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INTERNATIONAL LITHOSPHERE PROGRAM (ILP)

Proposal for new Task Force: 2015-2019

“FATE OF THE SUBDUCTED CONTINENTAL LITHOSPHERE: INSIGHT THROUGH ANALYTICAL MINERALOGY AND MICROSTRUCTURES”

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Scientific rationale and objectives. The subduction of the continental lithosphere into Earth's interior leads to dramatic changes in the dynamics of the mantle as well as seismic and volcanic activities at the convergent systems. The geological processes that resulted from the continental crust-mantle interaction are complex and diverse and may evolve into different scenarios. One well-accepted model is that the Si-rich continental material keeps subducting into the mid-upper mantle where it is subjected to partial melting, thus causing volcanic events. However, experimental studies have shown that a part of the crustal material that delaminated and avoided melting may be modified to become denser than surrounding mantle. The latter “sunk down” into the mantle transition zone, and possibly the lower mantle, to stagnate for a long geological time. High-pressure experiments showed that the “average continental crust” will be denser than the surrounding mantle by $\sim 0.20 \text{ g/cm}^3$ at depth $\sim 410 \text{ km}$, whereas with increasing pressure at depth $\sim 660 \text{ km}$, the “average continental crust” becomes slightly less dense than mantle rocks at $\sim 0.15 \text{ g/cm}^3$ (Nishiyama et al., 2005; Dobrzhinetskaya & Green, 2006). Therefore, the 660-km seismic discontinuity zone can be considered a place where continental materials can stagnate. Because samples of rocks at that depth are not directly accessible, studies of small fragments such as xenocrysts, xenoliths, or geochemical and mineralogical anomalies containing records of a crust-mantle interaction are first-order questions for modern geosciences.

It is now believed that only very small fragments of the continental materials of a specific composition will reach 660-km seismic discontinuity and stagnate there, as well as in the neighboring horizons of the lower mantle. These fragments will eventually be assimilated into the mantle minerals, or preserved as tiny xenocrysts within them. Through the mantle convection, the relicts or remnants of the modified crustal materials are re-distributed within different geological settings and eventually may be delivered to the Earth surface through deep volcanisms, mantle plumes, tectonic exhumations, etc (e.g. Dobrzhinetskaya et al., 2014; Sumino et al. 2011).

The minerals and microstructures indicative of ultrahigh pressure (UHP) conditions and phase transformations in a variety of tectonic environments represent a new insight into an understanding of the fate of the subducted continental lithosphere. The number of tectonic settings in which new UHP minerals have been discovered is no longer limited only by orogenic belts. During the last five years, the numbers continue to grow and an interdisciplinary approach is required to understand how the fragments of the continental lithosphere are “amalgamated” with the mantle.

We propose a new Task Force project to make breakthroughs in studying integrated processes that lead to the mineralogical-geochemical assimilations of the continental lithosphere that was subducted to the deep Earth's interior. These studies will provide a foundation for understanding first-order problems that will advance modeling of the larger scale processes related to plate tectonics and deep geophysics. Multidisciplinary in nature, the project will

integrate efforts of geologists from the U.S., China, Germany, Israel, Bulgaria, S. Korea, Canada, and Russia. The new Task Force will have also a strong intellectual connection to well-established interdisciplinary organizations such as the International Geological Correlation (IGCP), the Consortium of Materials Research in the Earth Sciences (COMPRES), the Deep Carbon Observatory (DCO), and The Asian Network in Deep Earth Mineralogy (TANDEM). Together, we will promote the advancement of experimental and computational studies on physical properties, structures, dynamics, and evolution of the Earth's deep interior.

GOALS AND SCOPES OF THE NEW TASK FORCE

Goals. The new Task Force project will be focused on the wide range of phenomena and processes that help to understand the fate of the continental lithosphere subducted to the deep Earth's interior. The project would attempt to answer first-order fundamental questions in regard to the depth at which the subducted continental lithosphere was stagnated, how its fragments could be recognized if the continental rocks are modified at high pressure and high temperatures, and if the relict fragments occur within non-traditional geological environments. The project outlines frontier questions of modern geology, geodynamics, and geophysics and solutions that require integration of new experimental technologies, achievements in modern geophysics and mineral physics, state-of-the-art analytical instruments, and modern synchrotron facilities. Analytical mineralogy in combination with petrology and geochemistry, mineral structures, phase transformations, rheology, microstructures, and modeling of different scales will be instrumental in understanding the mantle geodynamics behind the ultra-deep subduction of the continental lithosphere.

The goal of the project fits the mission of the ILP, which promotes interdisciplinary studies to build larger observational and experimental modeling platforms for understanding the mantle dynamics through the fate of the subducted lithosphere as well as its deformational and mineralogical-geochemical evolution.

Scope #1. Light elements as indicators of the continental lithosphere assimilated into the mantle. Light elements such as carbon, nitrogen, hydrogen, oxygen and others, including their volatile derivatives (e.g., CO₂, CH₄, N₂O, C₂F₄ and others) can be sequestered by mantle rocks and minerals due to the assimilation of the continental lithosphere into the Earth's mantle. On a larger scale, these elements, being chemically bonded in the structure of high-pressure minerals, may drastically change the mantle's physical properties followed by formation of some regional seismic discontinuities, similar to that described in the Alps (Nita et al., 2011). On the other hand, during decompression of high-pressure phases due to the uplift through the mantle convection and tectonic exhumations, the light elements can be liberated and they may lower solidus temperatures, viscosities, and plastic deformation features of the bulk rocks. Moreover, the light elements' dissolution into the grain-boundary melts may promote more rapid mantle convection, return flows, mantle plume formations, and mantle de-volatilization. A better understanding of these phenomena requires high-resolution analytical studies of mineral microstructures and small inclusions of liquid and solid matter trapped by high-pressure minerals during crystallization.

Scope #2. Geophysical aspects of carbon and nitrogen. Both the elements of carbon and nitrogen are considered hypothetical candidates that account for the density deficit of the Earth's core. The reason for such a hypothesis is that seismic S-waves travel through the Fe-Ni inner core of the Earth at about half the speed expected for most Fe-Ni alloys measured under relevant pressure in a laboratory setting. Contrary to the traditional concept that the gap in seismic S-wave velocities can be attributed to the presence of liquid in the inner core, more recent models

consider that light elements, including C, N, S, Si, O and H (or one of all), should be added to the existing Fe-Ni compositional model of the inner core to satisfy the seismic-velocities record (e.g. Chen et al., 2014). Studies of carbide and nitride group minerals in the natural environment as well as in a laboratory will help to determine what kind of light elements better fit S-wave velocities during their travel through the Earth's inner core.

Scope #3. Isotope chemistry of C and N as an indicator of the fate of the subducted continental lithosphere. Since the range of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ measured in many geological complexes allow researchers to distinguish (with some degree of approximation) the “crustal” (shallow) reservoirs from their mantle counterparts, both elements are important for a search of the continental lithosphere relicts that reside within rocks of the Earth's mantle. For understanding the assimilation of crustal C and N into the mantle by creating new ultra-high pressure minerals or through incorporation into well-known mantle high-pressure phases, we need to observe the natural minerals and to continue experimental modeling of conditions leading to the mixing of crustal and mantle materials. Moreover, consideration of the global carbon and nitrogen cycles has traditionally been focused primarily on near-surface, low-temperature reactions. This knowledge has been limited by the assumption that the oceans, atmosphere, and shallow surface and oceanic sediments represent a “closed system” with respect to biological carbon and “continental” nitrogen. However, new findings of carbides and nitrides in different terrestrial sources have changed this paradigm and demanded a reappraisal of the “fluctuating” role of carbon, nitrogen, and other volatiles as a flux that could trigger chemical reactions and control light elements in regards to (1) partition between solid and melt, and (2) strengthen mineral plastic flows in the deep Earth.

Scope #4. A new focus on studies of terrestrial minerals of the carbide and nitride groups. Although carbides and nitrides are accessory minerals, their presence within rocks of the mantle environments has not been fully appreciated until the recent discoveries of moissanite (SiC) and cBN within a mantle section of ophiolite formation (Yang et al., 2007; Dobrzhinetskaya et al., 2014). Both groups of minerals have a lot to offer in understanding the deep mantle's state of oxidation, and if carbon and nitrogen constituents in both groups belong to only crustal, or mantle, or mixed reservoirs. Carbides and nitrides may be formed only in environments with a high deficiency of oxygen, and pressure and temperature are considered the varying factors.

Moissanite (SiC) is traditionally considered a high-pressure mineral whose formation requires extremely reduced conditions of 4.5–6 log units below the IW fugacity buffer. Most moissanites are found as inclusions in diamonds and as xenocrysts in kimberlites, in ophiolitic chromitites, peridotites, and in metasomatic rocks with references to their mantle origins (for review see: Shirayev et al., 2013). We will continue to study in detail one of the new moissanite deposits in Israel that is connected to interplate alkali basalts magmatism (Mukhin et al., 2015).

Qingsongite (cubic BN). Our recent discovery of a new mineral qingsongite, cubic BN (sphalerite/zincblende structure), in the mantle section of the Tibetan ophiolite, showed that this mineral has a mixed “parentage”—boron has a crustal origin, whereas nitrogen ($\delta^{15}\text{N} = -10.4 \pm 3$ ‰) is most likely from the mantle (Dobrzhinetskaya et al., 2014). This mineral was crystallized under highly reducing conditions accompanied by high pressure (10–15 GPa) and high temperature (~1300 °C) at the depth > 250–300 km. Such a combination is not a surprise for a crustal material that was, at least once, deeply subducted and then exhumed back to shallow Earth levels. The occurrences of cBN in association with osbornite (TiN), coesite pseudomorphs of stishovite, moissanite and coesite exsolution lamellae in chromium spinel in the Tibetan ophiolite

mantle section, have important implications for understanding the assimilation processes of the continental material into the mantle (e.g. Dobrzhinetskaya et al., 2009; Yang et al., 2007).

Scope #5. Experimental exploration of the stability fields of carbides and nitrides. Both of the SiC and cBN compounds were first synthesized in laboratories and only later discovered as minerals in the Earth's geological formations. SiC and BN are extremely valuable technological materials for electronics and ceramics and were industrially produced at a wide range of high temperatures (1200–2500 °C). Experiments on both materials at high pressures are very rare, although it is known that some polytypes of SiC remain stable at pressures up to 100 GPa (Yoshida et al., 1983), while cBN is stable at pressure > 22 GPa. Recent experiments (Schmidt et al., 2014) have shown that SiC can be formed from an ultra-reduced fluid at T = 700–800 °C, and its formation in experiments does not reflect any equilibrium with the surrounding host rocks. The new experimental programs with diamond-anvil cell, multianvil, and piston-cylinder apparatus techniques will address this controversy in the future.

Scope#6. The use of state-of-the-art microanalytical techniques and synchrotron-related technologies for mineralogical studies. The Task Force will continue to promote advanced electron microscopy, synchrotron-related X-Rays, and other spectroscopic methods. The growing field of nanoscale geoscience has already demonstrated the importance of establishing a profound correlation between results obtained with synchrotron light sources, focused ion beam (FIB), high-resolution transmission scanning electron microscopy, secondary ion-mass spectrometry (nano-SIMS) and other techniques. Our new Task Force will promote knowledge and explain the scientific importance of these instruments and techniques to students and colleagues through collaboration with the above mentioned interdisciplinary organizations.

Administration of the Project. The new Task Force office will be established at the University of California at Riverside. A website will be developed that describes the project and make it available to the scientific community. Meetings among the active members will be held once a year during official large conferences and workshops. Between the meetings, the chairperson and the coordinator of the project will communicate with active members and ILP administration via e-mail, fax, and telephone.

Short - and Long-Term Activities:

1. Organizing workshops and special sessions at international meetings for scientific exchanges and discussion, and encouraging participations of the graduate students.
2. Publish new developments and achievements in Books, Special Volumes, and international scientific journals.
3. Circulating information by setting up an electronic mailing list and a webpage. Strengthening the relationship with other programs such as IGCP, COMPRES, DCO and TANDEM in order to better understand continental and mantle dynamics.

REFERENCES

Chen et al., 2014, *PNAS* 111:17755–17758; Dobrzhinetskaya & Green, 2007 *J. Met.Geol.* 25:83-96; Dobrzhinetskaya et al., 2009, *PNAS* 106:19233-19238; Dobrzhinetskaya et al., 2014, *Am. Miner.* 99:764-772; Mukhin et al., 2015, *Goldschmidt Conf., Abstracts*; Nita et al., 2011, *Phys. Earth & Planet. Inter.* 206-207:1-15; Nishiyama et al., 2005, *Phys. Chem. Minerals* 32:627–637; Shirayev et al., 2011, *Lithos* 123:152-164; Schmidt et al., 2014, *Progr. Earth Planet.* 1:27; Yang et al., 2007, *Geology*, 35:875-878.

CURRICULUM VITAE

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EDUCATION

Doctor of Science (geology/mineralogy). Supreme Commission of Education, Moscow, 1990

Ph.D (mineralogy/geophysics) Institute of Geology & Geochronology, S.-Petersburg, Russia, 1982

Diploma (M.S.-B.S. in structural geology) S.-Petersburg University, Russia, 1978

ACADEMIC POSITIONS:

1998-present – Professor (Step VI), Research Geophysicist, Institute of Geophysics and Planetary Physics; Department of Earth Sciences, UC Riverside

2004-2005, International Scholar – JSPS Fellow, Waseda University, Tokyo, Japan

1998-1999, Center for Materials Science, Los Alamos National Laboratory, New Mexico

1993-1998, Research Geophysicist, Institute of Geophysics and Planetary Physics, UCR

1992-1993, Senior scientist. Geological Survey of Norway, Trondheim, Norway

1991-1992, Lecturer. Faculty of Geology. Moscow University, Russia

1984-1992, Leading Scientist. Institute of the Lithosphere. Russia

1978-1984, Leading Scientist, Scientist, Junior Researcher, Institute of Physics of the Earth,

GUEST LECTURES given at following institutions (last 5 years):

Annenberg Educational Center, USA (2014), Carnegie Institution of Washington – Geophysical Laboratory (2013); University of British Columbia, Canada (2013); University of Colorado, Boulder, USA (2012); Syracuse University, New York, USA (2012); Gemological Institute of America (2011); Mineralogical Society of South California, Pasadena, CA (2011); Charles University, Czech Republic, Prague (2010), China University of Geosciences, Wuhan (2010).

HONORS and FELLOWSHIPS

Fellow of Mineralogical Society of America

Fellow of American Association for Advancement in Science

Fellow of Geological Society of America

Fellow of Japanese Society for Promotion in Science

Distinguished Researcher Award, 2001, UC Riverside

Recipient of Fellowship from the Los Alamos National Laboratory, 1999

Recipient of Fellowship from Norwegian Council for Scientific and Industrial Research, 1993

Goldschmidt's Lecture Series (GLS), Invited Lecture, Trondheim, Norway, 1996

PROFESSIONAL ACTIVITY:

Editorial Board member: *Journal of Metamorphic Geology*, *Journal of Earth Sciences*, *Springer*.

Editor of Books: 1. *Ultra-high Pressure Metamorphism: 25 year after discovery of coesite and diamonds in collisional belts*. Elsevier, 2011, pp500. 2. *Advances in high-pressure technology for geophysical applications*, Elsevier, 2005, pp.511.

Author of the text Book: *Minerals and Human Health*. Cognella, 2015, pp.475.

Invited Editor for Spec.Volumes: *Gondwana Research*, 2011; *J. Earth Sciences*, 2010; *J. Met. Geol.*, 2011, 2009, 2006; *Lithos*, 2009, 2007.

Member of the MSA and GSA Committees of the "Best Student in Research" (2007-2012).

Chair of Education and Outreach Committee, AGU, 2009-2010; member: 2004-2008.

Chair of Task Force IV, International Lithosphere Program, 2010-2014; 2005-2009.

Vice-chair of the Mineral Equilibrium Group, IMA (2010-2014).

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EDUCATION:

- 2001-2005 Ph.D., Department of Earth Sciences, University of California, Riverside, USA, Supervisor: Dr. Harry W. Green II
- 1997-2000 M.S., School of Earth Sciences, China University of Geosciences at Wuhan, P.R. China
- 1993-1997 B.S., School of Earth Sciences, China University of Geosciences at Wuhan, P.R. China

ACADEMIC POSITIONS:

- 2014.05-present Associate Dean, School of Earth Sciences, China University of Geosciences, Wuhan
- 2013.05-present Chairman, Department of Structural Geology, School of Earth Sciences, China University of Geosciences, Wuhan
- 2008-present Professor, School of Earth Sciences, China University of Geosciences
- 2008-2013 “Hubei Chutian Scholar” Professor, School of Earth Sciences, China University of Geosciences
- 2007-2008 Associate Professor, School of Earth Sciences, China University of Geosciences
- 2006-2008 Postdoctoral research fellow, Tectonophysics Laboratory, Department of Earth Sciences, University of California at Riverside

SCIENTIFIC SERVICES:

- 2010-2014 Vice Chair, Task Force IV, International Lithosphere Program
- 2010-present Vice Director, Committee of Experimental Mineralogy, Petrology and Geochemistry, Chinese Society of Mineralogy, Petrology and Geochemistry
- 2012-present Associate Editor-in-Chief, Journal of Earth Science
- 2012-2013 Guest editor, Gondwana Research special volume on HP/UHP terranes
- 2010-2011 Editor, Journal of Earth Science

PUBLICATIONS:

More than 33 peer-reviewed publications in international journals.