analyses of MSI in the garnet of Dabie eclogites show patterns with depletion of HFSE but more enrichment of LILE than LREE. Nevertheless, the MSI also exhibit very large variations in trace element ratios, e.g., from 0.37 to 1333 for Sr/Nd and from 0.05 to 2.54 for Th/U.

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