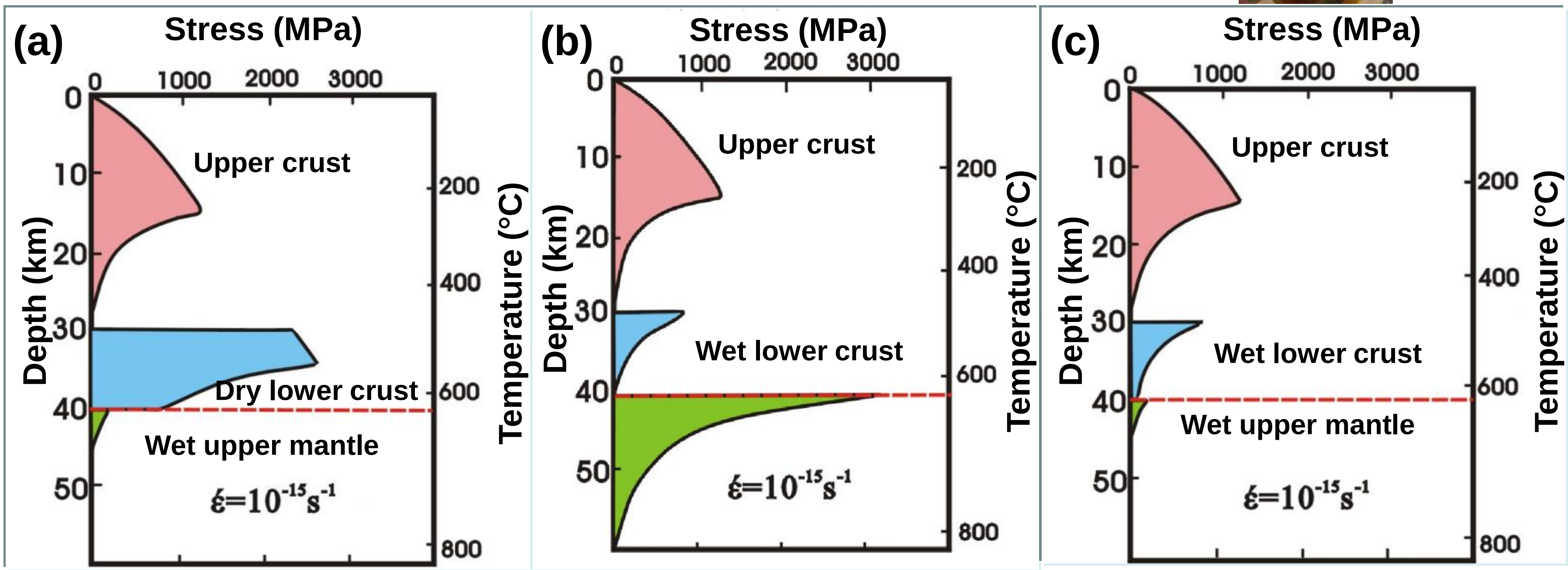
EGU2020-22134

Water Content, Deformation and Seismic Properties of the Lower Crust Beneath the Siberian Craton: Evidence from Granulite Xenoliths

Qin Wang[1], Tianlong Jin[1], Vladislav Shatsky[2,3]

1. State Key Laboratory for Mineral Deposits Research, School of Earth Sciences and Engineering, Nanjing University, Nanjing 210046, China
2. Sobolev Institute of Geology and Mineralogy, Koptyuga 3, Novosibirsk 630090, Russia
3. Novosibirsk State University, 2 Pirogova St., Novosibirsk 630090, Russia

Water content in the lower crust: the key for the crust-mantle coupling



Banana split | **Jelly sandwich** | **Crème brûlée**

Weak-strong-weak

Bürgmann & Dresen, 2008

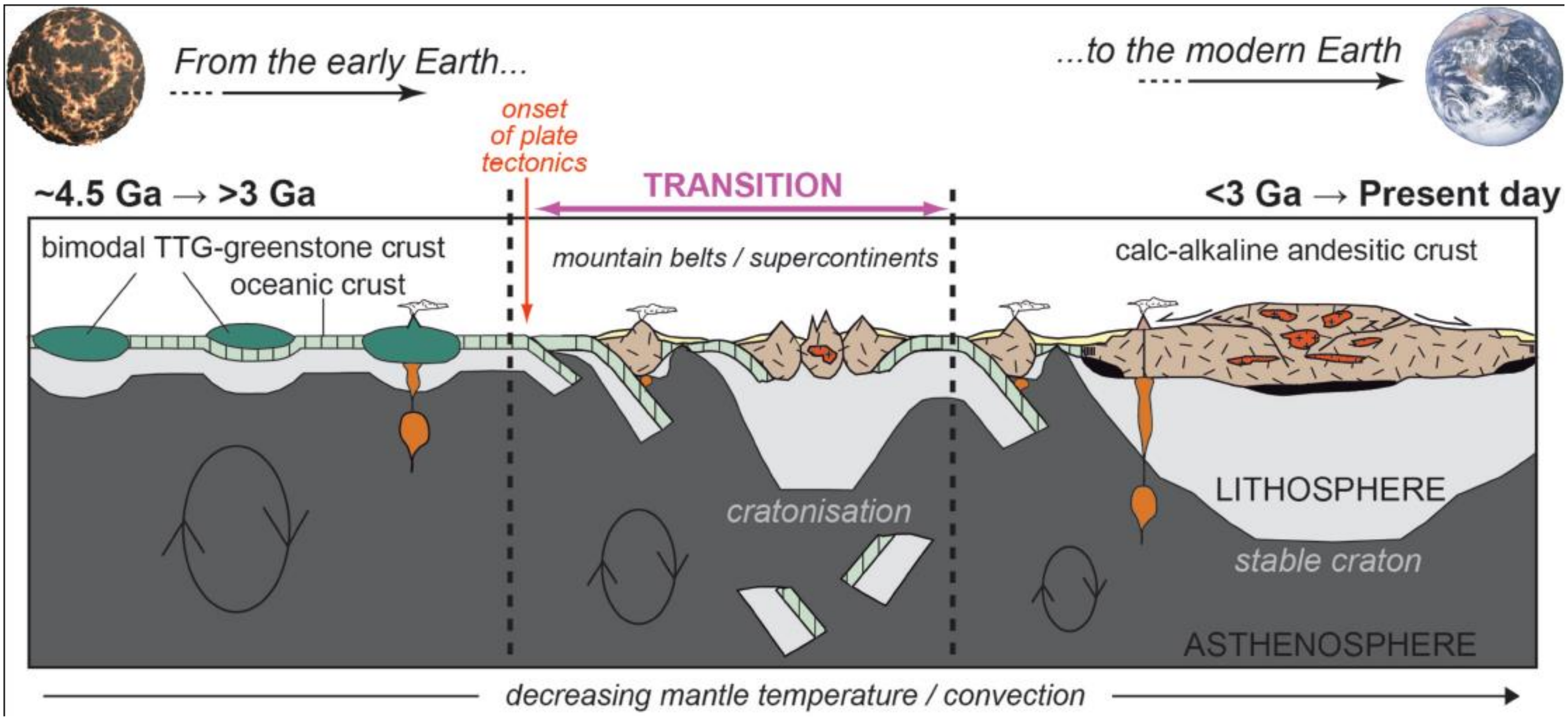
Strong-weak-strong

Brace & Kohlstedt, 1980;
Ranalli & Murphy, 1987;
Kohlstedt et al., 1995

Strong-weak-weak

Burov & Watts, 2006;
Jackson, 2002;
Jackson et al., 2004

Composition of new continental crust and formation of cratons



Dhuime et al. (2015)

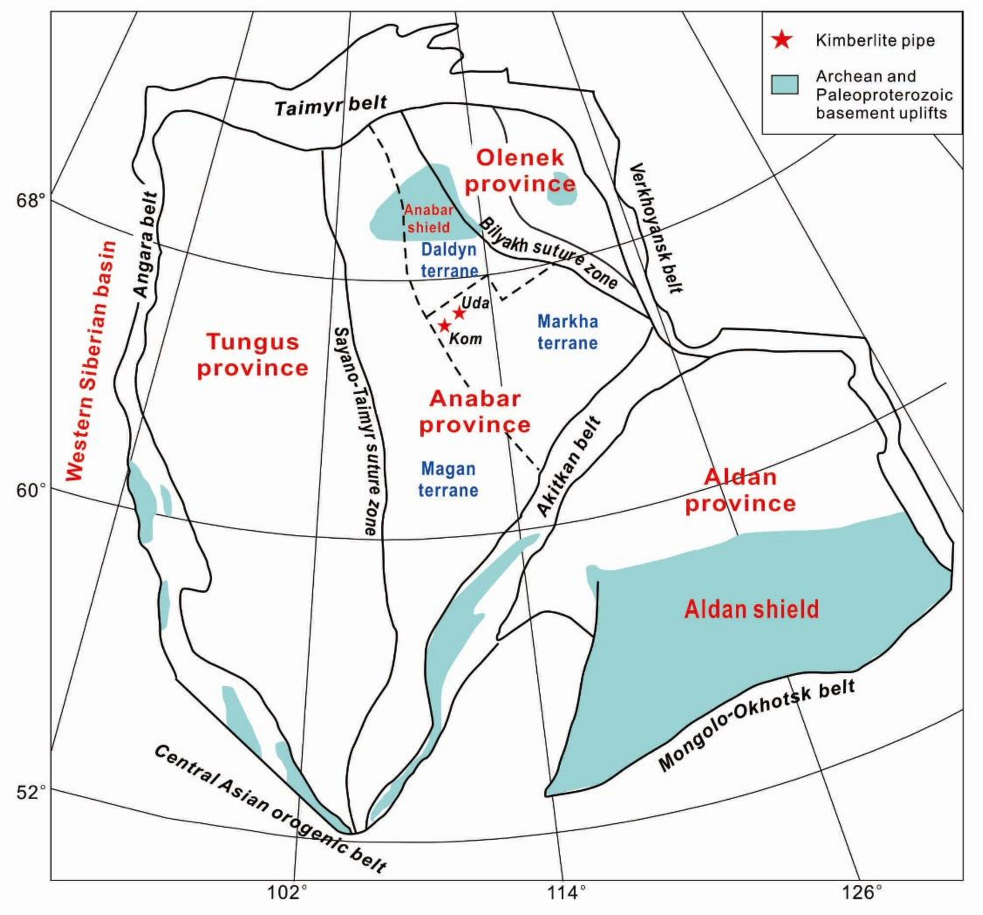
Large igneous provinces (LIPs) can be traced back to 3.79 Ga

(Isley and Abbott, 1999, 2002; Ernst and Buchan, 2001)

Objectives

- How to keep the long-term mechanical coupling between the lower crust and upper mantle over geologic time and in different tectonic settings?
- Can we trace spatial and temporal changes in water content in the lower crust?
- What is the role of magma underplating (heat & dehydration) in the stability of cratons?
- Will water content affect fabrics and seismic anisotropy of granulites?

Kimberlite-brought granulite xenoliths from the Siberian craton

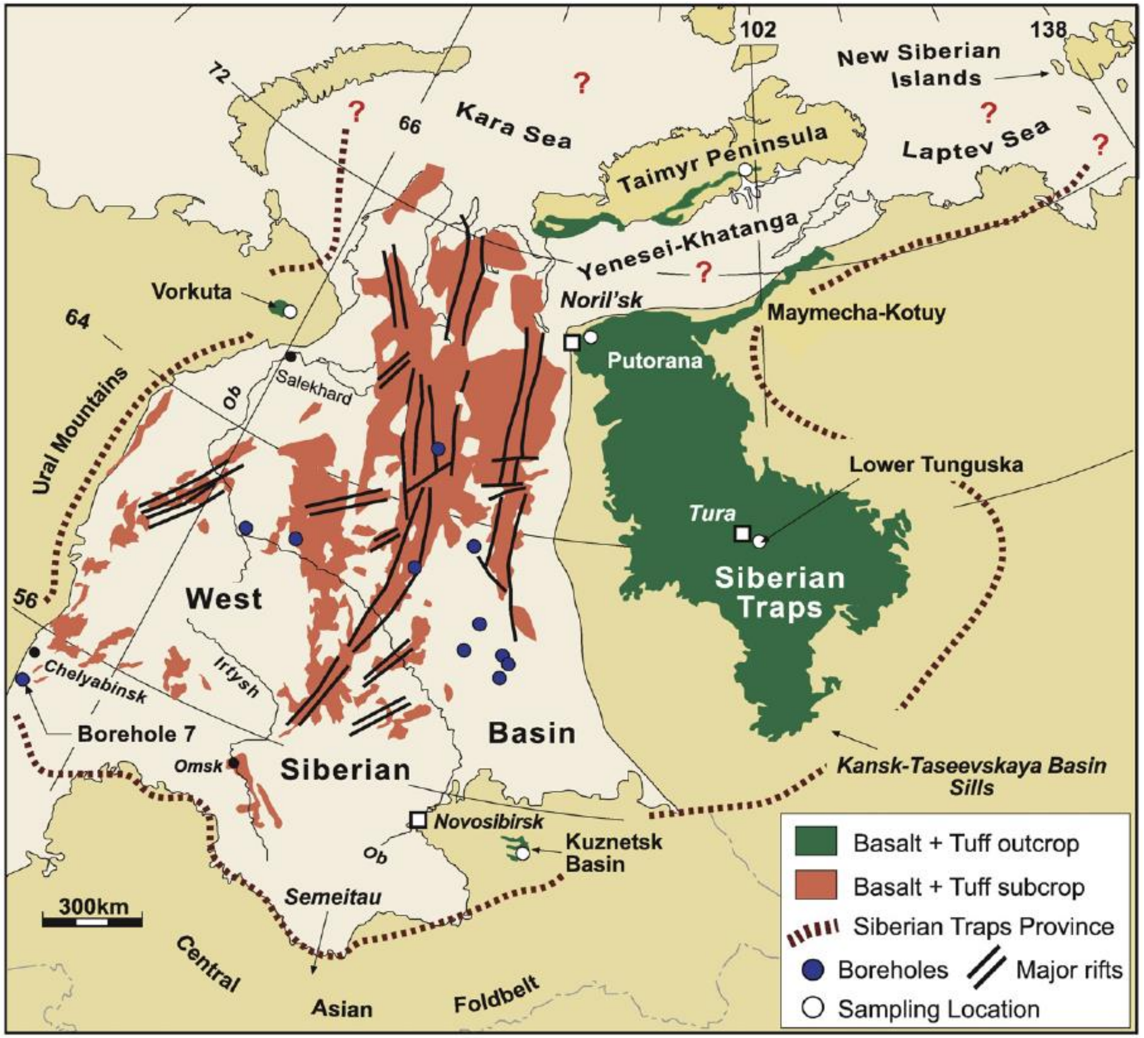


- Crustal formation: 3.4–3.1 Ga (Poller et al. 2005; Gladkochub et al. 2009)
- Thermal events: 2.9–2.8, 2.6, 2.4, 1.97 and 1.8 Ga
- Final assemblage at **1.9–1.8 Ga**
- Crust-mantle coupling since Paleoarchean (Shatsky et al., 2019)

- **16 granulite xenoliths from diamond-bearing Udachnaya and Komsomolskaya kimberlite pipes**

- **Eruption in the Late Silurian** (Kinny et al., 1997; Agashev et al., 2004)

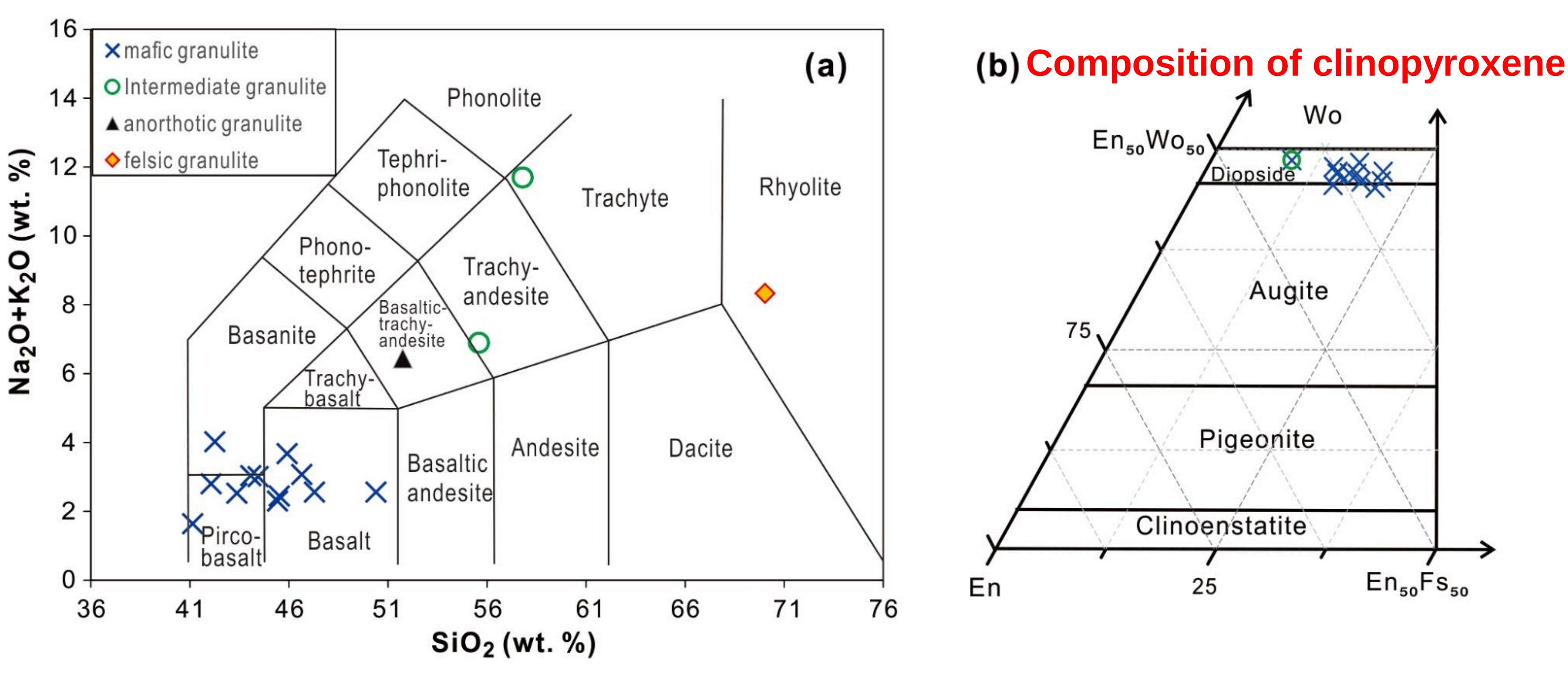
The Siberian Traps large igneous province



- **Timing: 250.3±1 Ma**
- **Extent: over an area of up to 5 million km^2**
- **Consequence: the end-Permian mass extinction**

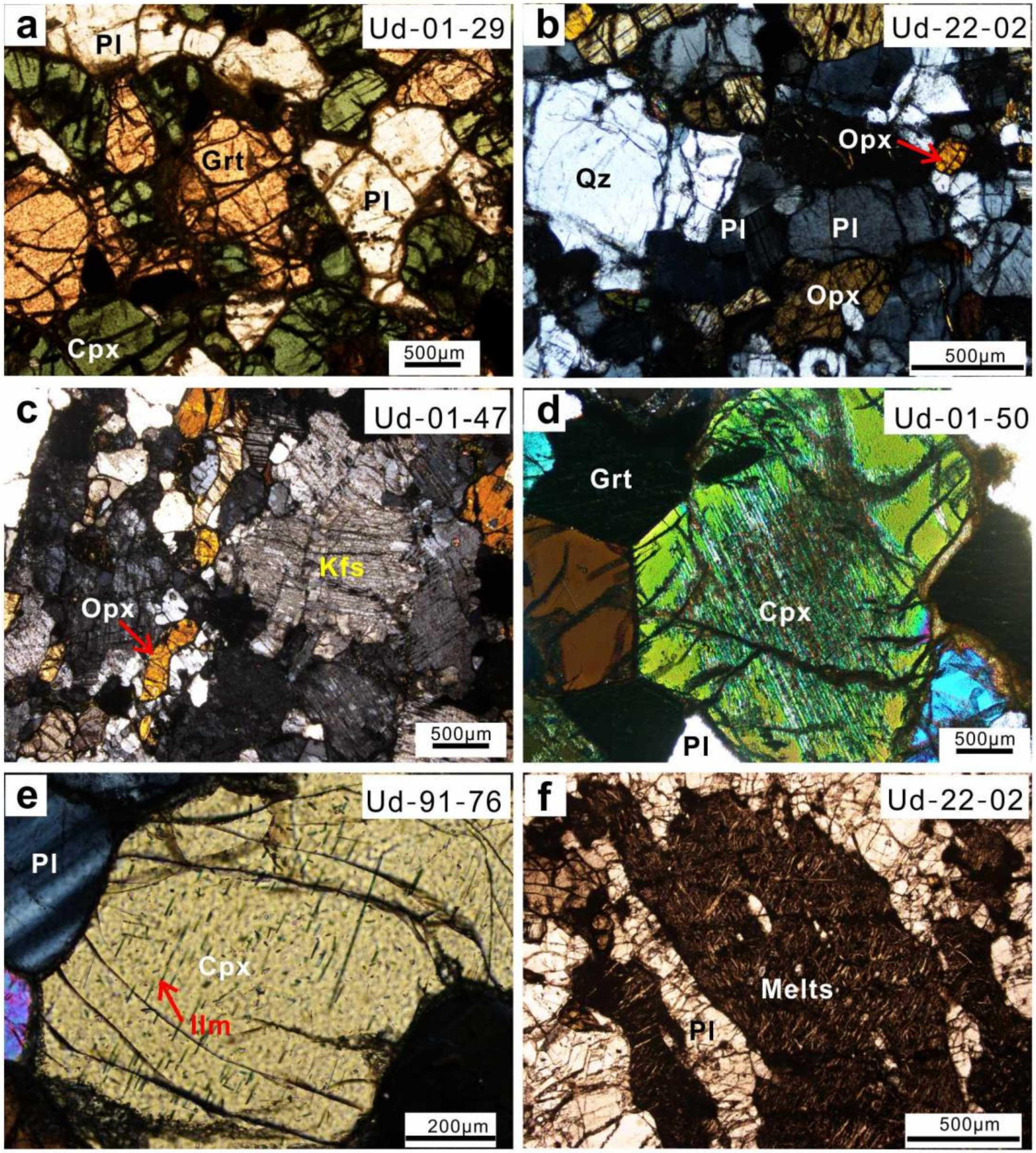
(Richow et al., 2009, EPSL)

Total alkali-silica petrochemical diagram



- Udachnaya pipe: 11 mafic granulites, one anorthositic granulite, two intermediate granulites, and one felsic granulite
- Komsomolskaya pipe: mafic granulite sample K-400-05

Microstructure of typical granulite samples



(a) Mafic granulite

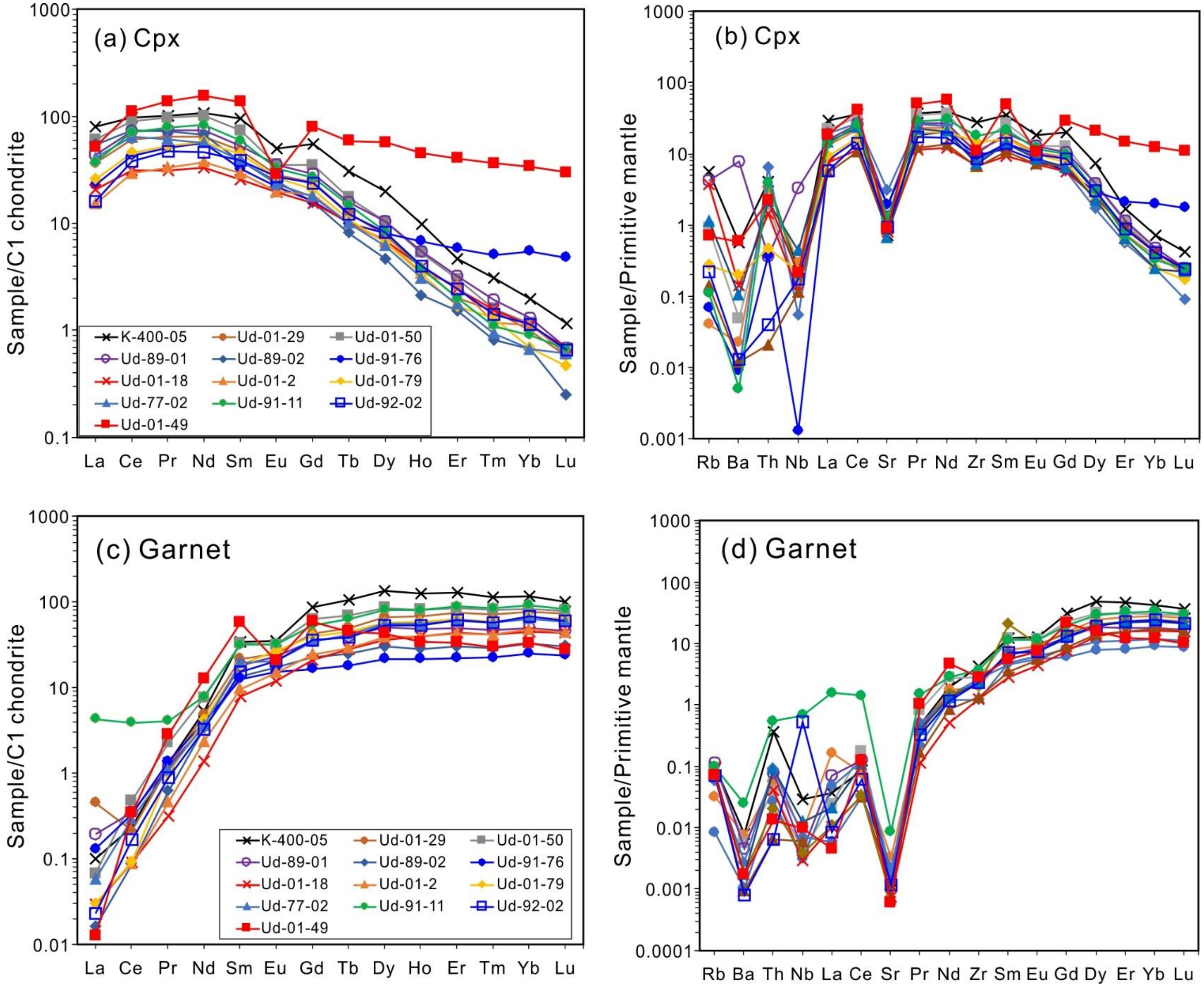
(b) Intermediate granulite

(c) Felsic granulite

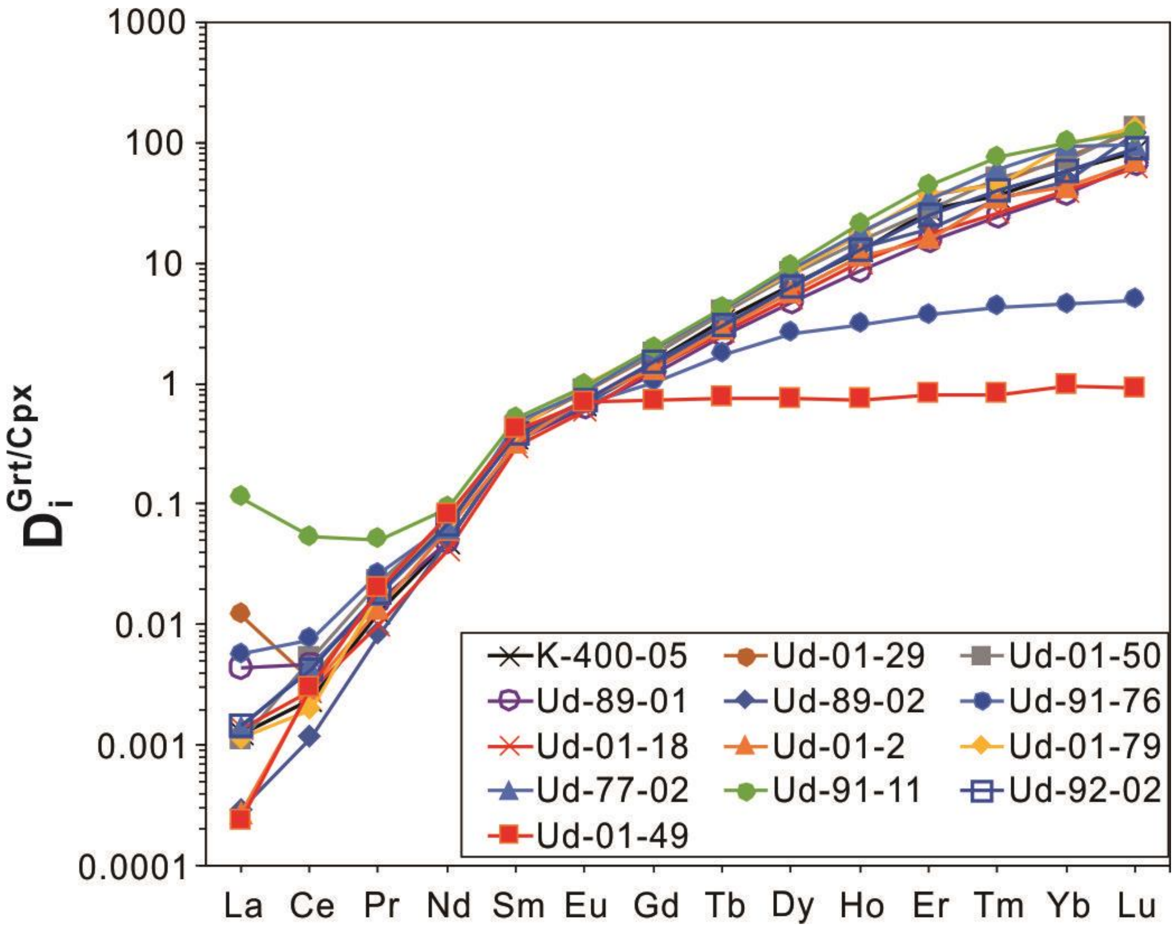
Exsolution lamellae of (d) orthopyroxene and (e) ilmenite needles in clinopyroxene from mafic granulites

(f) melts in intermediate granulite

Patterns of REEs and trace elements in clinopyroxene and garnet



Partitioning coefficients of REE between garnet and clinopyroxene



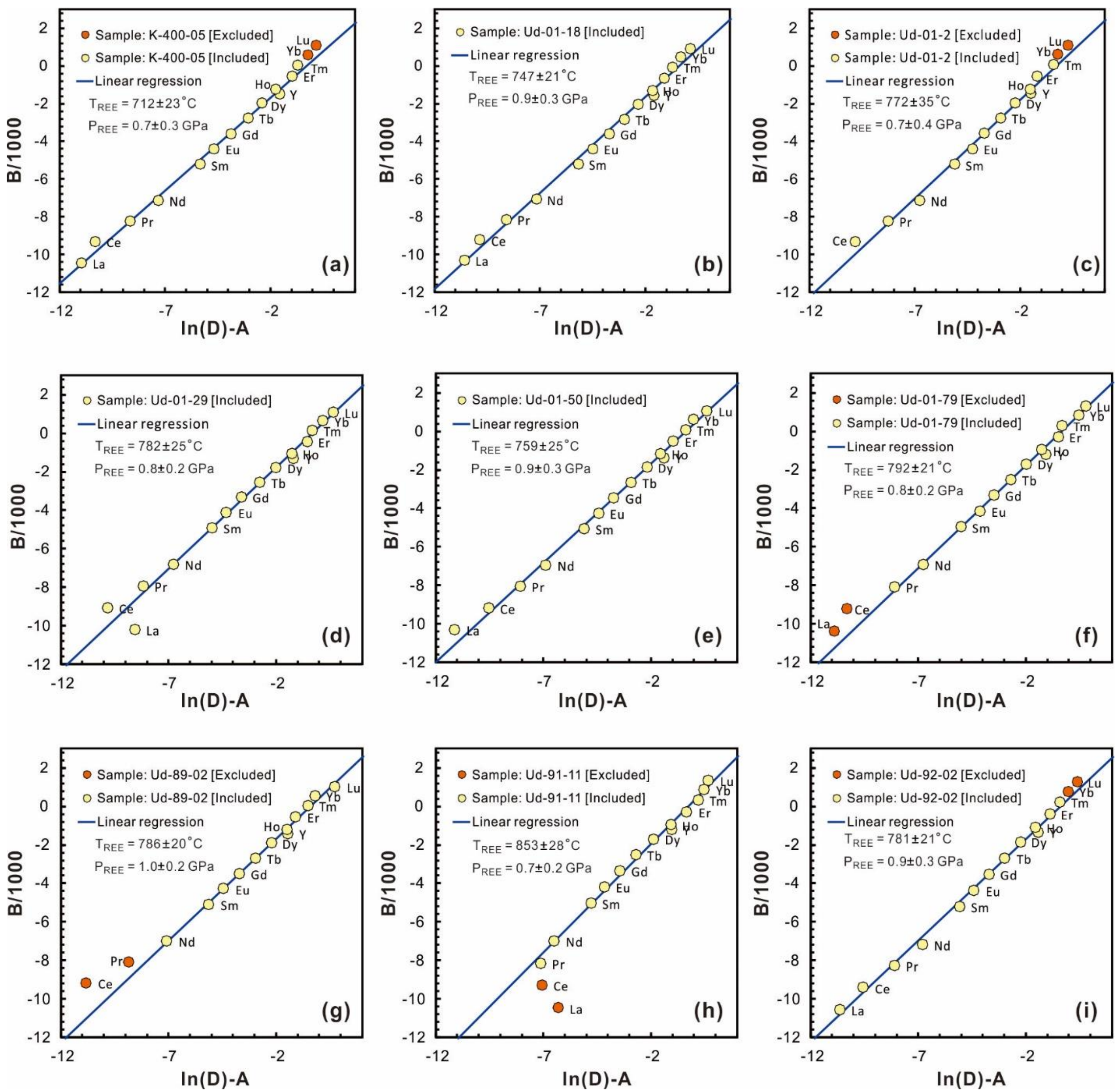
Secondary alteration

Ud-91-76

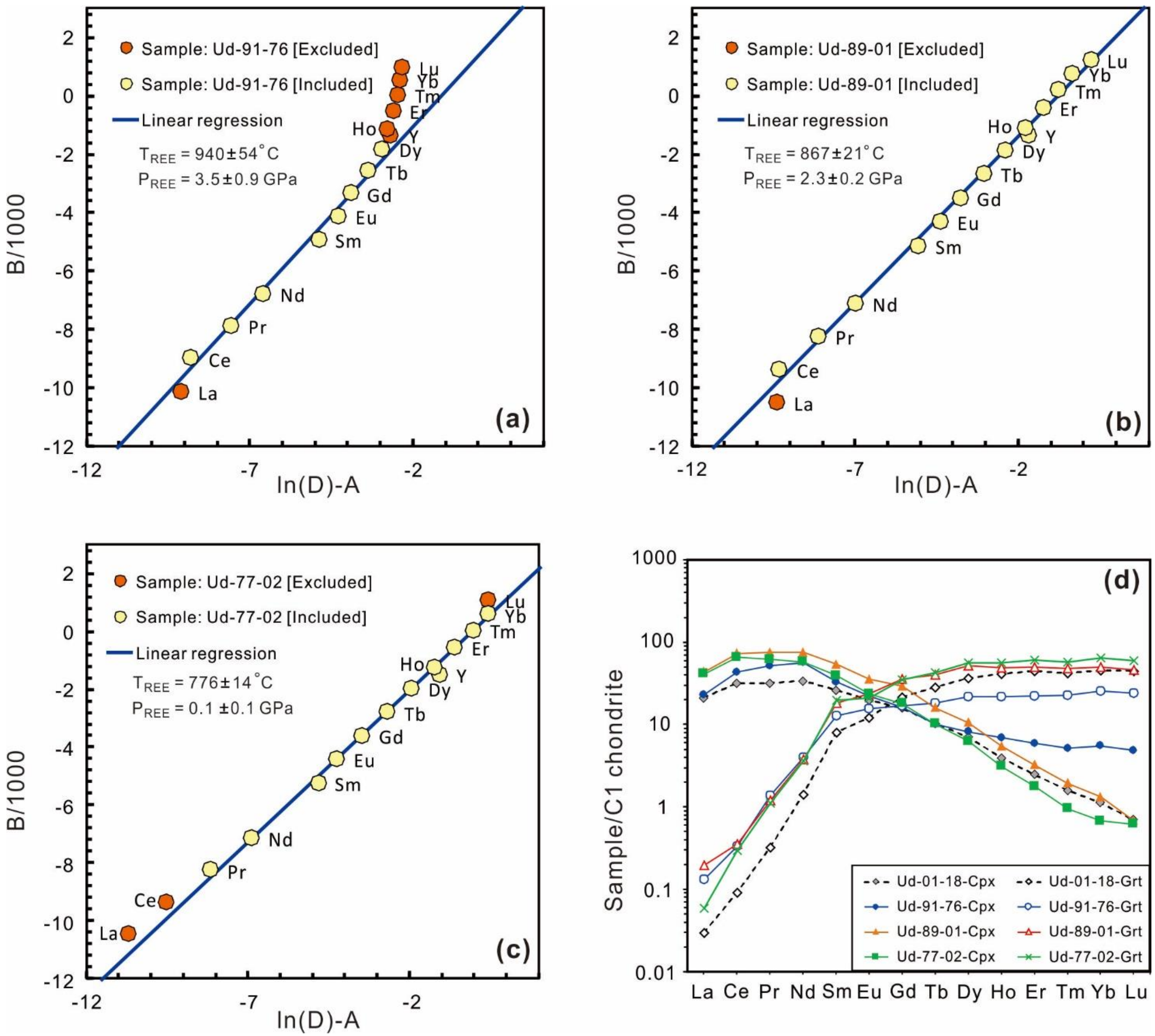
Ud-01-49

REE-in-Grt-Cpx thermobaromer: distribution of REEs between Grt and Cpx depends on T, P, mineral major-element compositions, and ionic radii of REE (Sun and Liang 2013, 2015)

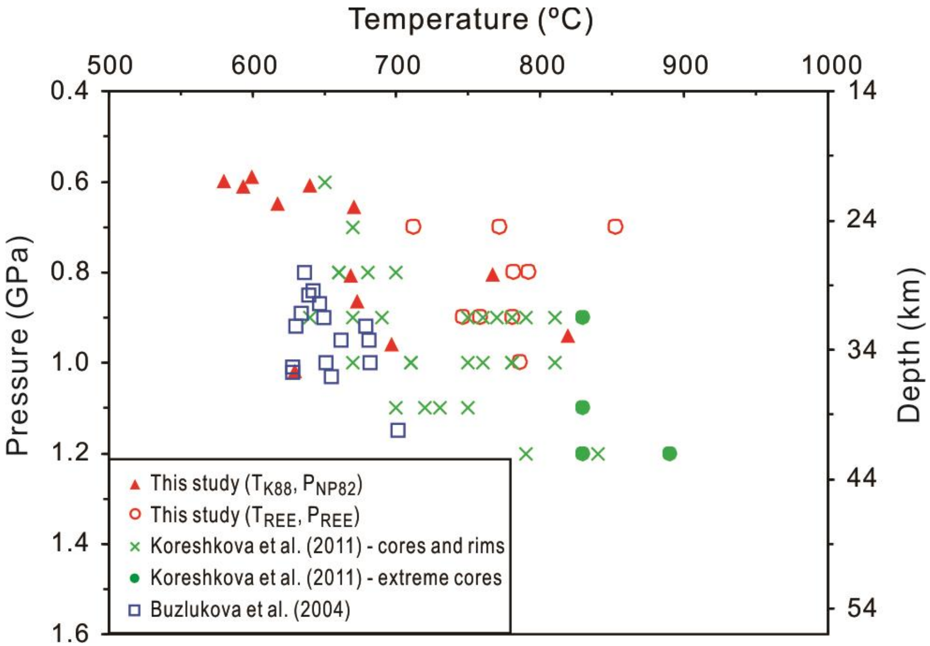
Inversions of T and P using the REE-in-Grt-Cpx thermobarometer

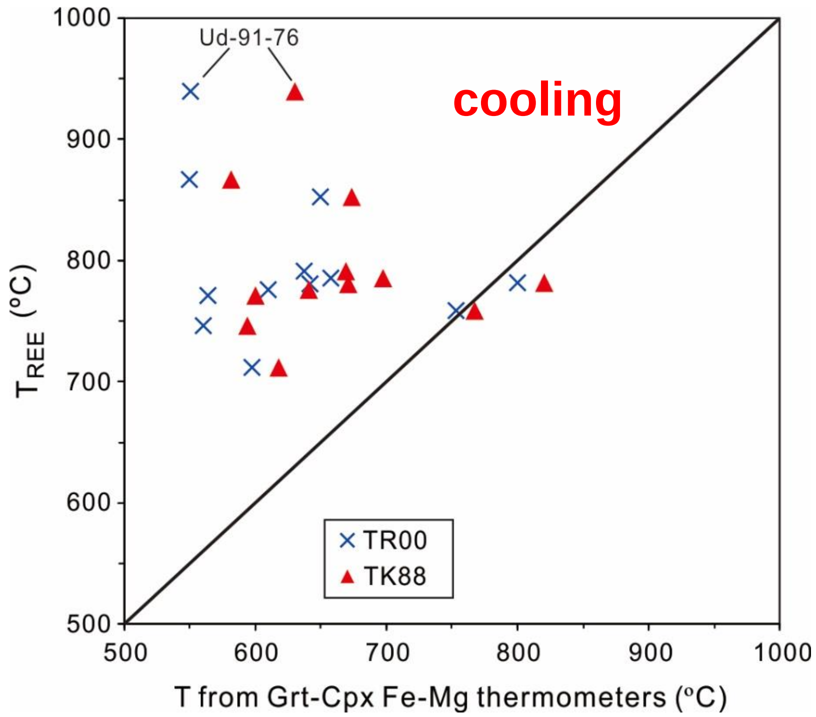


Strange inversions results: Disequilibrium between Grt and Cpx



Comparison of P-T estimates for granulite xenoliths from the Siberian Craton

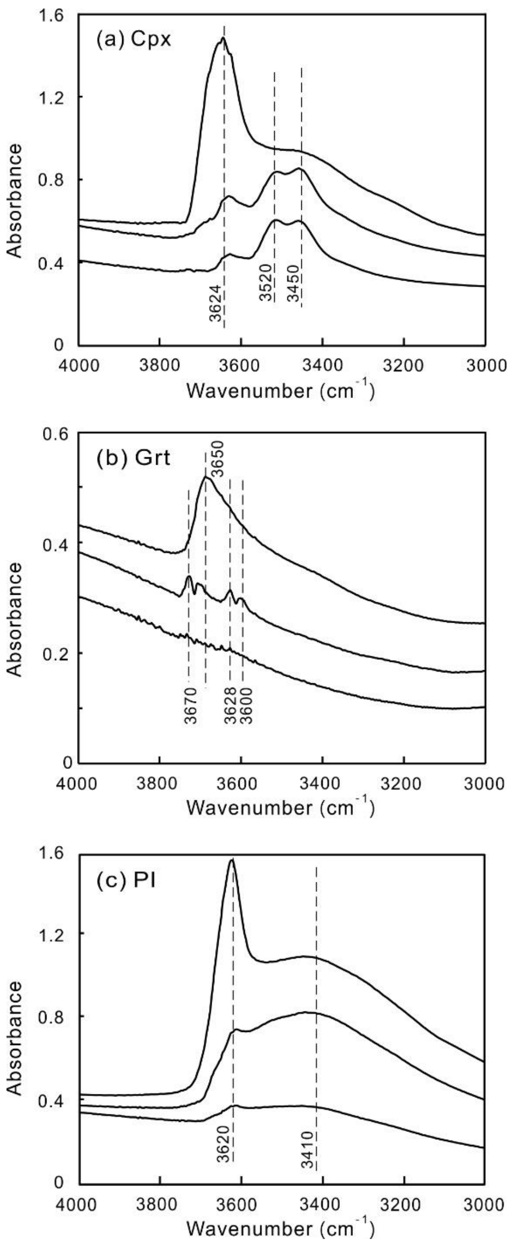




P = 0.6–1.0 GPa, T = 581–819 ºC

Thermobarometry: NP82, Grt-Pl-Cpx-Qz barometer (Newton and Perkins 1982); K88, Grt-Cpx Fe-Mg thermometer (Krogh, 1988); REE, REE-in-Grt-Cpx thermobarometer (Sun and Liang 2015). Data from Koreshkova et al. (2011) were calculated using NP82 for pressure and the Grt-Cpx Fe-Mg thermometer (Ravna 2000) for temperature. Date from Buzlukova et al. (2004) were determined by the Grt-Cpx Fe-Mg geothermometer (Ellis and Green 1979) and the Grt-Cpx geobarometer (Mukhopadhyay 1991).

Representative unpolarized FTIR spectra



Moderate to high water contents:

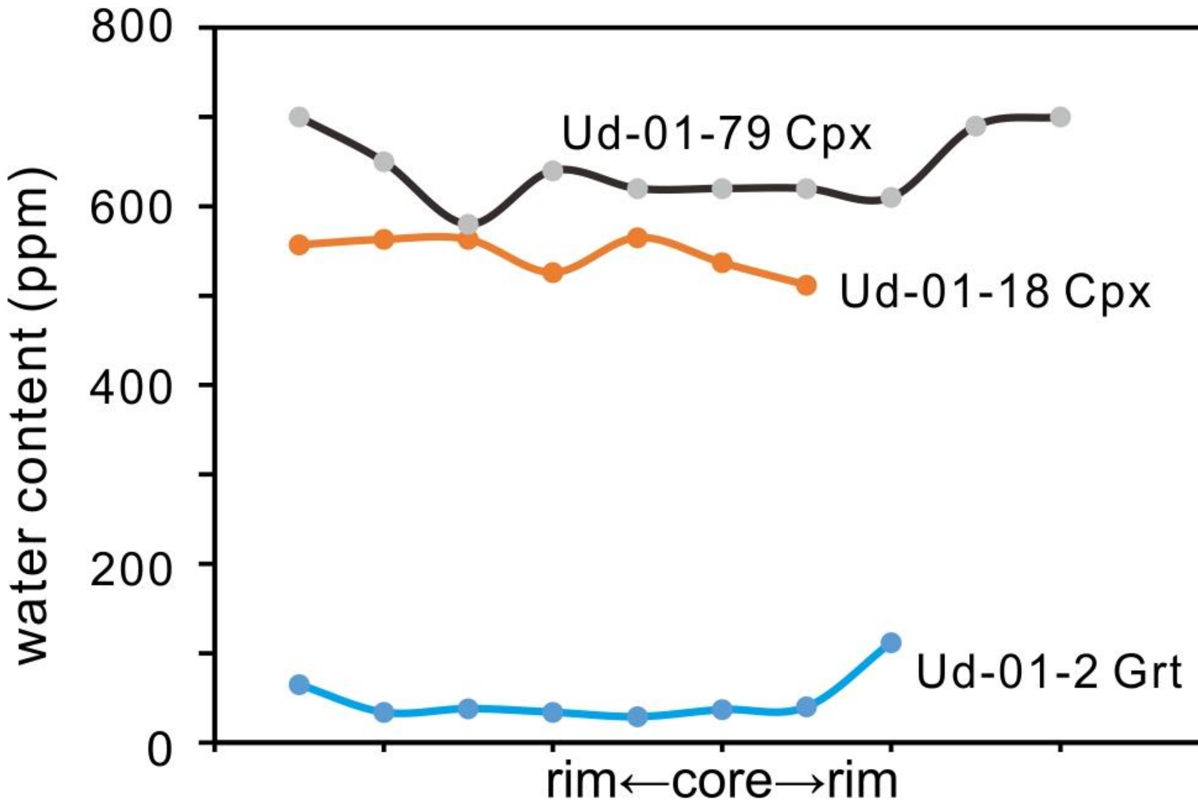
- ➢ **clinopyroxene (334–977 ppm H_2O)**
- ➢ **garnet (23–149 ppm H_2O)**
- ➢ **plagioclase (157–779 ppm H_2O)**

⇩

Bulk water content (267–707 ppm H_2O)

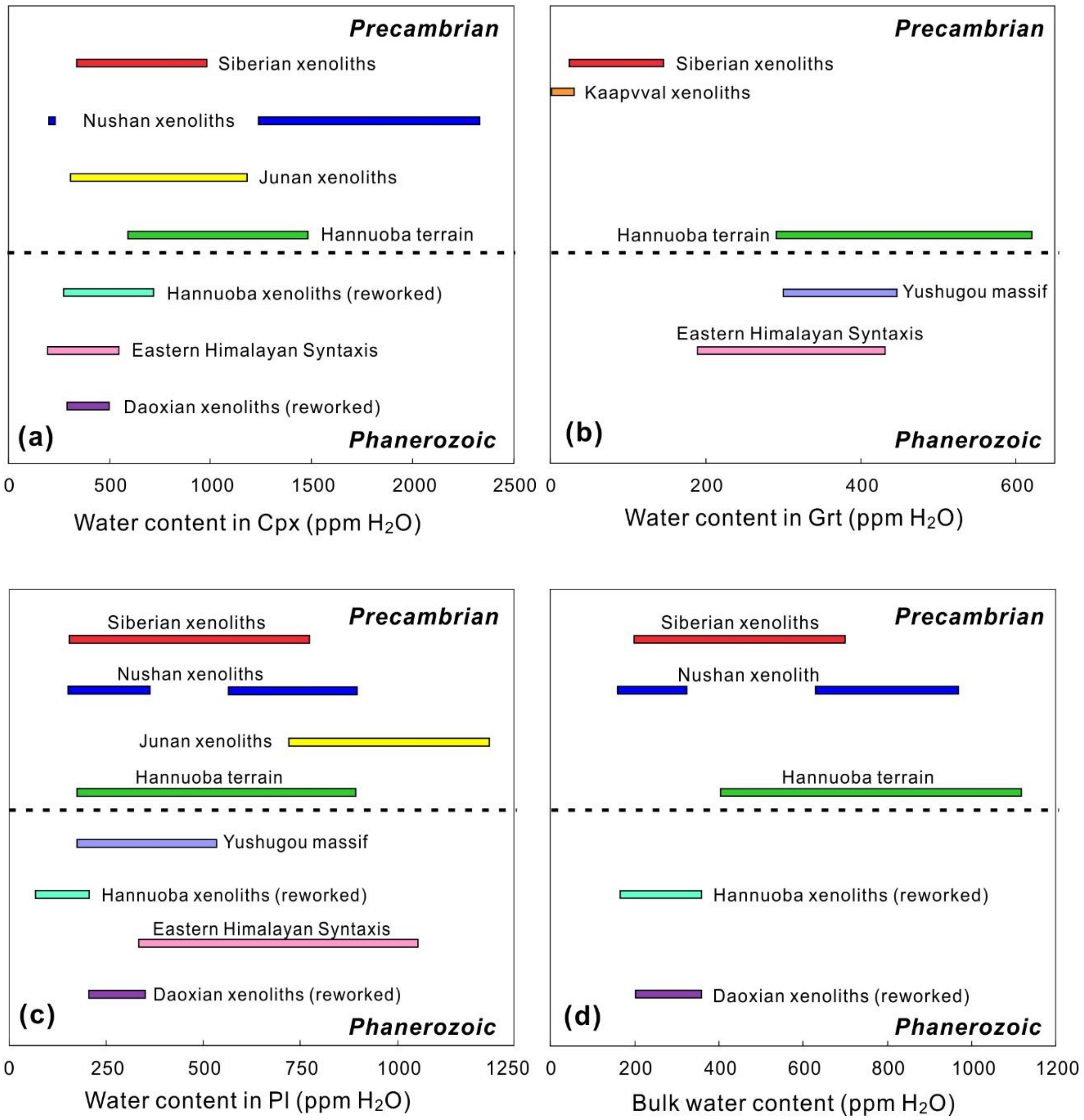
The lack of remarkable metasomatism and hydrogen loss in clinopyroxene and garnet from most samples indicates that the measured water contents in granulite samples preserved *in situ* hydrous conditions of the lower crust at ~1.8 Ga, not affected by later mantle metasomatism.

Water content profiles of clinopyroxene and garnet



Kimberlite magmas rise at a rate of 15–20 km/h (Peslier et al. 2008): ignorable hydrogen diffusion in NAMs

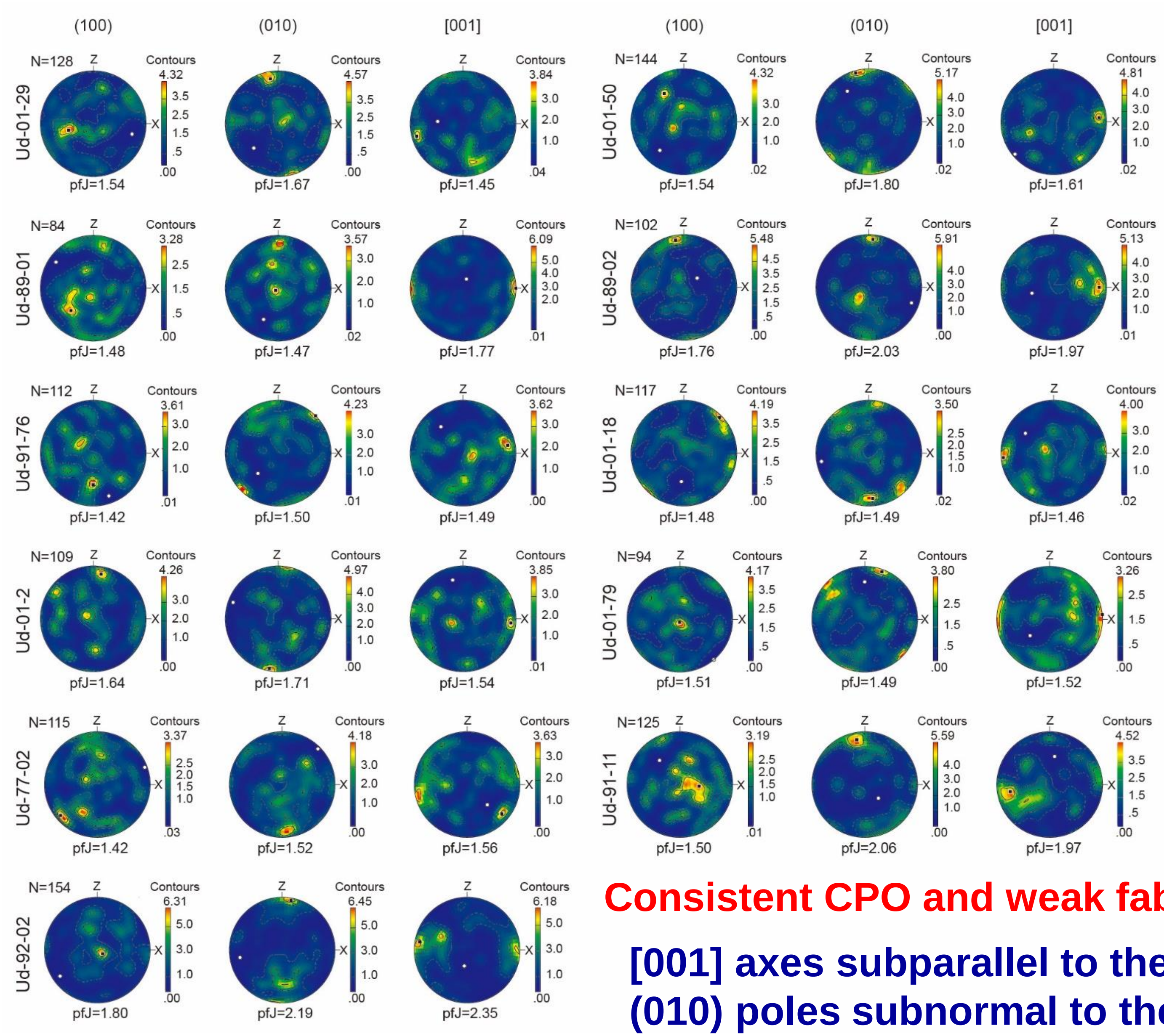
Water contents in granulites from different tectonic settings



The Precambrian lower crust in the Siberian Craton and the North China Craton contain comparable or less water contents than the Phanerozoic lower crust in orogenic belts.

Magma underplating will trigger partial melting of the ancient hydrous lower crust and produce a mixture of metamorphosed water-poor residues and young accumulates, and the water-rich Precambrian lower crust.

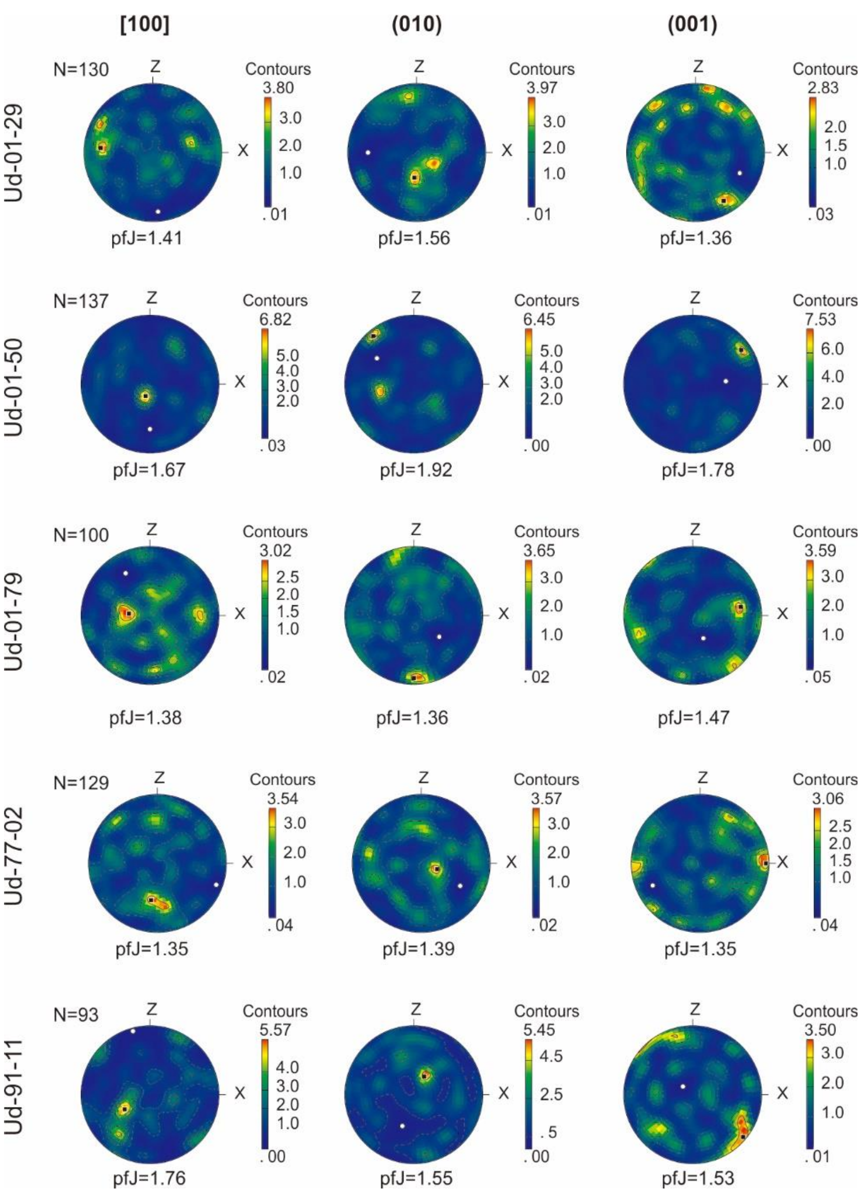
Crystal preferred orientation (CPO) of clinopyroxene



Consistent CPO and weak fabric strength

[001] axes subparallel to the lineation
(010) poles subnormal to the foliation

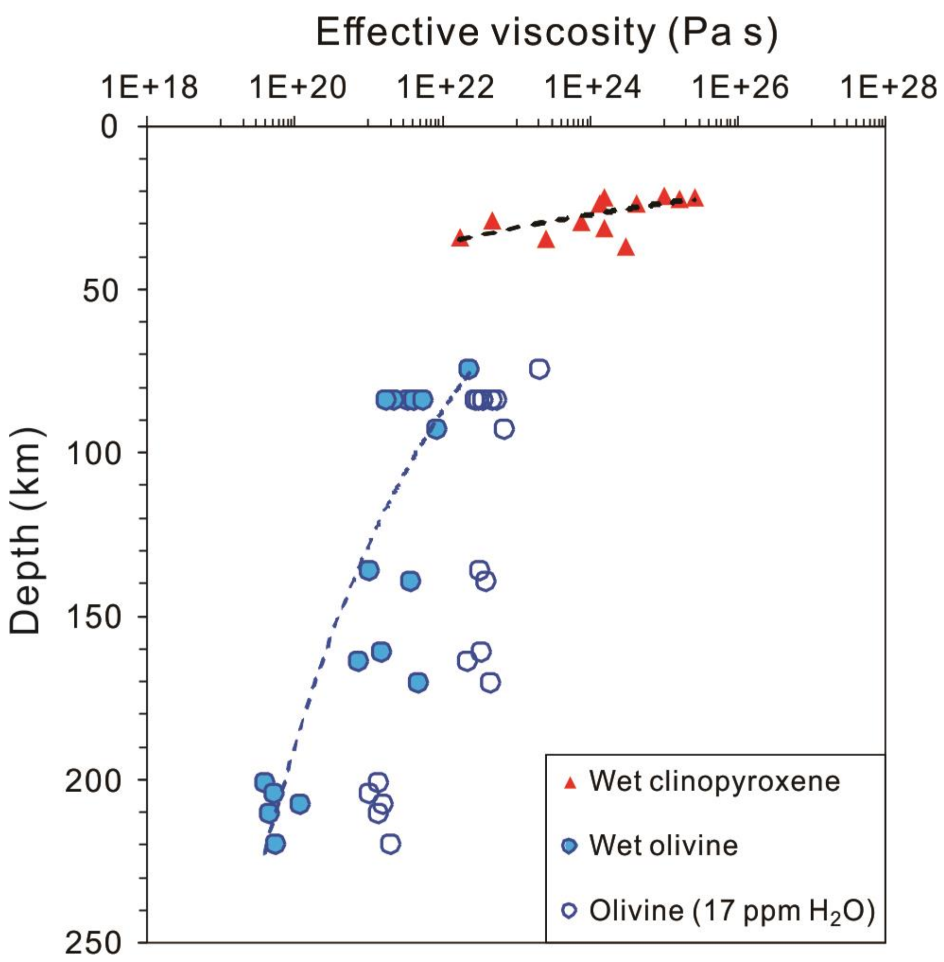
Crystal preferred orientation (CPO) of plagioclase



Complex CPO and weak fabric strength

- **Ud-01-29 and Ud-91-11:** [100] axes subparallel to the lineation and (001) poles normal to the foliation.
- **Ud-01-50 and Ud-01-79:** (001) poles subparallel to the lineation and (010) poles subnormal to the foliation.
- **Ud-77-02:** (001) poles subparallel to the lineation and [100] axes subnormal to the foliation

Effective viscosity profile from the Udachnaya kimberlite pipe

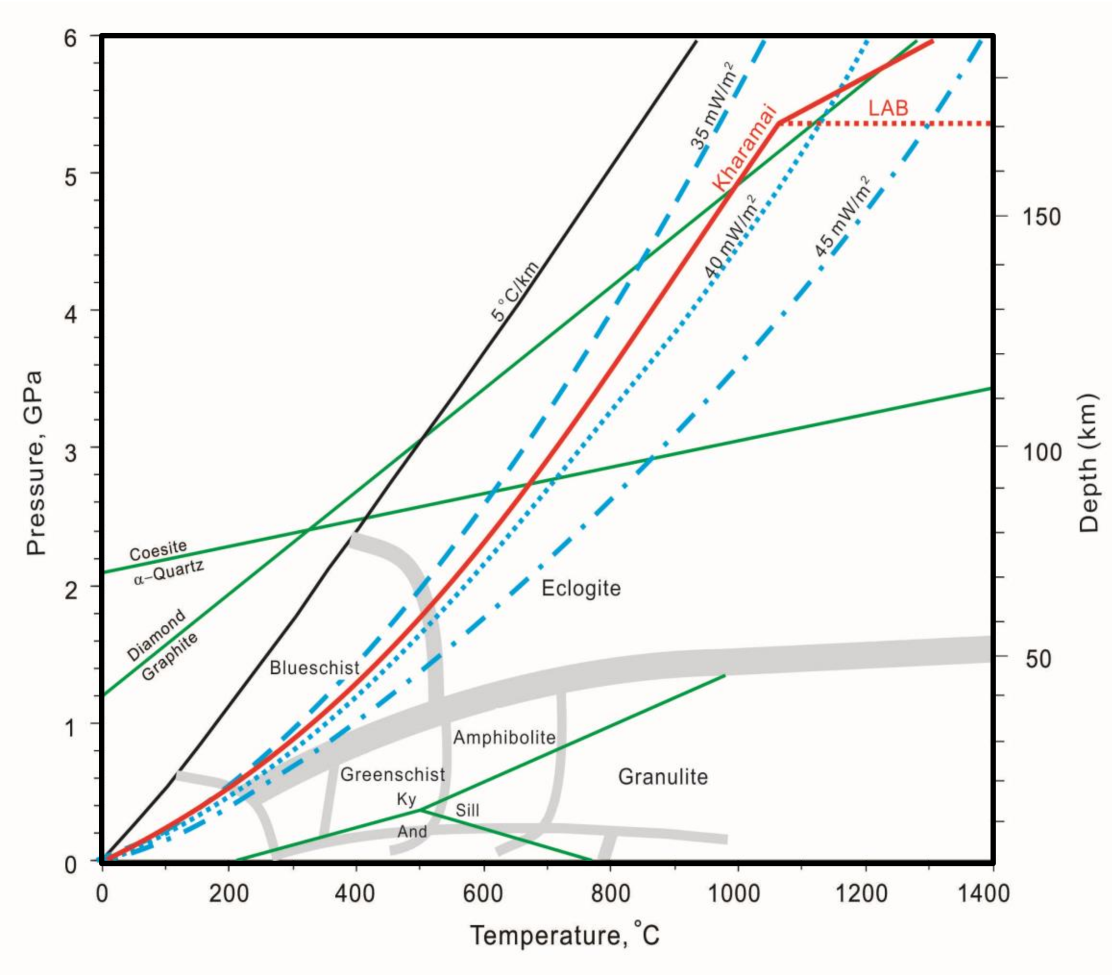


Assuming the strain rate of 10^{-15} s^{-1}

Effective viscosity was calculated using P-T conditions of xenoliths and dislocation creep flow law of wet clinopyroxene (Chen et al 2006) and wet olivine (Mei and Kohlstedt 2000; Karato and Jung 2003):

Water contents in olivine (Doucet et al. 2014) and clinopyroxene (this study) are used as wet conditions. Water content of 17 ppm H_2O in olivine was assumed to represent the water-poor lithospheric mantle beneath cratons (Wang, 2010).

Geotherms of the Siberian craton



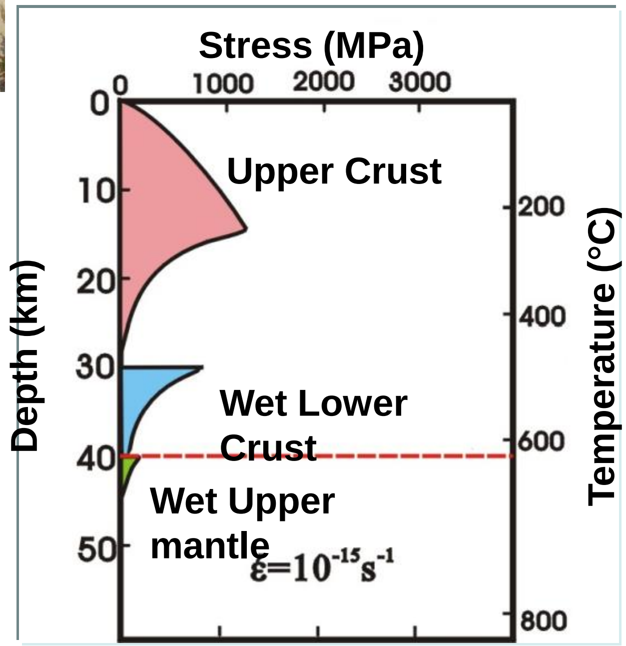
Red line: geotherm of garnet xenocrysts from the Kharamai kimberlites (Griffin et al., 2005)

Mantle xenoliths:

- **Denovian kimberlites:** **35 mW/m²**
- **Kharamai kimberlites:** **38 mW/m², 170 km LAB** (Griffin et al., 2005, Lithos)
- **Present-day thermal strucuture:**

39±2 mW/m² (Xu and Qiu, 2017)
180-300 km thick thermal lithosphere (Artemieva & Mooney, 2001)

High water contents in NAMs of the lower crust will result in mechanical coupling at the crust-mantle boundary, no matter the upper mantle is water-rich or water-poor.



Crème brûlée model

Strong-weak-weak

⇩

Long-term crust-mantle coupling during plate tectonics

Conclusions

- Granulite xenoliths from the Siberian Craton recorded pressures of 0.6–1.0 GPa and temperatures of 581–819 ºC using the Grt-Cpx Fe-Mg thermometer, which are consistently lower than temperatures from the REE-in-Grt-Cpx thermobarometer. This suggests a cooling history of granulites since the last granulite facies metamorphism.
- Moderate to high water contents were measured in Cpx (334–977 ppm H_2O), garnet (23–149 ppm H_2O) and plagioclase (157–779 ppm H_2O), representing hydrous lower crust of the Siberian Craton since 1.8 Ga.
- Clinopyroxene and plagioclase show weak crystallographic preferred orientation, resulting in weak seismic anisotropy.
- Precambrian lower crust in cratons contain comparable or less water than Phanerozoic lower crust in orogenic belts. Magma underplating will produce heterogenous water distribution in the lower crust.
- The wet and weak lower crust supports the “crème brûlée” model and explains the long-term crust-mantle coupling.

Thank you

Acknowledgements: This research was supported by the NSFC projects (41825006 and 41590623) and the NSFC-RFBR Cooperative Project (No. 4141101061).

Baikal lake