Compositional Heterogeneity of the Upper mantle beneath the Siberian Craton: Reconciling Thermal, Seismic and Gravity Data

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Compositional heterogeneity of the upper mantle beneath the Siberian craton: Reconciling thermal, seismic and gravity data

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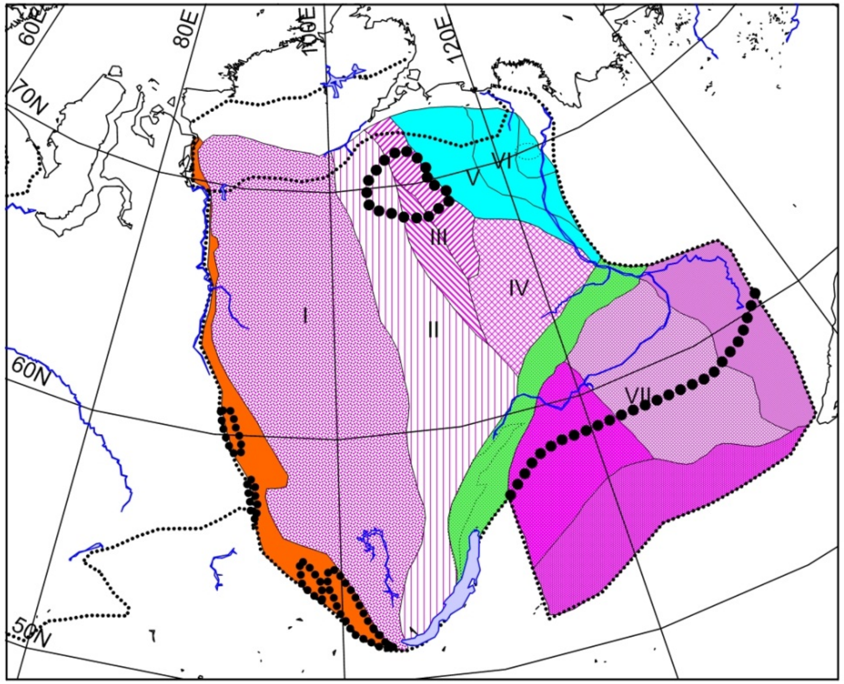
Siberian craton: tectonics and topography



🟪 Archean-Paleoproterozoic (> 1.8 Ga)
3.6-3 Ga – oldest blocks of the Tunguska, Magan, Daldyn terraines, Aldan and Anabar shieled
2.5-2.4 Ga –oldest blocks of Birekte and Markha terraines

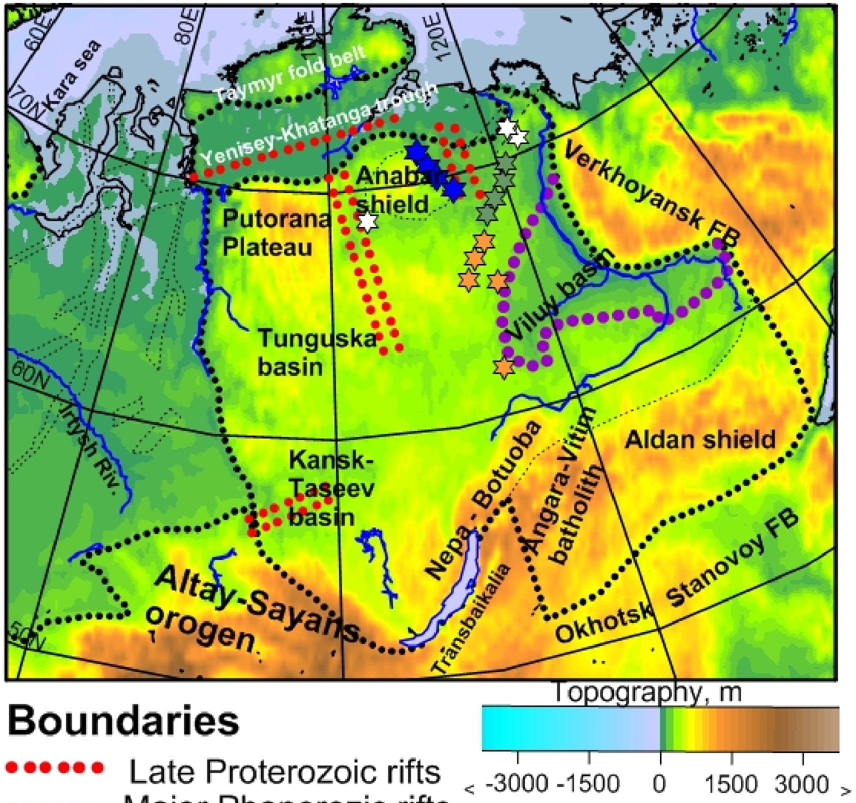
🟧 Proterozoic orogenic belt (Angara belt) with Archean basement (1.8 - 1.2 Ga)

🟦 Meso- Paleoproterozoic (1.8 -1.0 Ga)

🟩 Proterozoic orogenic belt (Akitkan belt, 1.8-1.2 Ga)

●●● Shields

2.6 Ga, 2.3 Ga and 1.95 Ga –collisions of terrains, platform stabilization



Boundaries

●●●●●● Late Proterozoic rifts
●●●●●● Major Phanerozic rifts
········ Outline of the West Siberian basin and the Siberian craton

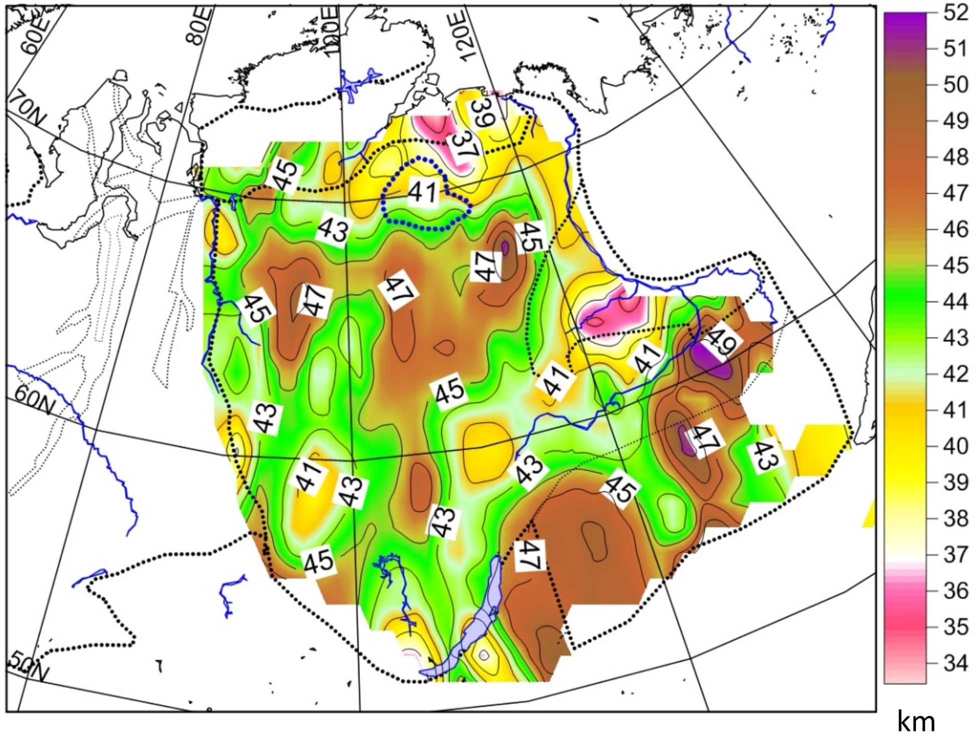
Major kimberlite fields

★ S1-D2 ★ D2-C1 ★ T1 ☆ J3-K1

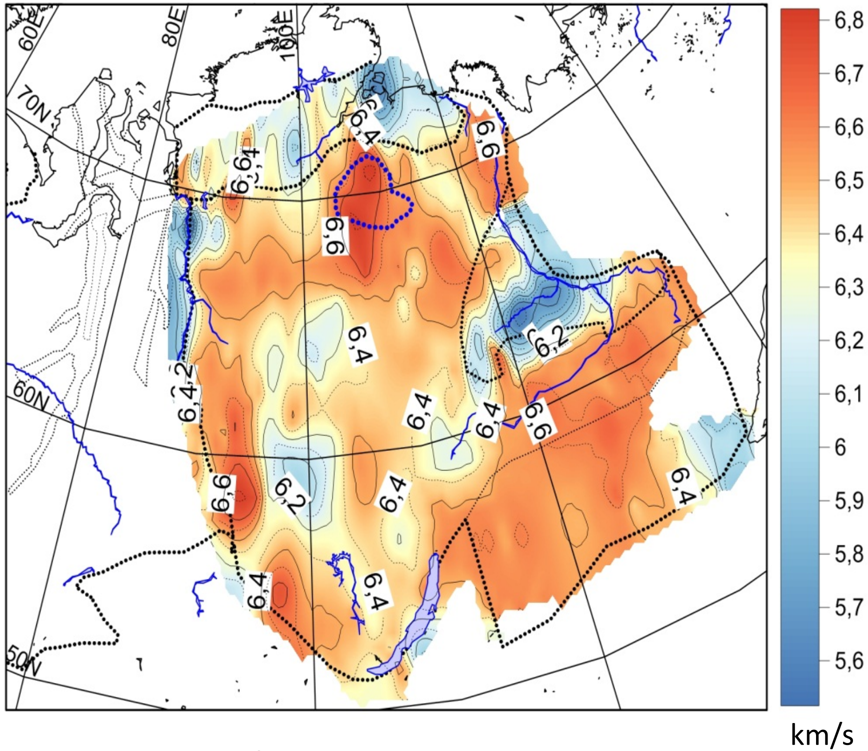
Topography ca. 400 m
Anabar Shield up to 700 m
Vitim-Aldan up to 1500 m

Crustal structure – new SibCrust model

Moho depth



Average Crustal Vp



Cherepanova et al., 2013, Tectonopysics

- Thick Archean crust with a thick lower crustal layer
- Thinned crust in paelorifts

- Average crustal Vp reflects strong heretogeneity of the crustal structure

Almost no surface topography, but highly heterogeneous crust -> where/how is it isostatically balanced?

Motivation of research

- Mantle structure within and outside of the kimberlite fields?
- Correlation between the crustal structure, surface topography, gravity and mantle density?

Two complementary approaches:

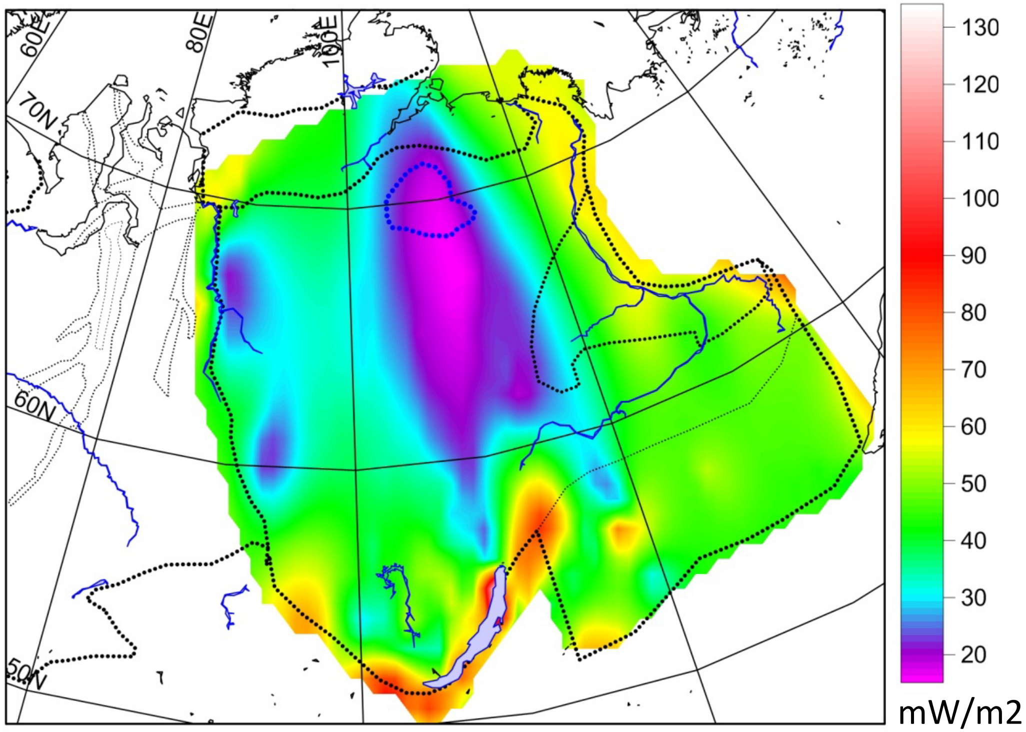
1. **Gravity modeling**
2. **Buoyancy modeling**

Input parameters:

- gravity / topography
- crustal structure
- thermal structure
- lithosphere thickness

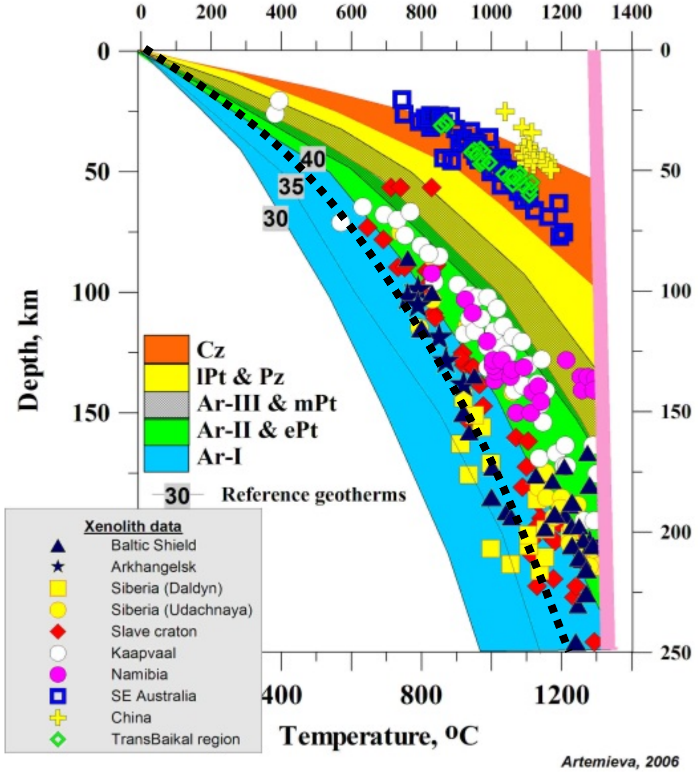
Lithosphere: thermal regime and thickness

Heat flow



Data from Artemieva and Mooney, 2001

Typical continental geotherms constrained by heat flow data

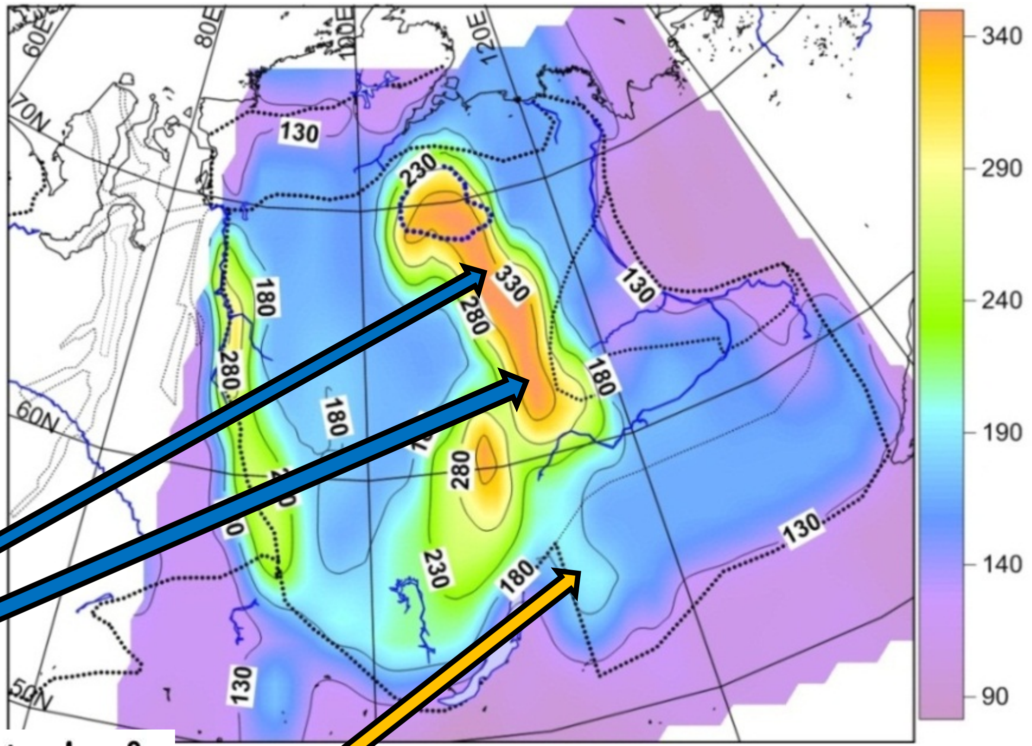


Artemieva, 2009

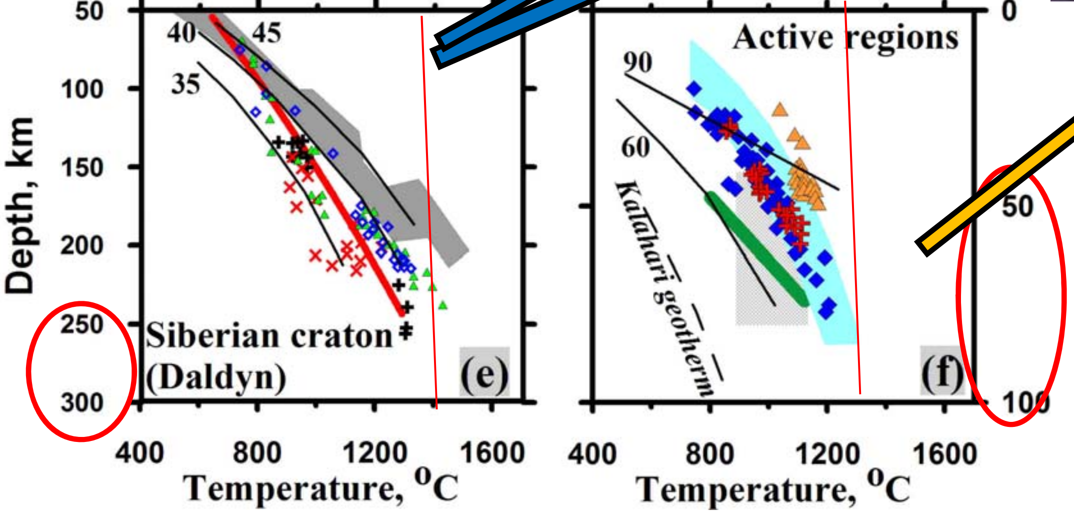
Lithosphere: thermal regime and thickness

Lithosphere thermal thickness

Data from Artemieva and Mooney, 2001;
Artemieva, 2006



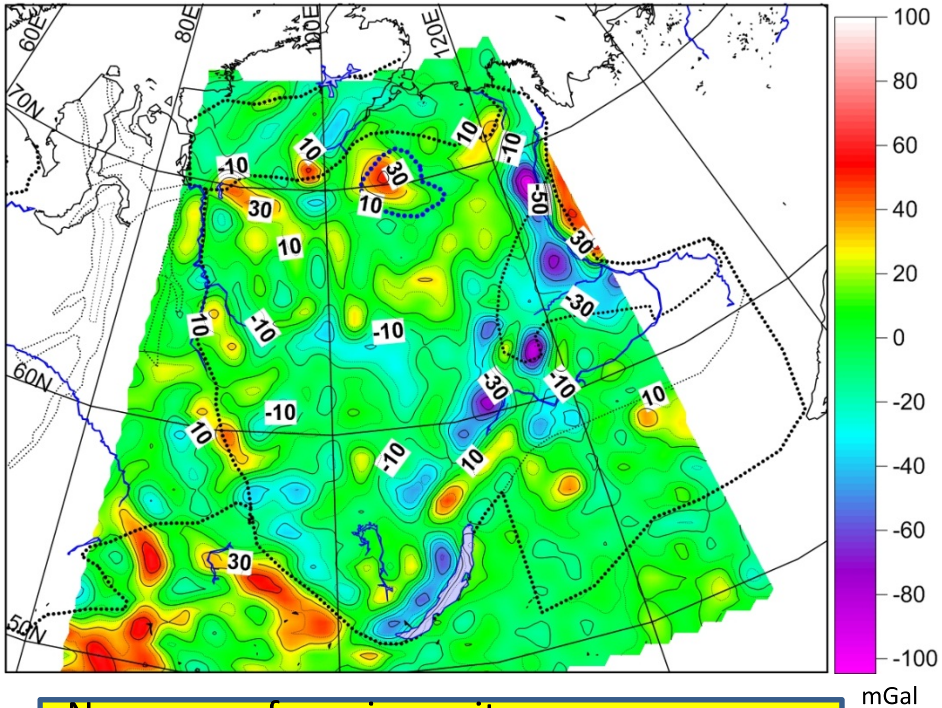
Xenolith P-T arrays:
(data of Griffin et al., Boyd et al., Aschepkov et al., Ionov et al.)

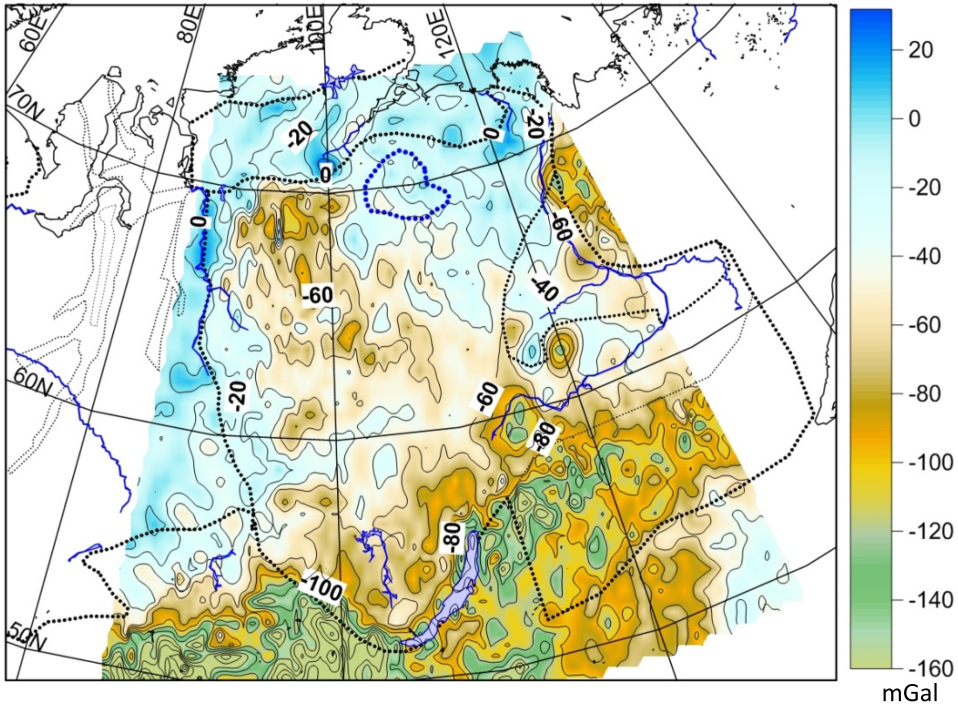


1. Gravity modeling

Free air gravity anomalies based on GOCE Satellite data

Bouguer gravity anomaly





- Near –zero free air gravity
  -> Isostatic equilibrium

- Strong negative anomalies in the Viluy basin and near-Baikal region
- Positive anomalies at the Anabar shield and Altay-Sayan orogen

- Negative anomalies in the south (Paleozoic orogens) suggest the presence of low-density material.
- Significant heterogeneity within the craton

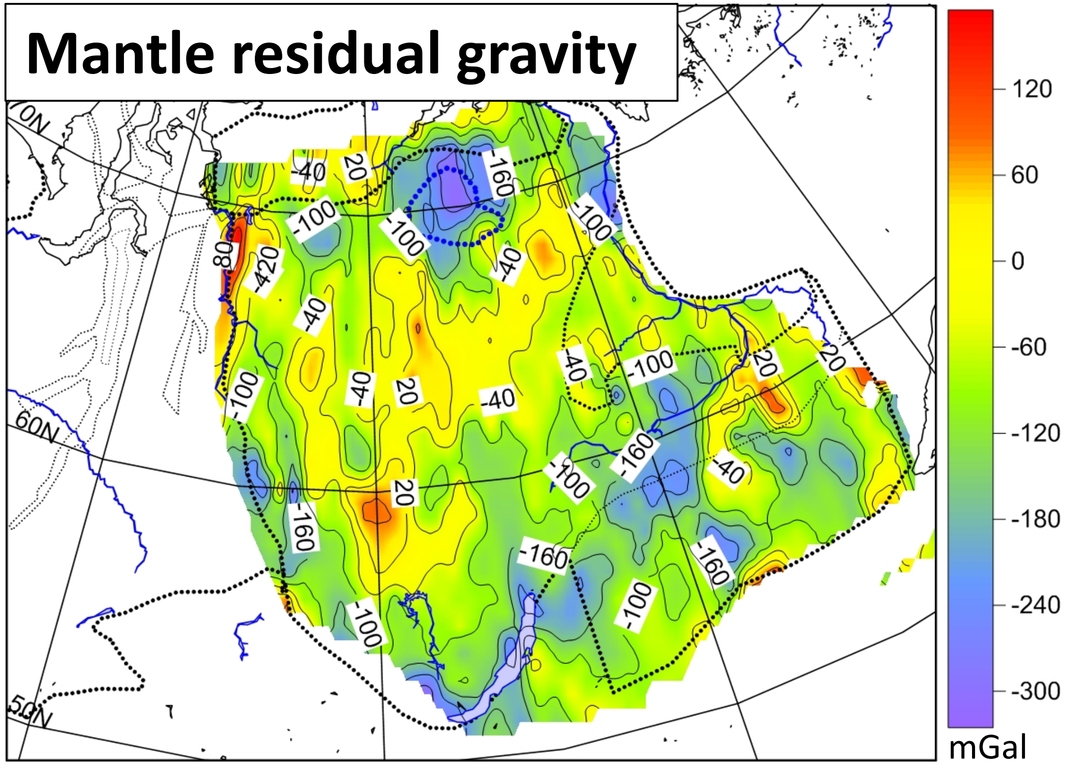
1. Gravity modeling: results

Modeling approach:

1) to remove deep mantle gravity signal by subtracting degree 1-10 spherical harmonics (empirical approach)

2) to remove gravity effect of the crust from the total gravity signal

Product: mantle residual gravity anomaly;
depth distribution of anomalies is unknown



Mantle residual gravity

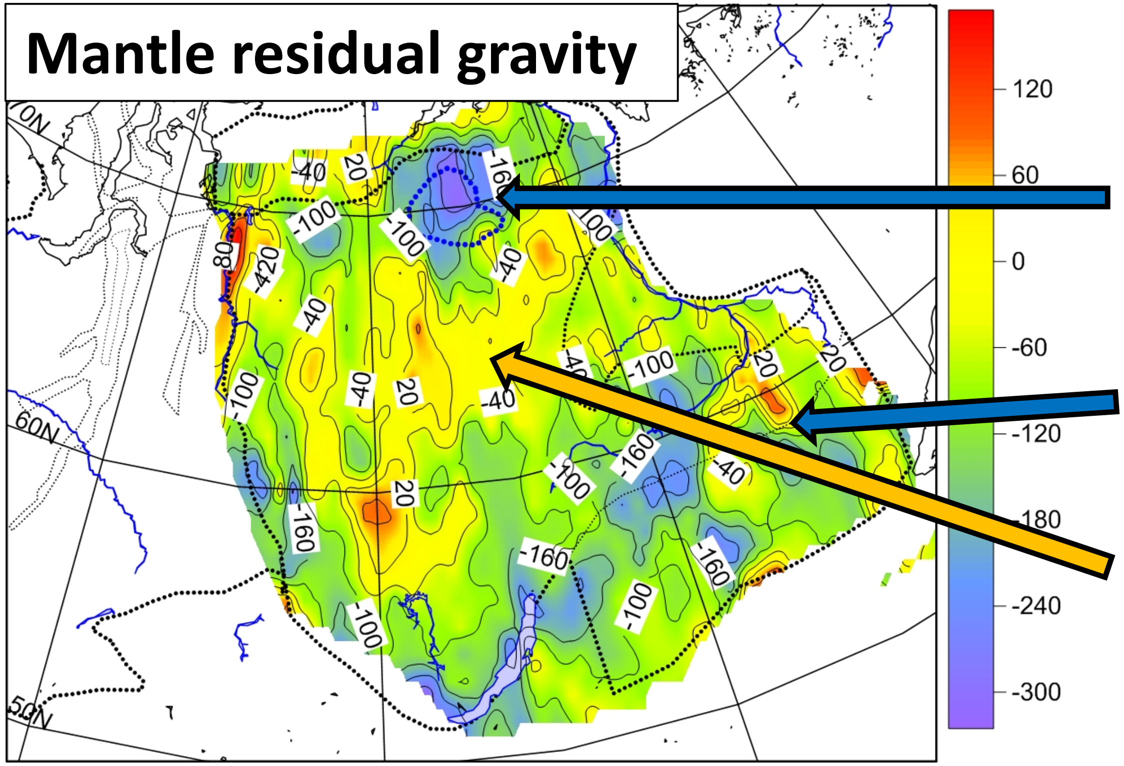
Input parameters:

- **gravity:** Bouguer with removed low frequency spectra (1-10 harmonics)
- **crustal structure:** new SibCrust model for thickness of crustal layers; Vp -> density

1. Gravity modeling: results

Depth distribution of anomalies is a priori unknown

- **Assumption:** all density anomalies (responsible for mantle residual gravity) are restricted to the lithospheric mantle LM (crustal effect has been already removed)
- **To calculate density anomalies of the LM**, one needs to know:
- lithosphere thickness -> based on regional thermal model
- thermal structure -> to convert in situ densities to room P-T (SPT)



Mantle residual gravity

Strong negative anomalies (low dense mantle material) in:

- Archean Anabar shield;
- Archean-Paleoproterozoic Yenisey Ridge;
- Archean Aldan shield (in parts)

Weak positive anomalies in:

- inner parts of the Siberian craton;
- major kimberlite fields

2. Buoyancy modeling: the approach

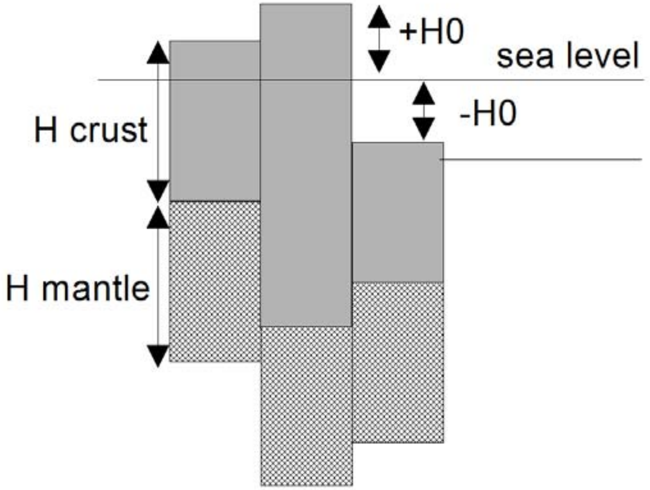
Justified by near-zero free air gravity (isostatically compensated region)

Method: Lachenbruch & Morgan (1990)

Model assumptions:

- Isostatic balance – at LAB
- Surface topo = crustal + lithospheric mantle contributions.
- Asthenosphere density 3.24 g/cm3 in situ, T =1300C at LAB.
- Densities: T- dependent; P-correction ignored.
- The height of the sea level above the asthenosphere calibrated at oceanic ridge (3.35 km).
- Dynamic contribution to topography =0

Topography – key to mantle properties



Input :

Topography (ETOPO1)

Crustal density and thickness (SibCrust)

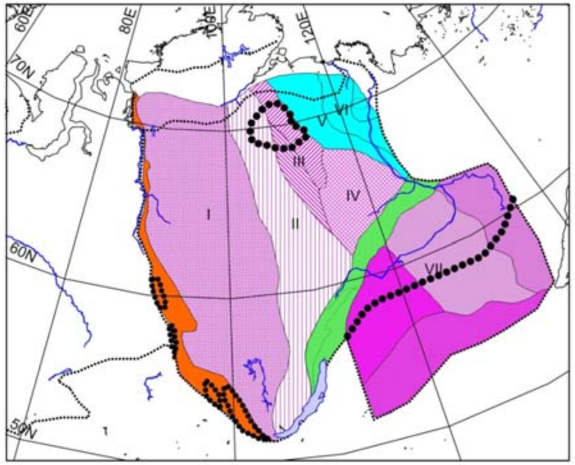
Moho T and LAB depth (TC1 model)

Output : Mantle density

- at in situ P-T

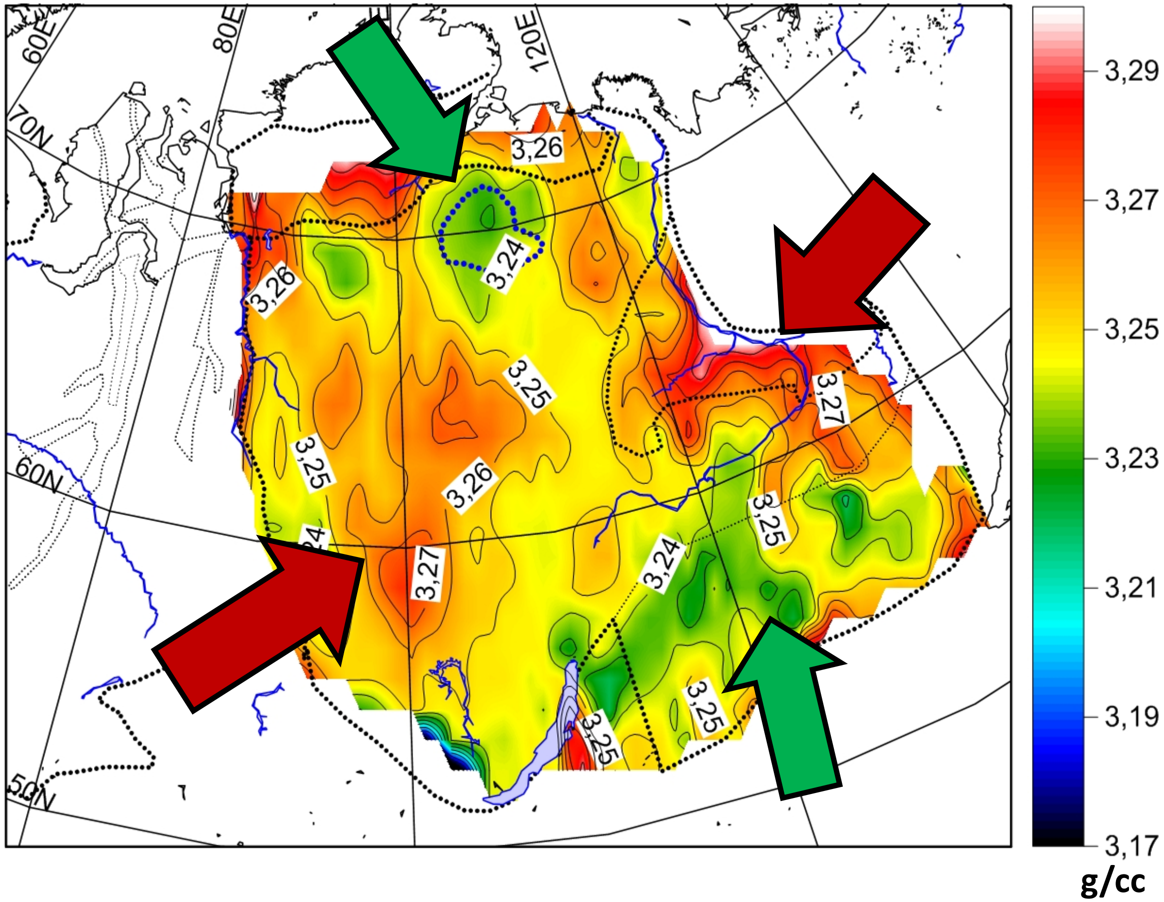
- at lab (SPT) conditions

2. Buoyancy modeling: results



Mantle density in situ

(at P-T of geophysical remote sensing)



Reflects, in part, temperature heterogeneity of LM

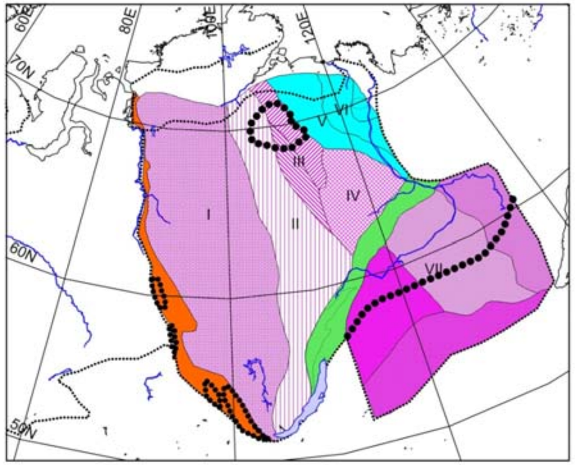
Low dense lithospheric mantle explains high topography of the Archean shields

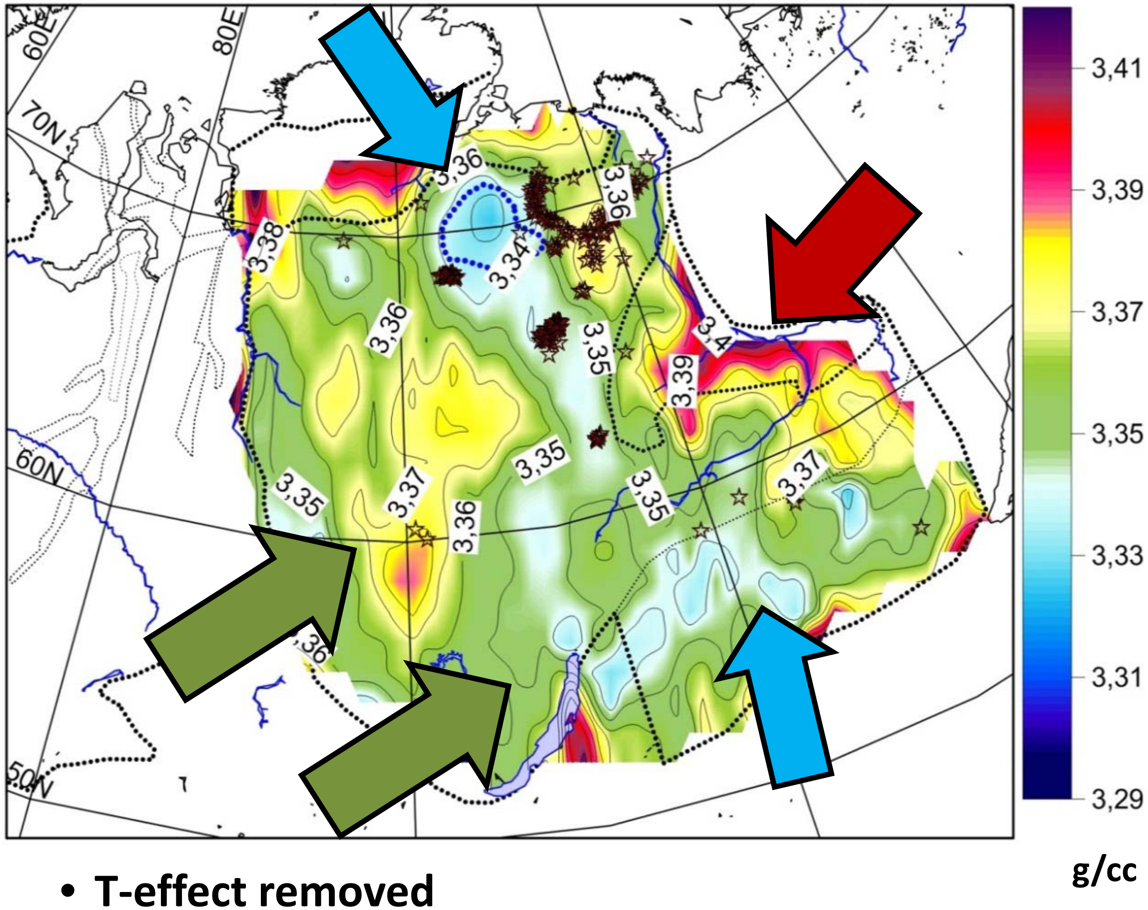
Dense LM beneath the Vilyu rift/basin and the Tunguska basin

2. Buoyancy modeling: results

Mantle density at SPT (room P-T)

(corresponds to P-T of lab measurements on rock samples)





- **T-effect removed**
- **Assume all mantle density heterogeneity is in LM**
- **Neglect dynamic topography**

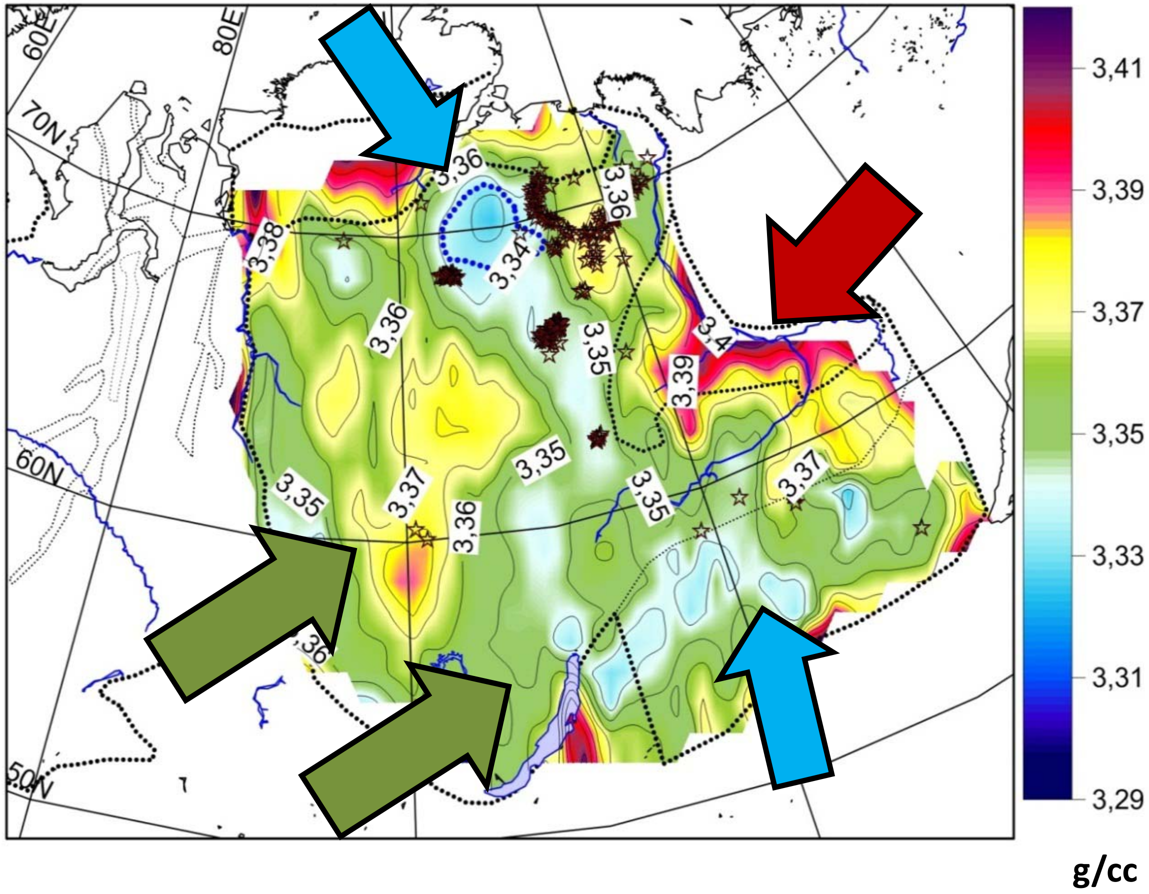
Compared to in situ P-T, the pattern of the density anomalies is more pronounced.

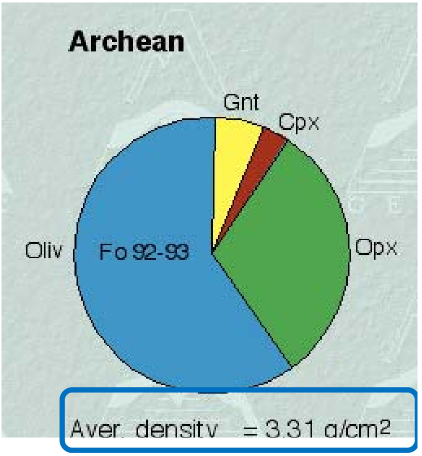
- In cold in Archean blocks, SPT density is typical of Archean mantle (based on xenolith data)
- **Well studied kimberlite fields do not sample depleted mantle**
- Proterozoic Akitkan belt is marked by some density increase
- Tunguska basin has SPT density typical of Proterozoic LM
- Viluy basin has extremely high mantle density

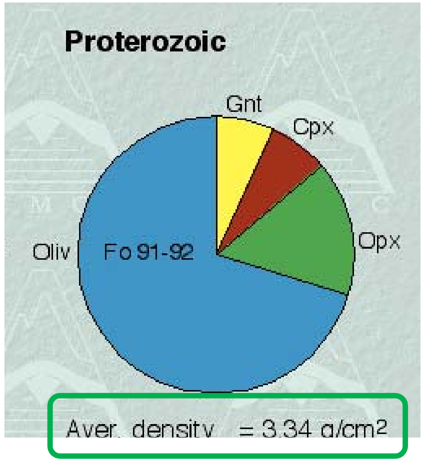
Comparison with xenolith data on LM densities

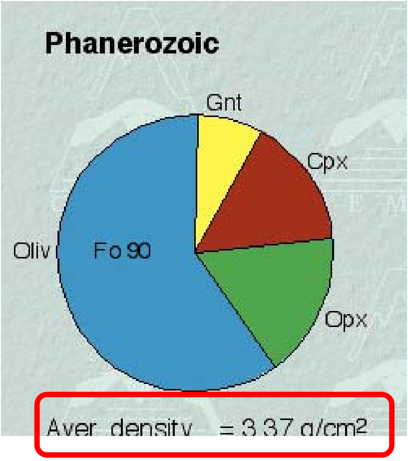
Mantle density at SPT (room P-T)

(corresponds to P-T of lab measurements on rock samples)





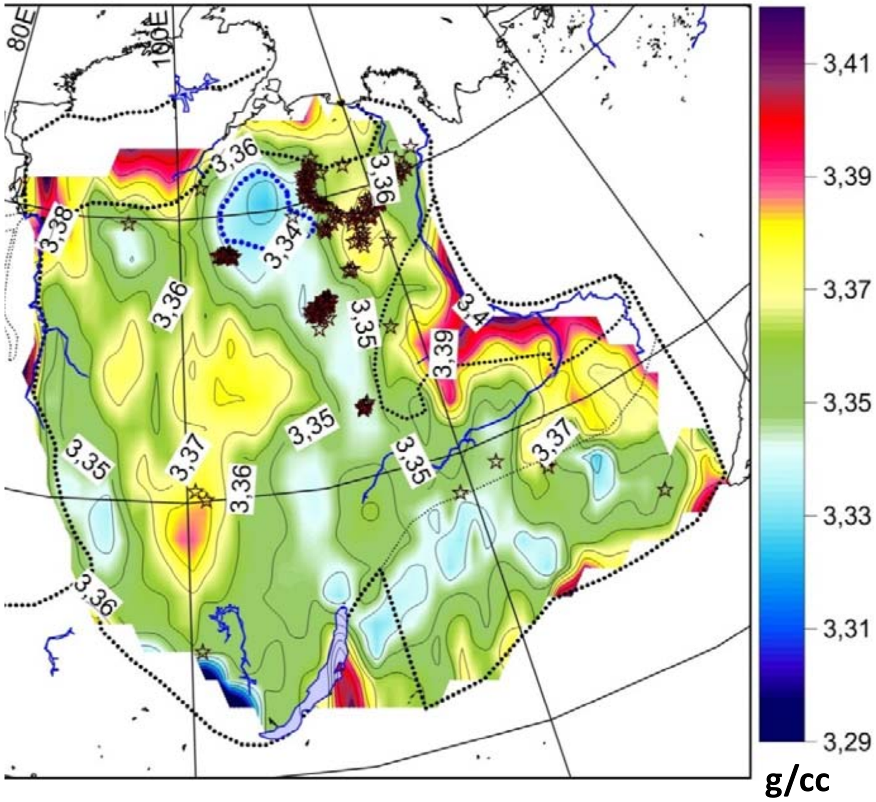




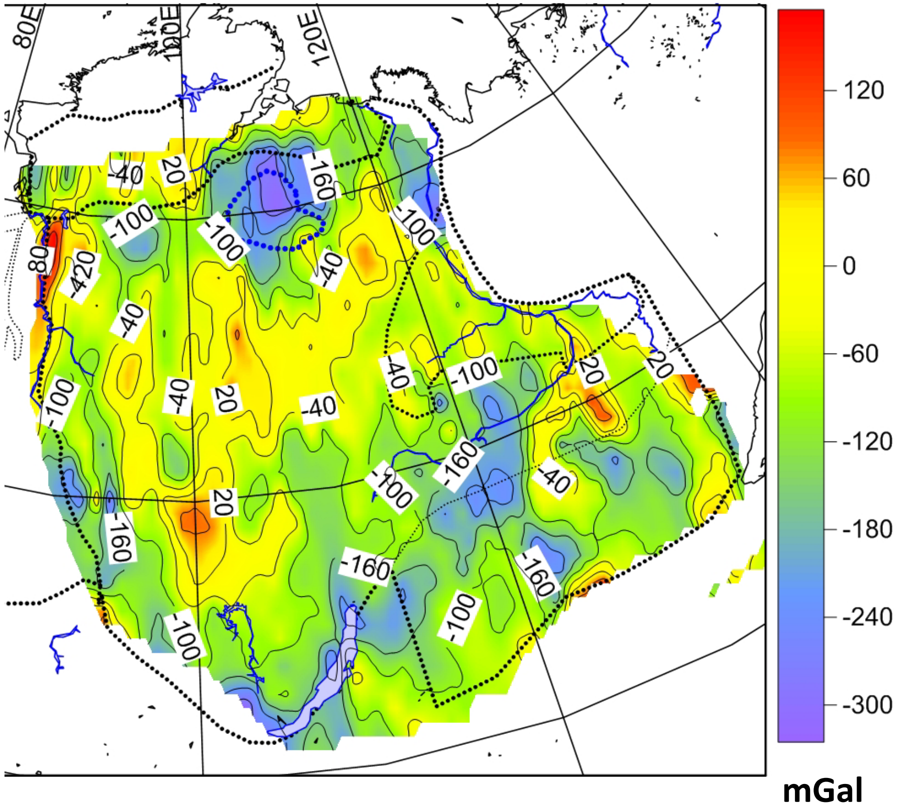
Griffin & O'Reilly, 1998

Comparison of LM density heterogeneity by two methods

Mantle density from buoyancy



Mantle residual gravity



Good agreement between the two independent approaches

Conclusions

- Lithosphere mantle of the Siberian craton is compositionally heterogeneous
- Density anomalies correlate with major tectonic provinces
- Kimberlites do not sample mantle with the strongest density anomalies
- Our results support isopycnicity of the Archean cratons