Integrated modelling based on shallow cross-gradient joint inversion and deep petrological approach on 2D/3D data in the Western Carpathians

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General aim of the work

<u>Understanding</u> *regional and local structural and thermal parameters in the crust and upper-mantle of the central Europe (Western Carpathians)*

<u>Consistent interpretation of</u>:

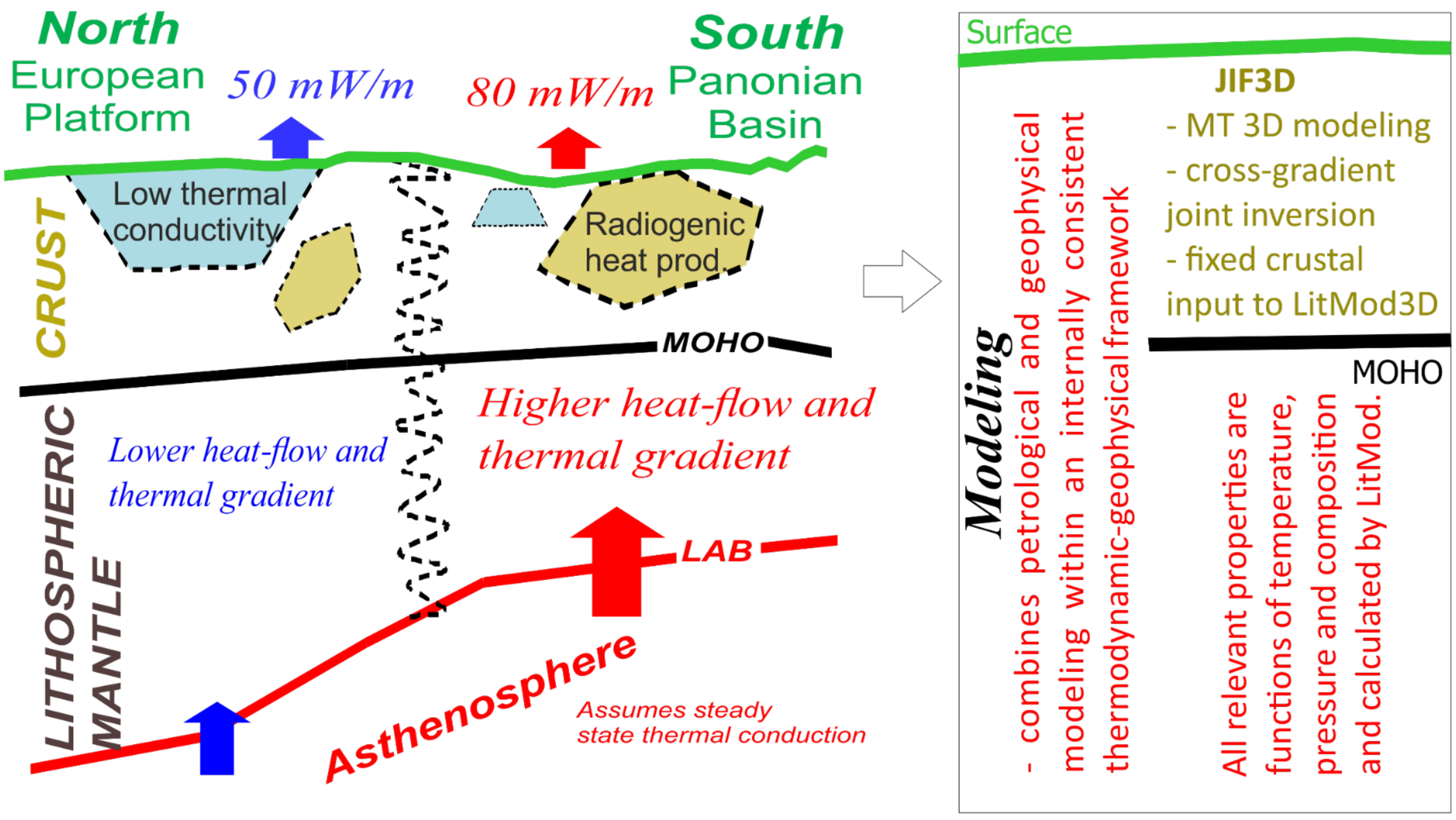
→ *crustal & lithospheric structure, Moho & LAB discontinuities*
→ *temperature & composition & structure estimation at depth*

✓ *Joint petrological, geological and geophysical characterization of the lithosphere in the studied region*

By integrated modelling we mean:

- *3D joint inversion of magnetotelluric, gravimetric and seismic data for **crustal** structures by coupling of electrical conductivity (σ), density (ρ) and seismic velocity (v) (JIF3D tool)*
- *3D geophysical-petrological modelling of the **lithosphere** and sub-lithospheric upper mantle within an internally consistent thermodynamic-geophysical framework, where all relevant properties are functions of temperature, pressure and composition (Litmod3d package)*

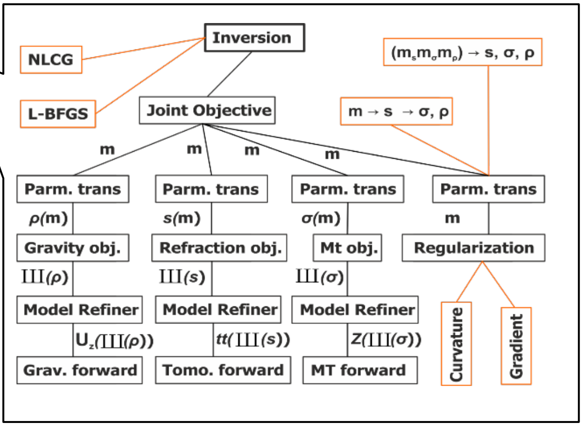
Methodology Scheme



1. **JIF3D -** Crustal model
2. **LitMod3D –** model is composed from JIF3D crustal model from step one and sub-crustal model, calculated based on petrology and constrains

Step 1: Crustal Joint Inversion

JIF3D – 3D joint inversion framework (Moorkamp et al., 2011)



- *joint inversion for electromagnetic, seismic and gravity data*

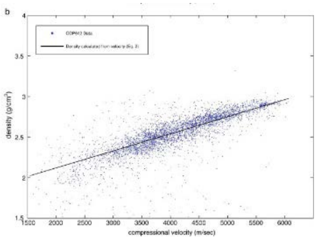
Models coupling options:

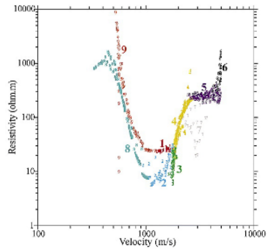
a) <u>Direct relationship</u> – borehole info (Christensen and Mooney, 1995; Jegen et al., 2009)

- between densities and seismic velocities (app. linear)

- between resistivity and velocity (structural dependence)

⇨ *too difficult for regional model –* ***not*** *used*

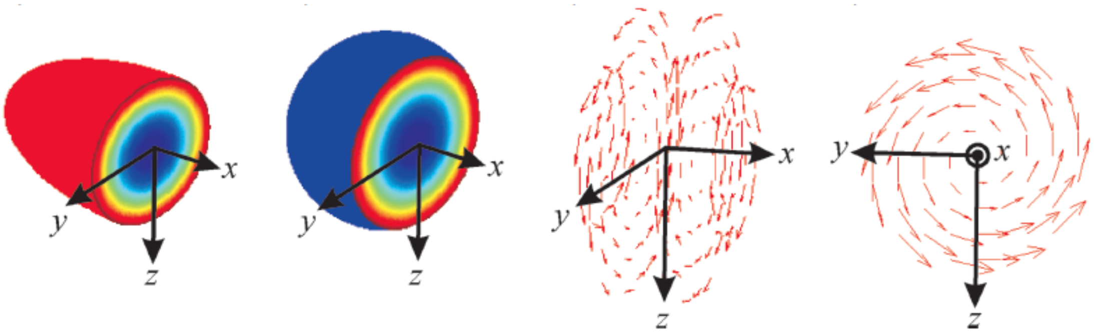




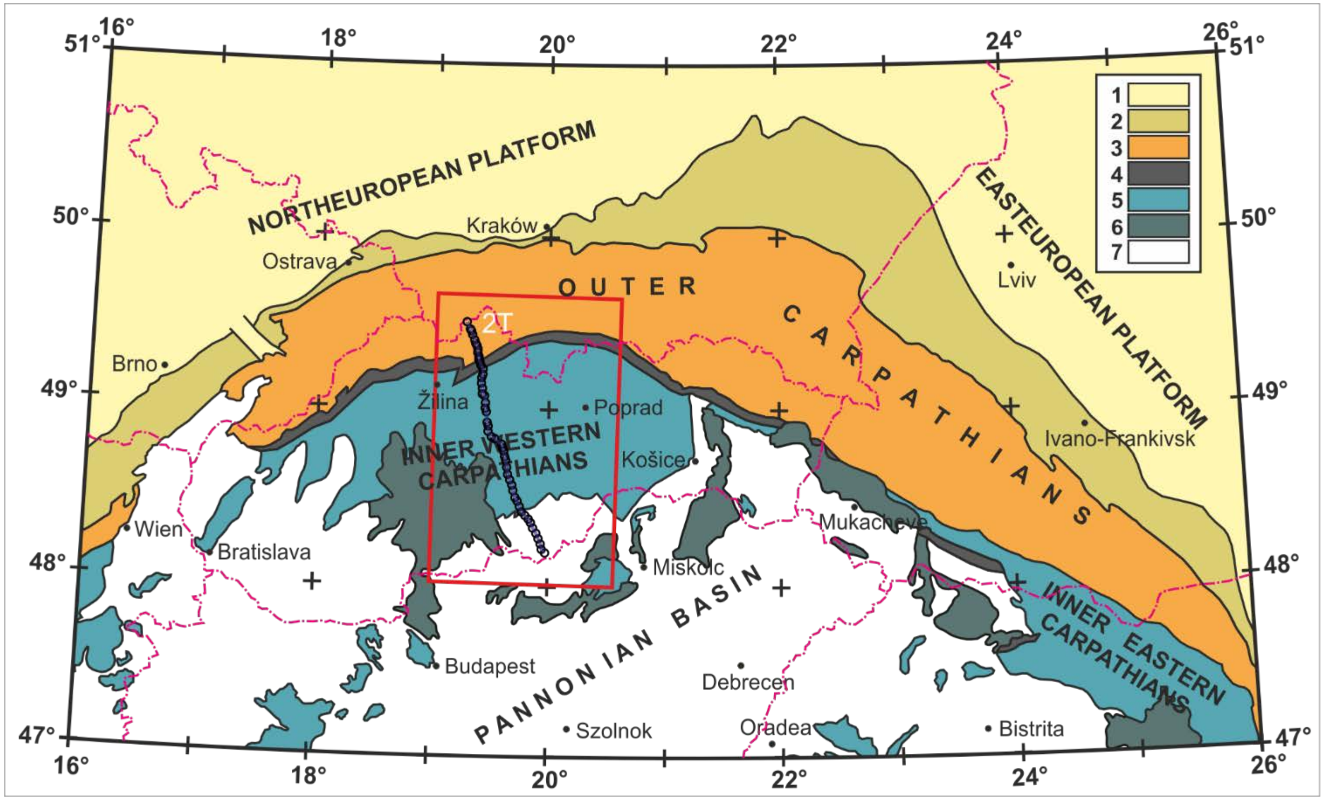
b) <u>Cross-gradient</u> (Gallardo & Meju, 2003; Moorkamp et al., 2013) – used in our modelling

$$\vec{t}(x,y,z) = \nabla m_1(x,y,z) \times \nabla m_2(x,y,z) \quad \Rightarrow \quad \vec{t}(x,y,z) = \vec{0}$$

Forced similarity of anomaly shape for all models



Modelled data and area

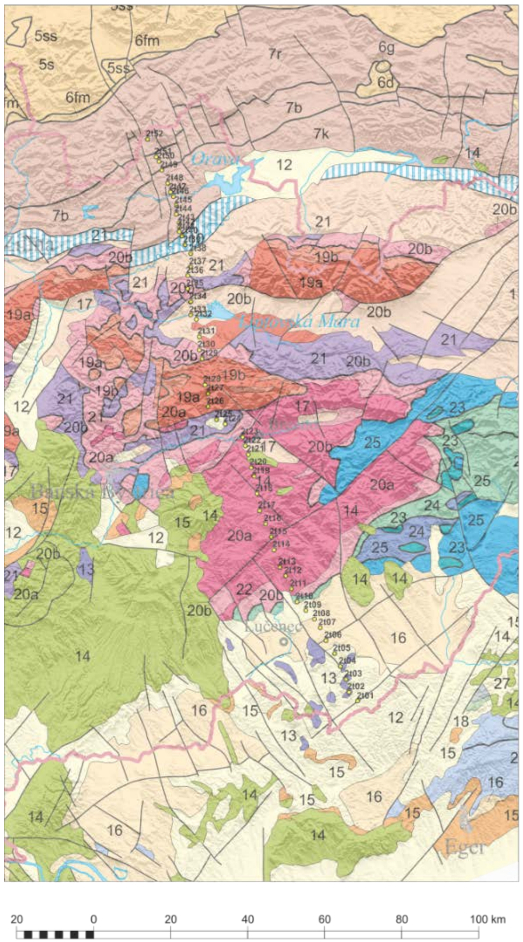


Position of the 2T profile (originally deep seismic reflection profile) in the Carpatho-Pannonian region. The basic tectonic map was modified after Majcin et al. (2017).

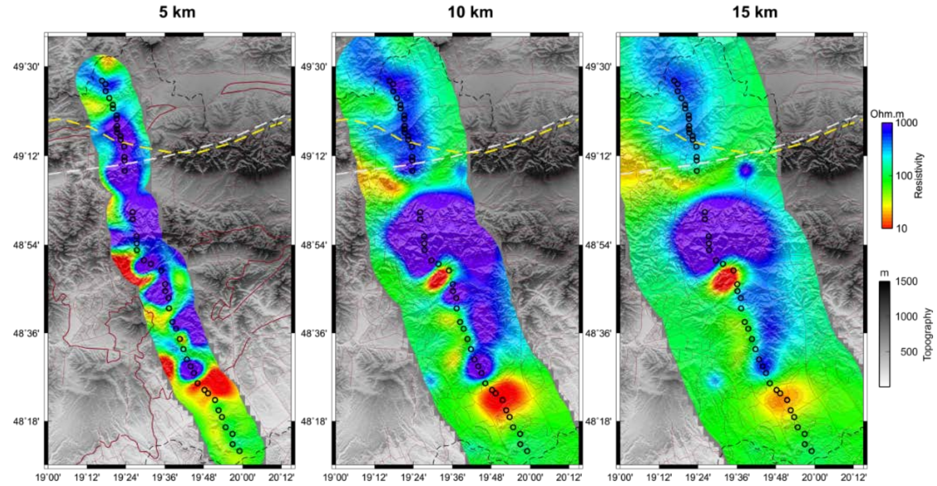
Key: 1 – European platform, 2 – Foredeep units, 3 – Outer Carpathian Flysch Belt, 4 – Klippen Belt, 5 – Inner Carpathian units, 6 – Neogene volcanites on the surface, 7 – Neogene and Quaternary sediments. Circles indicate MT sites position.

Results of joint inversion - 2T

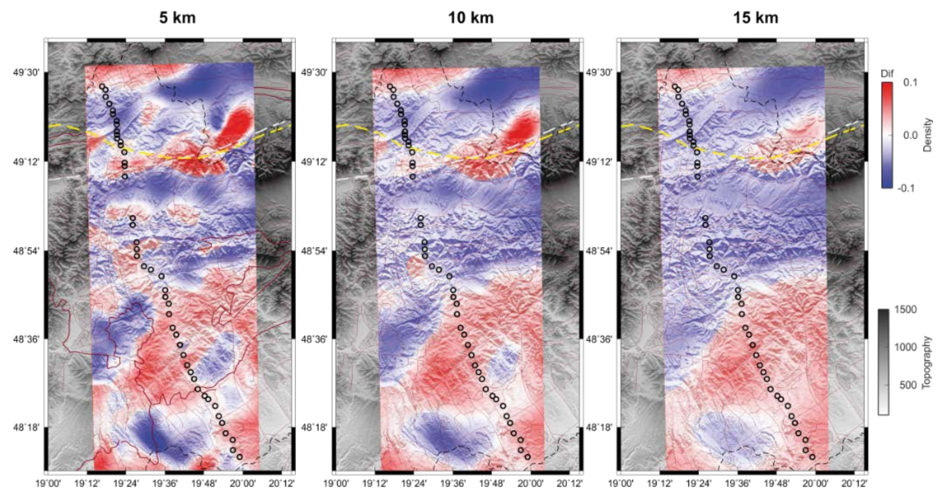
2T profile



3-D Joint Inversion Resistivity Model

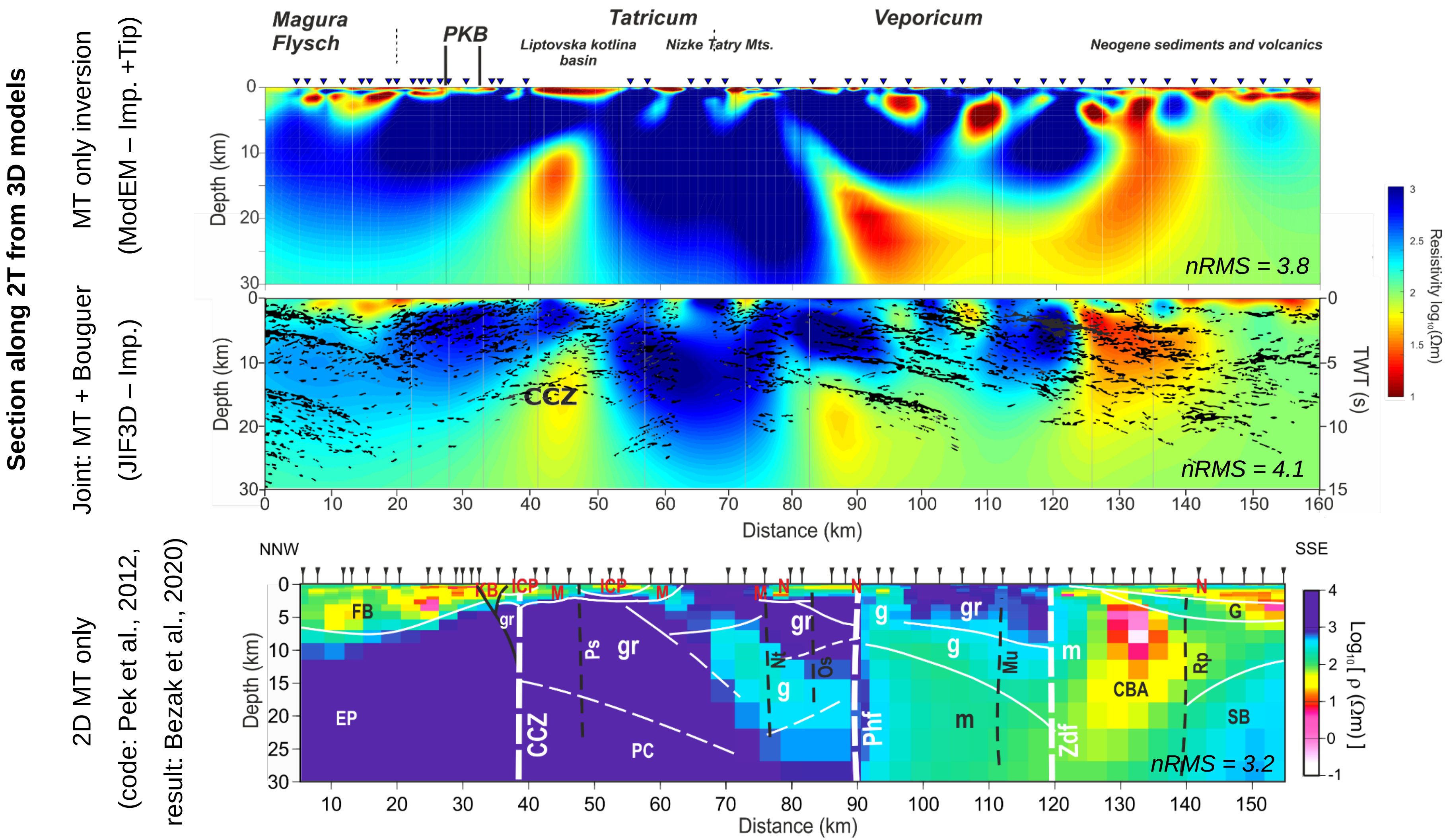


3-D Joint Inversion Differential Density Model



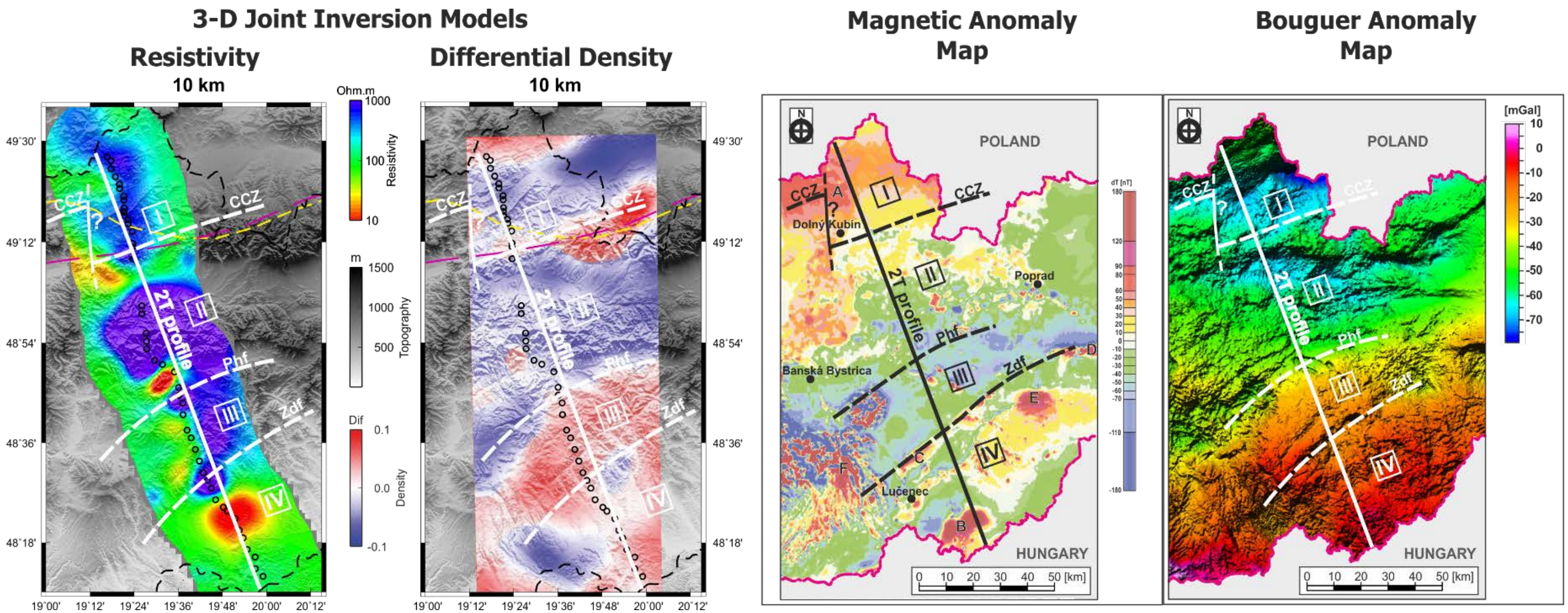
There are no seismic data suitable for use within our 3D joint inversion. Only constrains are used from CELEBRATION 2000 models and deep seismic reflection section 2T

Results of joint inversion – MT models



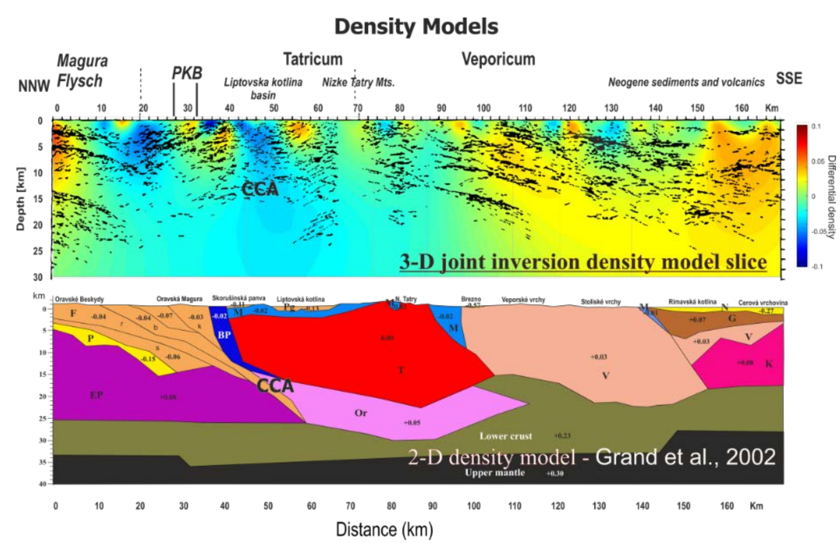
Most significant difference is in the position of Carpathian Conductivity Anomaly Zone (CCZ), due to offset of Pieniny Klippen Belt (PKB)

Comparison with other data



Offset of the CCZ. The purple dashed line is the CCZ position based on Jankowski et al. (1985). The yellow dashed line following from Cerv et al. (2001).

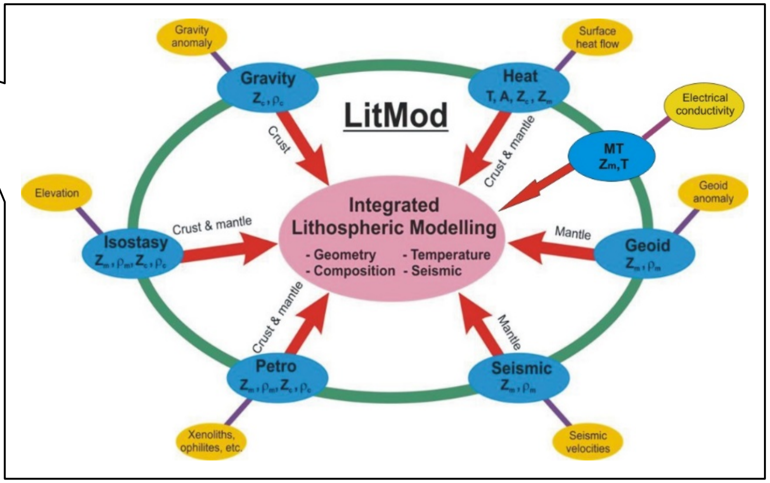
Phf – Pohorelá fault system, Zdf – Zdychava fault system



Step 2: Mantle modelling

Litmod3D – (Fullea at al., 2009)

- *Combines forward petrological and geophysical modelling*

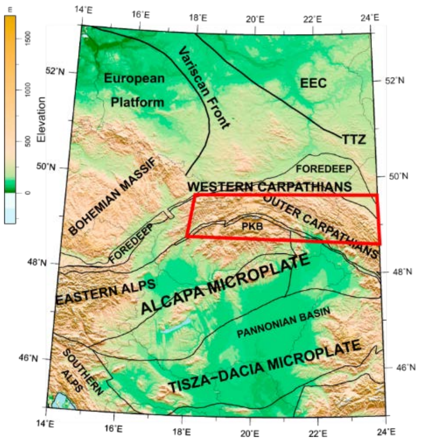


Model parameters coupling:

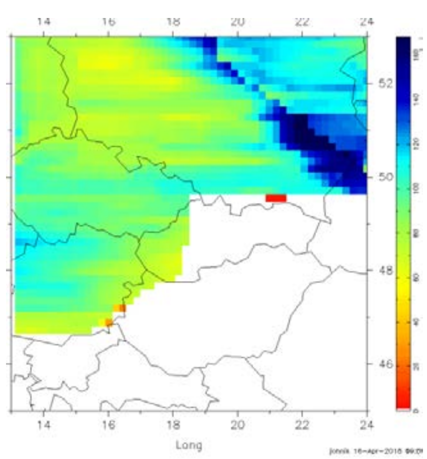
a) *Direct relationship*

- all relevant properties are functions of temperature, pressure and composition – only mantle *is calculated*

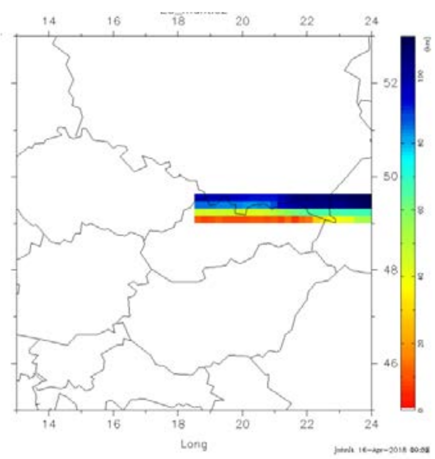
Background global model based on Alasonati-Tasarova et al., (2016). The main changes are situated on the contact zone between European platform and ALCAPA.



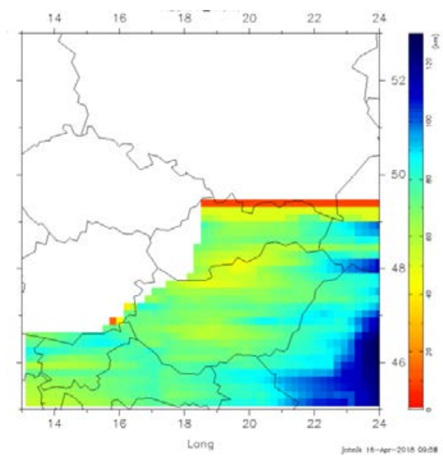
Thicknesses: EU Mantle



Transition zone EU

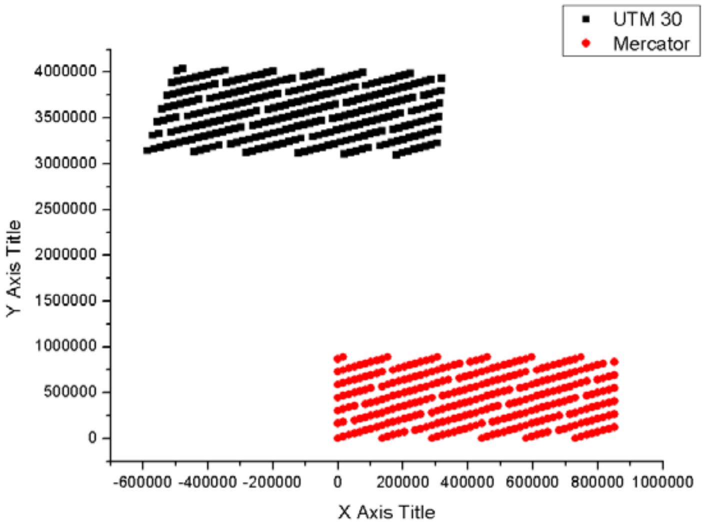


ALCAPA

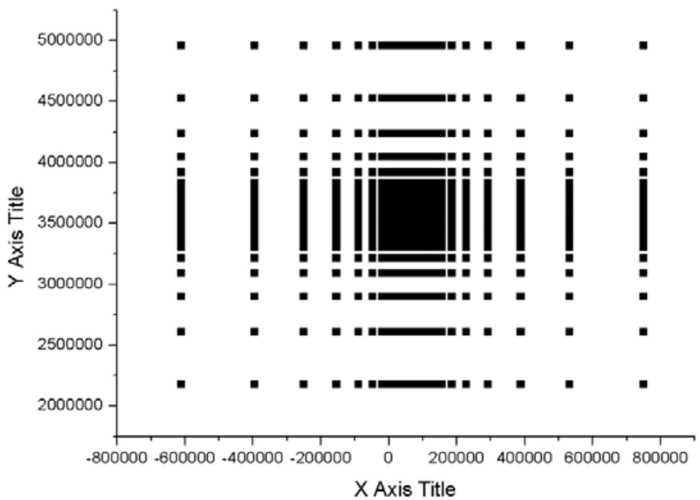


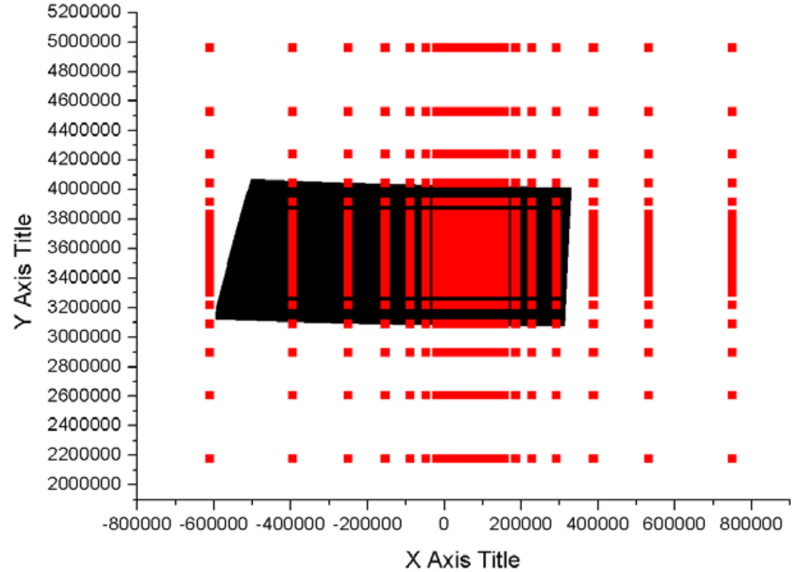
Model grid convertor – LitMod <-> MT

LitMod3D



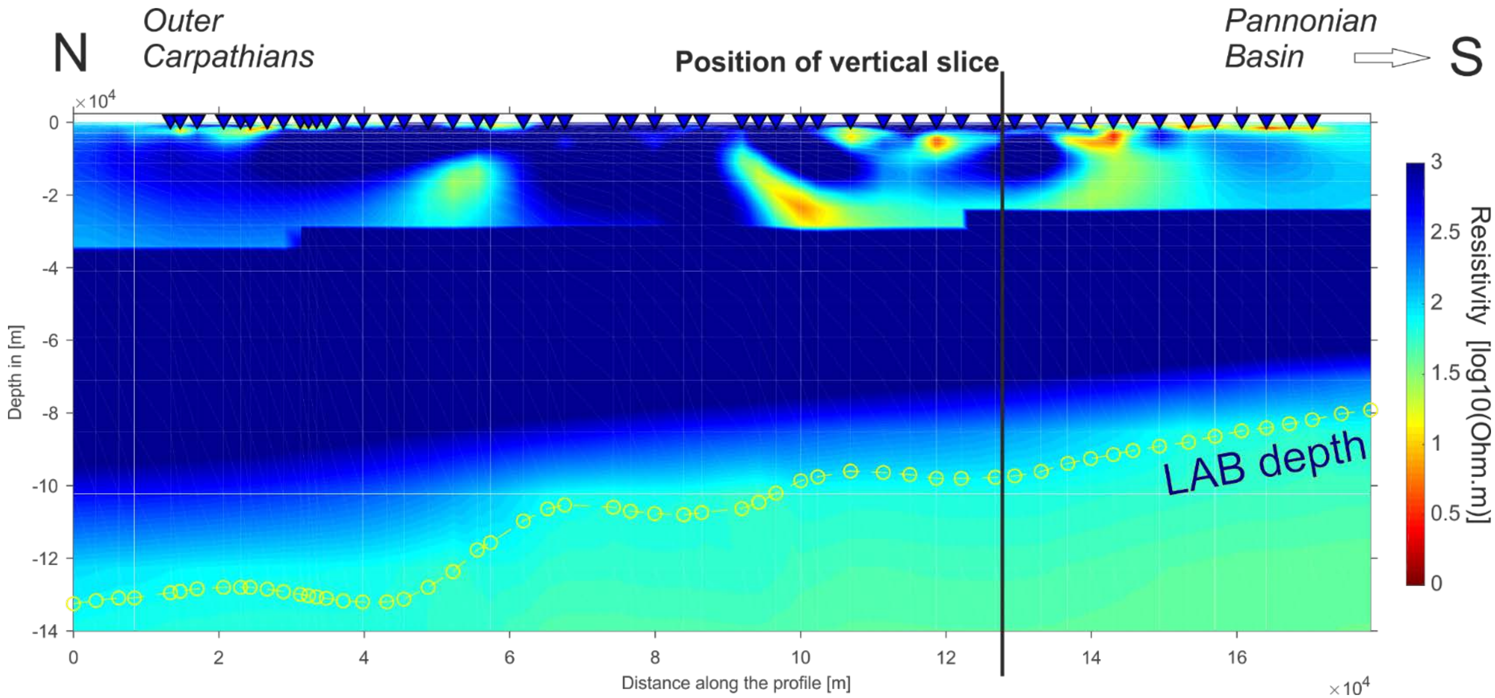
MT codes – finite differences





- *Geolocated model data are regrided for area (120x170km)*
- *Vertical discretization of MT mesh is restricted to 32, due to JIF3D restrictions*
- *The 3D regridding tool is based on Amidror, I. (2002) for scattered data interpolation with extrapolation correction*

Conductivity model based on Litmod3D



- Crustal model is imported from previous phase and mantle part is calculated by Litmod3D.

- The mantle part is fixed, only the crustal part undergoes new inversion process to fit the surface MT data (nRMS improved from 3.8 to 3.6).

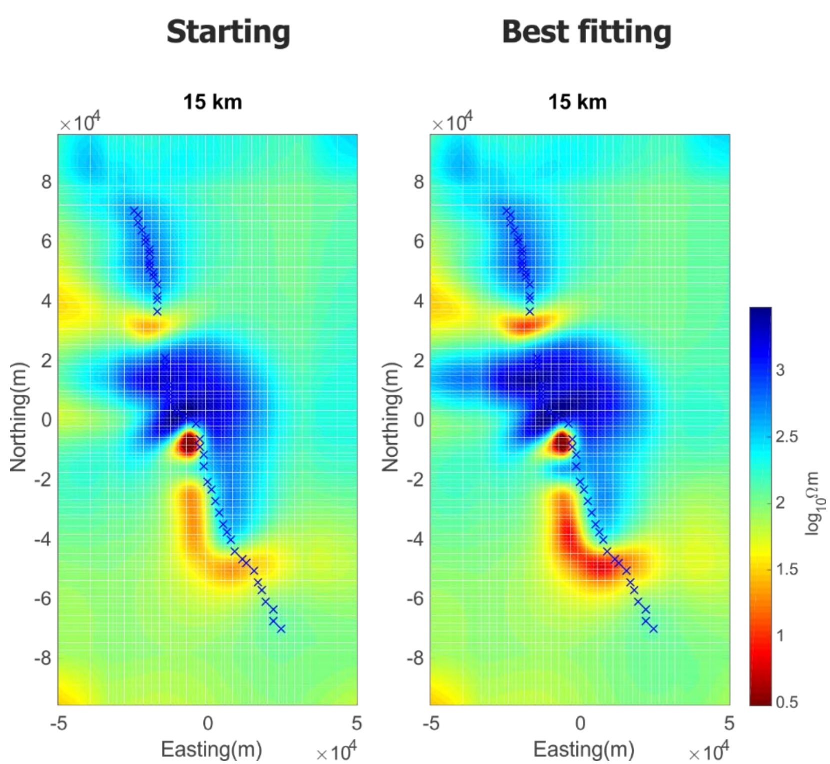
- The best fitting geoelectrical model is converted back to LitMod3D package. Within the process, the depth of Moho and LAB need to be changed in LitMod3D, to fit other geophysical data.

Conductivity model – tests

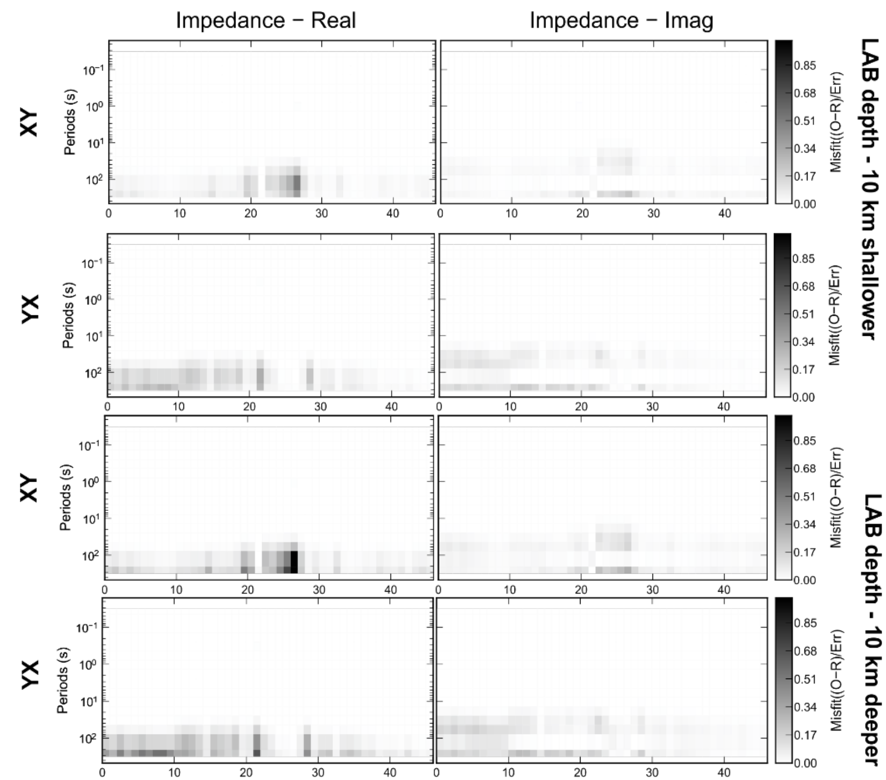
Integrated model with LitMod3D mantle part. The new inversion with fixed mantle shows improved fit of MT data and the resolution of CCZ.

Responses are sensitive to LAB depth change for periods of 10 seconds and longer, which allows lithospheric modelling.

Integrated model



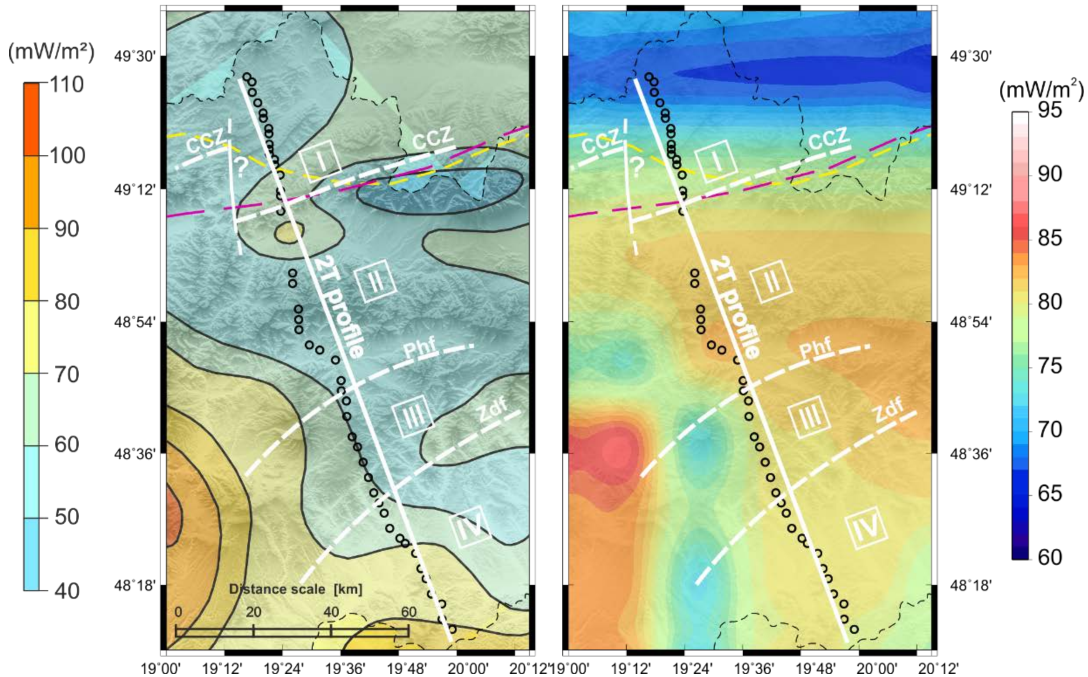
Change in responses for shifted LAB



Thermal modelling

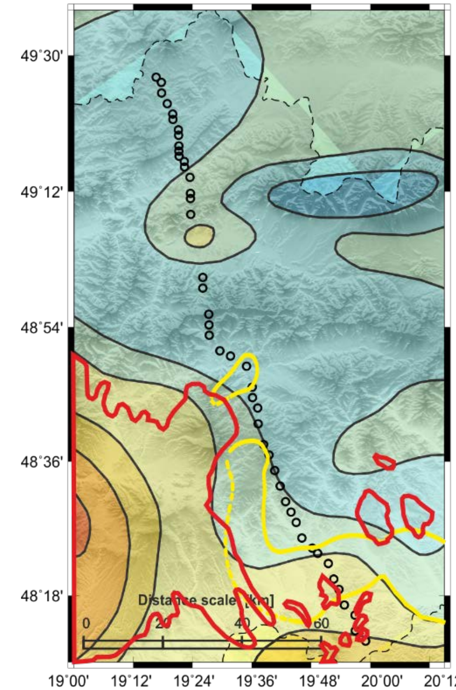
Terrestrial heat flow density distribution map

From measurement ***Calculated by LitMod3D***



Thermal map, based on Majcin et al., 2017 (left) derived from borehole measurements, exhibits lower heat flow. Elevated values in calculated version are probably due to high radiogenic heat production coefficients in granite units.

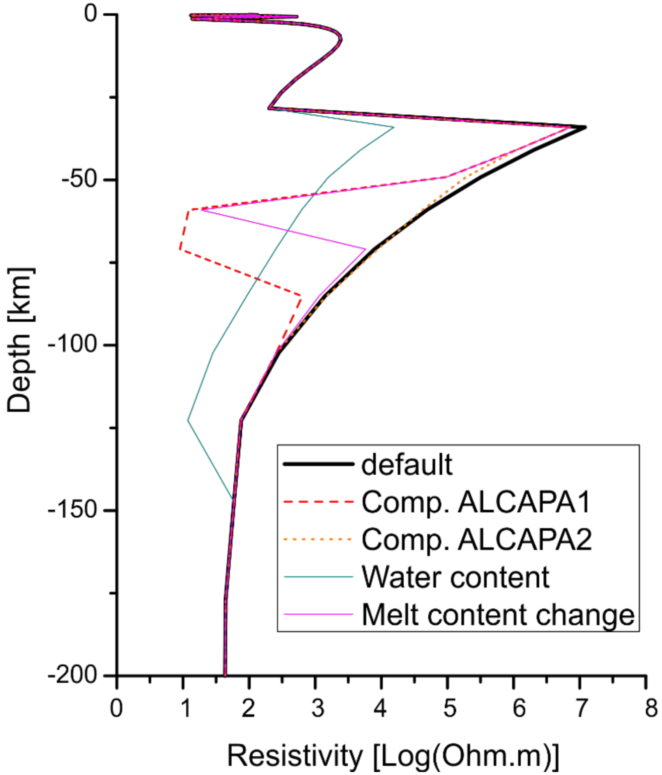
Neovulcanites



Areas with increased heat flow and young neovulcanic rocks (red line) correlate with conductive structures at depth 12km (yellow line, dashed line means uncertain boundary) indicates presence of melt in middle to lower crust.

Composition effects

Change in model resistivity for different compositions



Lit-Man	SiO2	Al2O3	FeO	MgO	CaO	Na2O	Mg#
ALCAPA	44.8	2.6	8.6	41.2	2.4	0.14	90.5
ALCAPA1	40.25	14.2	9.15	12.59	10.29	2.17	71.0
ALCAPA2	45.9	1.79	8.25	42.95	1.22	0.01	92.4
PUM	45	4.45	8.05	37.8	3.55	0.36	89.3

The compositions were determined from bulk xenolith samples information, collected in the Pannonian Basin from Balaton Highland (ALCAPA1, see Table) and from Kapfenstein (ALCAPA2). Water content change is modeled only in the mantle layers. In similar way the melt is distributed through the composition (partial melt in Na2O, SiO2, bulk value).

We are testing hypothesis, which can explain shallower electrical LAB depths in comparison to seismic models within the Pannonian basin.

Conclusion

- Joint inversion modelling for crust shows, that within the Carpathian block itself physical contrasting crustal segments exist. An oblique collision of the Western Carpathians with the European Platform occurred by the gradual shifting of various crustal segments with different geological composition along subvertical shear-zones.

- 3D modelling necessary to reveal well known CCZ, which was not mapped by 2D model due to offset of 20 km in north south direction along profile

- In southern part of the profile (neovulcanic area) melt and its penetration in NEE direction is shown

- The joint inversion process we used improves geological meaning of the density model, but nRMS of MT model is higher than in single MT model

- Our integrated 3D MT modelling, based on geophysical-petrological mantle model, improves the fit of MT data and better estimates the LAB depth

- Moreover, the mantle part is fully constrained by density and velocity model

- New parameters can be studied by MT modelling such as water and melt content, composition and effect of different temperature distribution.