Calculation of temperature distribution and rheological properties of the lithosphere along transect II in the Western Carpathian-Pannonian Basin region

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Abstract: The temperature model of the lithosphere along transect II passing through the Western Carpathians and the Pannonian Basin has been calculated using 2D integrated geophysical modelling methodology. Based on the extrapolation of failure criteria, lithology and calculated temperature distribution, we derived the rheology model of the lithosphere in the area. Our results indicate a decrease of the lithospheric strength from the European platform and the Western Carpathians towards the Pannonian Basin. The largest strength can be observed within the upper crust which suggests rigid deformation in this part of the lithosphere. In the lithospheric mantle, strength almost disappears which allows us to assume that the ductile deformation dominates in this part of the lithosphere.

Key words: geophysics, integrated modeling, temperature distribution, rheological parameters, compressional and extensional strength, the Western Carpathians, Slovakia

1. Introduction

The Carpathian-Pannonian Basin region is a very complex area where in a relatively small space, many different thermotectonic units can be identified. The Pannonian Basin is young and hot, whereas the Western Carpathians,

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although being young as well, are colder. The Bohemian Massif and the European platform, which underthrust beneath the Western Carpathians, represent the thermotectonically old lithosphere that forms a sharp rheological contrast to the former two lithospheric units. Despite the fact that the Carpathian-Pannonian Basin region has been very well studied and is geophysically covered by a huge amount of data such as deep seismic reflection and refractions transects (*Beránek and Zátopek, 1981; Mayerová et al., 1994; Tomek et al., 1987, 1989*), gravity data (*Bielik et al., 1990, 2006; Alasonati Tašárová et al., 2009; Zahorec et al., 2013*), radiometric data (*Mojzeš, 1998; Putiška et al., 2005*), geoelectric data (*Putiška et al., 2012*) and surface heat flow data (*Čermák et al., 1991; Majcin 1994; Majcin et al., 1998*) that provide valuable constraints on tectonic models, the Carpathian-Pannonian Basin region still remains a very challenging area to study the interactions among different tectonic units and influence of different parameters on the rheology of the lithosphere.

The first attempts on the rheological calculations of the lithosphere have been done by *Bielik and Striženec (1994)*, *Bielik and Ursíny (1997)*, *Ursíny and Bielik (1997)* and *Lankreijer et al. (1999)*. In 2012, for the first time, 2D integrated modelling algorithm has been applied to calculate temperature distribution and derive the rheological model along transect I passing through the Carpathian-Pannonian basin region (*Dérerová et al., 2012*). We continue in our effort to create a comprehensive and complete rheological model of the Carpathian-Pannonian lithosphere and apply our integrated modelling approach for calculating rheological model along transect II.

2. The Western Carpathian Transect II

The studied Transect II (*Zeyen et al., 2002*) starts in the European platform, crosses the western part of the Western Carpathian mountains in south-eastern direction, passes through the Danube Basin and finishes in the Pannonian Basin (Fig. 1). It traverses through Czech Republic, Slovakia and Hungary in length of 500 km. The layout of the main geological structures of investigated area is also depicted on Fig. 1.

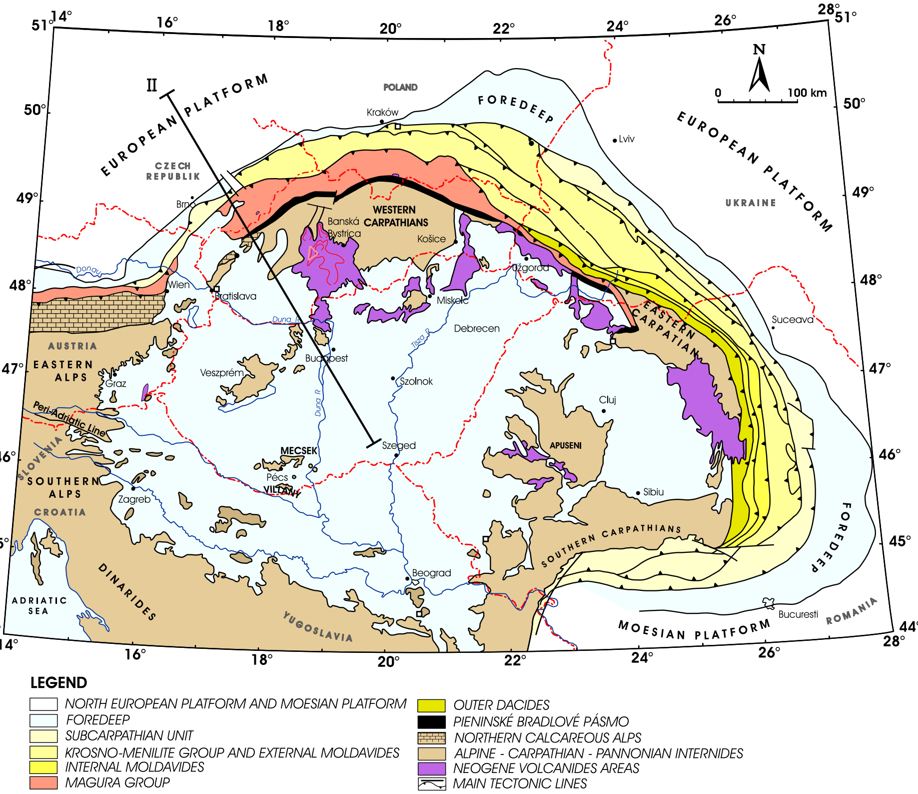


Fig. 1. Location of transect II on the map of the Carpathian-Pannonian basin region (modified after *Zeyen et al. (2002)*).

3. Method

Lithospheric structure along Transect II (Fig. 2) has already been modelled as a part of geophysical and tectonic reconstruction of the Western Carpathians-Pannonian basin region (*Zeyen et al., 2002*). 2D integrated geophysical modelling method that combines the joint interpretation of surface heat flow, gravity, and topography data for the determination of the lithospheric thermal structure has been used. Detailed description of the method can be found in *Zeyen and Fernàndez (1994)*. Based on the determined temperature distribution in the lithosphere, we can calculate the

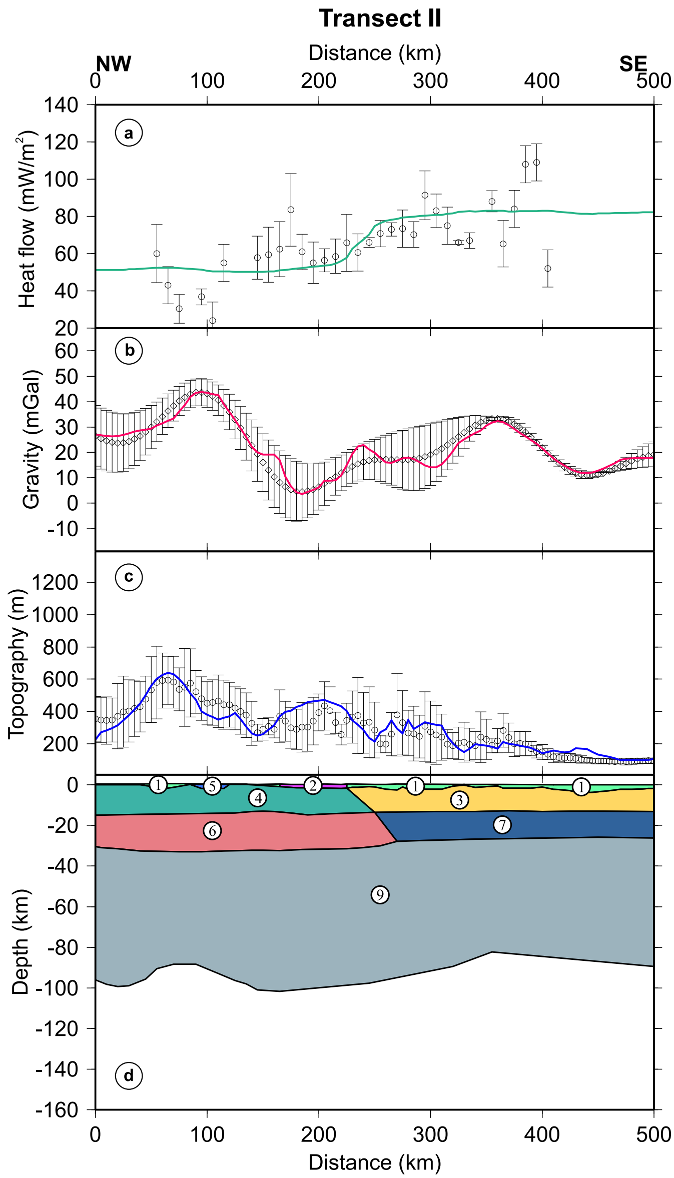


Fig. 2. Lithospheric model along transect II. (a) Surface heatflow, (b) free air gravity anomaly, (c) topography with dots corresponding to measured data with uncertainty bars and solid lines to calculated values. Numbers in (d) correspond to material parameter values in Table 1b (*Zeyen et al., 2002*).

yield strength for a given distribution of rheological rock parameters. The strength is defined as the minimum of brittle and ductile strengths at each point. For brittle strength calculation we have assumed that deformation occurs according to the frictional sliding law given by *Byerlee (1978)*:

$$\sigma_{brittle} = \alpha\, \rho\, g\, z(1-\lambda),$$

where $\sigma_{brittle}$ is brittle failure function [Pa], parameter $\alpha = R - 1/R$ is valid for normal faulting, $\alpha = R - 1$ for thrust faulting, $\alpha = R - 1/[1+\beta(R-1)]$ for strike-slip faulting. Parameter $R = \left[\left(1+f_s^2\right)^{1/2} - f_s\right]^{-2}$ depends on coefficient of static friction f_s, λ represents the hydrostatic pore fluid factor, ρ is material density [$\mathrm{kg\,m^{-3}}$], g is acceleration of gravity [$\mathrm{m\,s^{-2}}$], z is depth [m], β is extension factor.

Ductile strength is calculated assuming power-law creep deformation given as (*Lynch and Morgan, 1987*)

$$\sigma_{creep} = \left(\frac{\dot{\varepsilon}}{A_p}\right)^{1/n} \exp\left[\frac{E_p}{n RT}\right],$$

where σ_{creep} is power law creep function [Pa], $\dot{\varepsilon}$ denotes strain rate [$\mathrm{s^{-1}}$], A_p is Dorn constant, n is power law exponent, E_p is power law activation energy [$\mathrm{kJ\,mol^{-1}}$], R is universal gas constant [8.314 $\mathrm{J\,mol^{-1}\ K^{-1}}$], T is temperature [K].

4. Results

We have calculated temperature distribution for a given lithospheric structure along transect II (Fig. 3), where the lower limit of the model corresponds to 1300 °C isotherm. The calculated temperature field highly depends on distribution of the heat sources mainly in upper crust and background heat flow density from the lower mantle. The reliability of the temperature model normally depends on the accuracy and density of measurements of the surface heat flow density data but our lithological model is constrained by calculation of free air anomaly and topography, which increases the reliability of the model.

Based on the rheological parameters shown in Table 1a and Table 1b, we

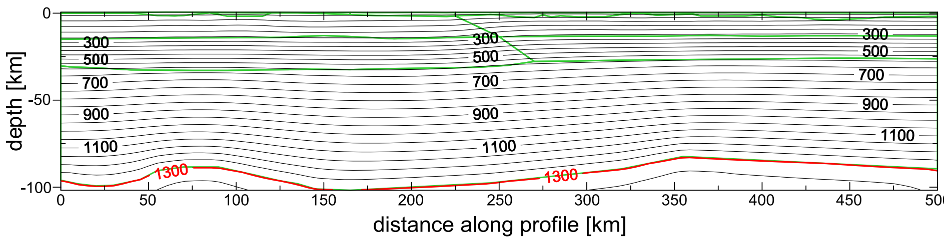


Fig. 3. Lithospheric temperature distribution calculated for transect II, isolines every 200 °C. The bottom of the model corresponds to the 1300 °C isotherm (red line).

have calculated strength distribution in the lithosphere for studied transect. Fig. 4 shows vertically integrated compressional and extensional strength calculated along transect II. Fig. 5 and Fig. 6 show the calculated yield strength contour plot for compressional and extensional deformations. In our calculations we adopted a strain rate 10^{-15} s^{-1}, which is commonly observed in compressional and extensional settings (*Carter and Tsenn, 1987*). The strength envelopes have been calculated for both compressional and extensional regimes. Fig. 7 shows strength distribution for selected lithospheric columns in the European platform, the Western Carpathians and the Pannonian Basin.

The results related to the vertically integrated compressional and extensional strengths along transect II (Fig. 4) indicate that the lithospheric strength decreases from the European platform and the Western Carpathians (with maximum in the Western Carpathians) to the Pannonian Basin. Decrease is more prominent in the case of compressional strength. Analysis

Table 1a. General properties used for calculation of rheological model

Definition	**Parameter**	**Value**
Gravity acceleration [ms^{-2}]	g	9.806
Universal gas constant [J mol K^{-1}]	R	8.314
Temperature at the base of the lithosphere [°C]	T_m	1300
Static friction coefficient	f_s	0.6
Strain rate [s^{-1}]	$\dot{\varepsilon}$	10^{-15}
Hydrostatic pore fluid factor	λ	0.35

Table 1b. Thermal and rheological parameters used for modelling along transect II (after *Carter and Tsenn (1987)* and *Goetze and Evans (1979)*). HP: heat production (μWm^{-3}), TC: thermal conductivity (Wm^{-1}K^{-1}), ρ: density at room temperature (kgm^{-3}), A_p: power law pre exponential constant, n: power law exponent, E_p: power law activation energy (kJ mol^{-1})

Nr.	**Unit**	**HP**	**TC**	**Density**	A_p	n	E_p
1	Neogene sediments	2.5 – 3.0	2.5	2400 – 2550	3.16E–26	3.30	186
2	Flysch and Volcanics	1.0 – 2.5	2.0 – 2.5	2550 – 2650	3.16E-26	3.30	186
3	Carpathian and Pannonian upper crust	3.0 – 3.5	3.0	2750	3.16E-26	3.30	186
4	European upper crust	0.5 – 2.0	2.5 – 3.0	2750 – 2800	3.16E-26	3.30	186
5	Anomalous upper crust (Bohemian Massif)	1.0	2.0	2900	3.16E-26	3.30	186
6	European lower crust	0.2	2.0	2960	6.31E-20	3.05	276
7	Carpathian and Pannonian lower crust	0.2	2.0	3000	6.31E-20	3.05	276
9	Lower (mantle) lithosphere	0.05	3.4	3325	7.94E-18	4.50	535

of the yield strength contour plot for compressional and extensional deformation (Figs. 5 and 6) and vertical strength distribution for different lithospheric columns for compressional and extensional deformation (Fig. 7) calculated along transect II shows the largest strength within the upper crust with the maximum around 450–500 MPa on the boundary between the upper and lower crust. This feature can be observed for all studied tectonic units: the European platform, the Western Carpathians and the Pannonian Basin. These results can be explained by mostly rigid deformation in the upper crust of the lithosphere. Towards the lower crust, the strength significantly decreases (more prominently in case of compressional strength) for all studied units. Within the uppermost mantle (lower lithosphere) the lithospheric strength almost disappears which can be explained by mostly

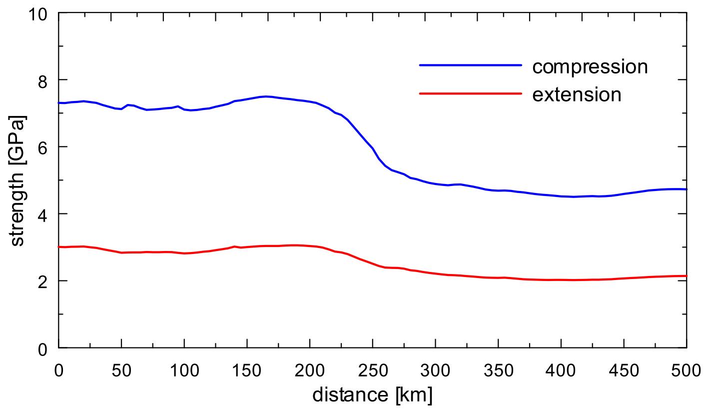


Fig. 4. Vertically integrated compressional (blue line) and extensional (red line) strength calculated along the transect II.

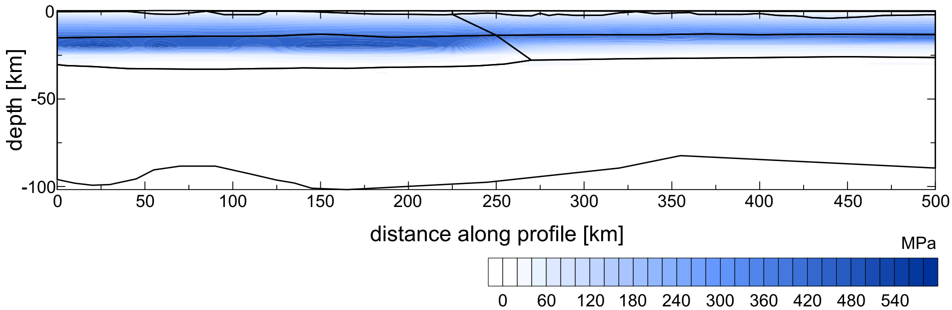


Fig. 5. Yield strength contour plot for compressional deformation calculated along transect II calculated at a strain rate 10^{-15} s^{-1}.

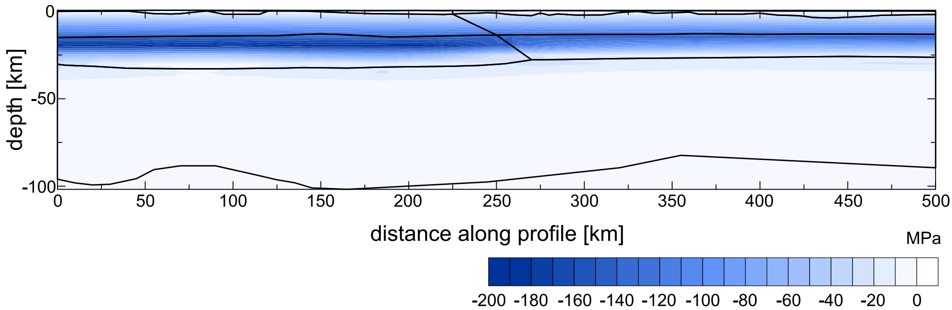
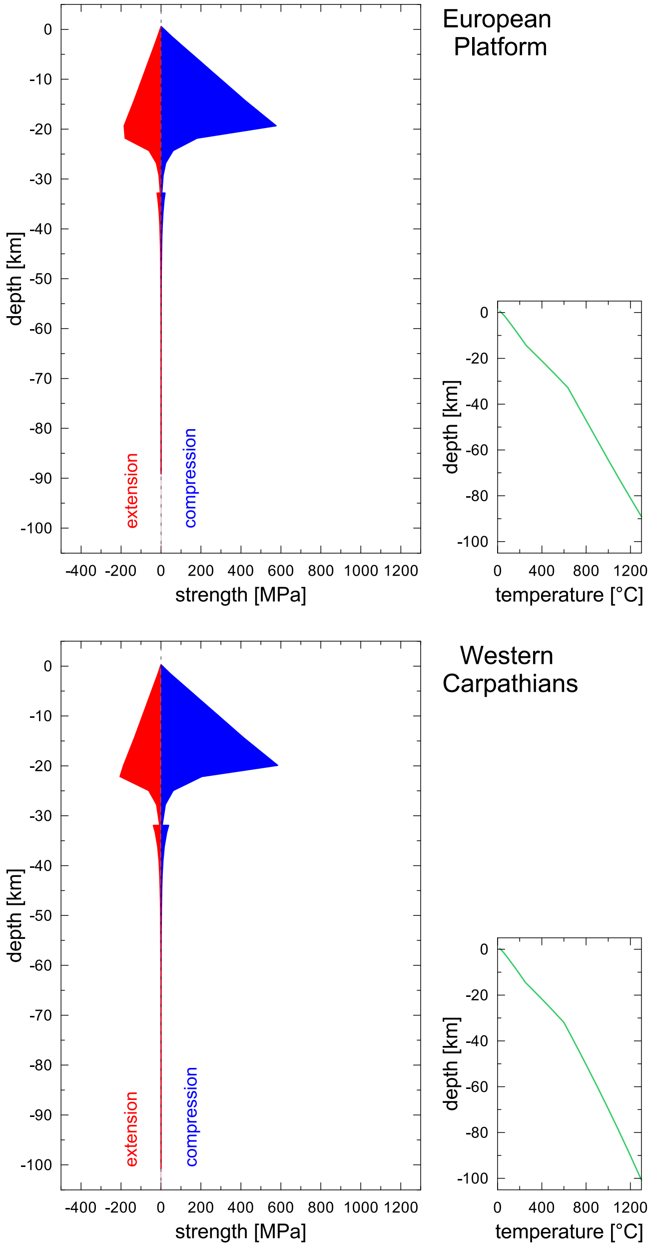


Fig. 6. Yield strength contour plot for extensional deformation calculated along transect II calculated at a strain rate 10^{-15} s^{-1}.



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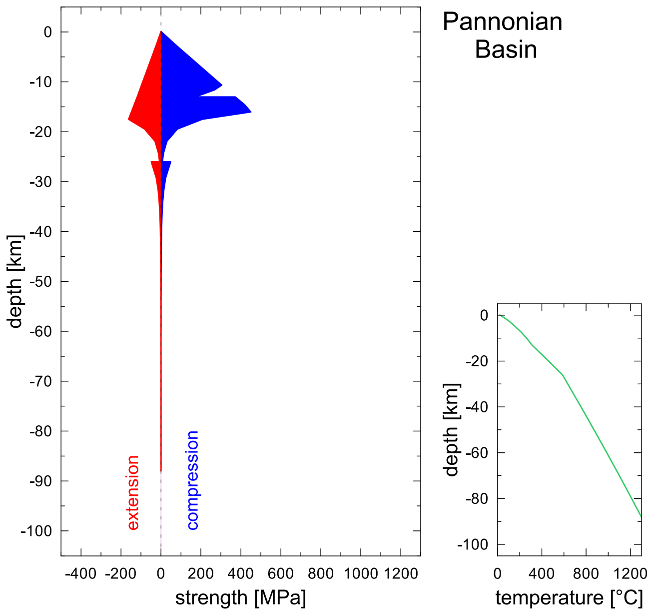

Fig. 7. Vertical strength distribution for different lithospheric collumns calculated along transect II. Negative and positive values correspond to extensional and compressional strength, respectively.

ductile deformation in this part of the lithosphere. Our results are in a good correlation with previously published results of rheological modeling for the transect I located in the Carpathian-Pannonian Basin region (*Dérerová et al., 2012*).

5. Conclusions

We have derived a rheological model of the lithosphere along transect II passing through the Western Carpathians-Pannonian Basin region. Our results indicate the decrease of the lithospheric strength from the European platform and the Western Carpathians towards the Pannonian Basin. The largest strength can be observed within the upper crust which suggests rigid deformation in this part of the lithosphere. In the lithospheric mantle, strength almost disappears whichallows us to assume that the ductile deformation dominates in this part of the lithosphere.

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