Research of deep crustal structures by electromagnetic sounding and other geophysical methods in the northern part of Slovakia

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Abstract: The new results of integrated geophysical modelling of deep structures in selected areas of northern Slovakia play an important role in the precise description of the geodynamic development of the entire Carpathian–Pannonian region. This knowledge is important from a scientific point of view and has a direct impact on economic activities connected with the shallow structures of the Earth's crust. Over the last years, we are focused on modelling of magnetotelluric (MT), gravimetric, and geothermal data mainly in NW and N part of Slovakia, particularly in the wider zone of the Inner and Outer Carpathian contact.

Methodology

Integrated modelling consisted of using mathematical algorithms to connect or represent different geophysical images (electrical conductivity, material density, and thermal parameters with depth) into a single geological interpretation model. The magnetotelluric (MT) method provides very important structural characteristics based on electrical conductivity, which is physically distinct from mechanical parameters obtained from the gravimetric and seismic methods. For example, the MT method provides much higher sensitivity to the transport properties of geological units, in particular for water (Blake et al. 2016) and melted rocks (Le Pape et al. 2012). We have used the latest methodologies and programmed tools, like IGMAS+ (Schmidt et al. 2011), JIF3D (Moorkamp et al. 2011) and LitMod (Fullea et al. 2009).

Multiple types of geophysical (electromagnetic, seismic, and gravimetric) methods utilization (Moorkamp et al. 2011) in the multi-dimensional inverse modelling, greatly enhances the correct interpretation of the collected geophysical data (Jegen et al. 2009). This approach based on the coupling between models also provides new information about the physical parameters and their relationships in the examined structures (Moorkamp et al. 2013). The MT data in form of impedance tensor were inverted to 3D geoelectrical MT models were by ModEM inversion code (Kelbert et al. 2014).

Results

For the W and N part of the Inner Western Carpathians the structure of the small mountain ranges (horsts) separated by small basins (grabens) with Tertiary sedimentary filling is typical. It is the result of the youngest stages of tectonic development in Neogene. In this case the old and newly collected geophysical data and methodology have been used concretely to model of the Tatry Mts. horst as the most northern horst in the Inner Western Carpathians and its relation to the so-called Ružbachy island (Bezák et al. 2018). Our magnetotelluric measurements focusing particularly on

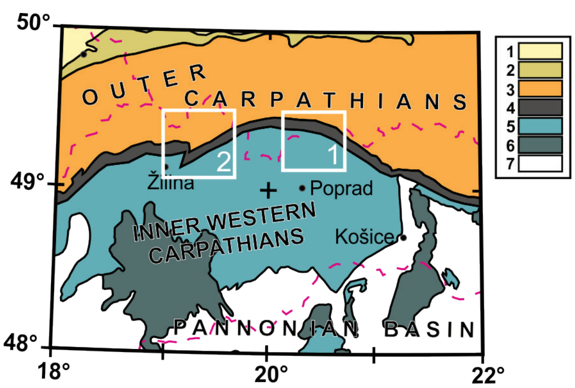

Fig. 1. Position of the studied areas (white rectangles). Basic tectonic map was modified after Majcin et al. (2017). Structure description: (1) European platform, (2) Foredeep units, (3) Outer Carpathian Flysch Belt, (4) Klippen Belt, (5) Inner Carpathian units, (6) Neogene volcanites on the surface, (7) Neogene sediments

the nature of the Sub-Tatra fault confirm steep dip of Sub-Tatra fault in the southern border of the Tatry Mts. Measurements show also the connection of Tatry and Ružbachy horsts to the one initially transpressional structure. The structural discordance between the axis of this structure and Klippen Belt direction is a result of younger tectonic processes.

Deep structure of Inner Carpathian Paleogene basin in the Spišská Magura Mts. and the nature of its contact with the Klippen belt units have been also investigated (Majcin et al. 2018). The older measurements from profile MT-04 (from MT continuation of the CELEBRATION 2000 project) were combined with the new perpendicular (the SW–NE oriented) MT profile SL-1 near Stará Ľubovňa, which passes through the Outer Carpathian Flysch Belt, Klippen Belt and ends in the Inner Western Carpathian Paleogene NE from Ružbachy horst structure. The 2-D geoelectrical models were reanalysed by 3-D MT modelling of the studied region, which enabled the evaluation of 3D effects in the original 2D modelling and prepares more robust and complex models (Fig. 2).

The MT data interpretations verified the northern inclination of the Flysch Belt structures and their smaller thickness out of Klippen Belt in direction to the Carpathian electrical conductivity zone (CCZ) axis. We consider this as a consequence of the flower structure-more precisely the southern branch of the suture zone related to the mentioned conductivity zone. Northerly from this zone the thickness of the Outer Carpathian Flysch Belt increases and the structures have an inclination to the south, i.e. to the subduction zone. The contact of Flysch Belt with Klippen Belt has a fault character and it is subvertical, slightly inclined to the North. The southern boundary between Klippen Belt and the Inner Western Carpathians has also fault character and is very steep. According to our results, the depth distribution of the pre-Tertiary basement below the Inner Western Carpathian units is non-uniform; the basement is also broken to a number of partial blocks-horsts and grabens.

The interpretation of our new measured MT profile LES-1, crossing the mentioned structures in NNW-SSE direction, allows revealing the overthrusting structure of Klippen belt over Flysch belt complexes. The contact of Flysch belt and Klippen belt is not influenced by a deep fault with shifted structures as in the profile SL-1. The newest MT works confirm, among other results, also the geologic interpretations of contributions (Plašienka & Mikuš 2010; Jurewicz 2018) made in this region of study.

The deep crustal and lithospheric studies with the goal to characterized Carpathian shear corridor and its relation to the Western Carpathian deep-seated structures have been performed along old deep seismic reflection profile 2T (Bezák et al. 2016). The MT, gravimetric and geothermal data were modelled on the section in addition to seismic information and were used for the interpretation. The CCZ was not clearly presented in the older 2D MT model due to offset in linear structure visible also in the Klippen Belt. This complex shape was revealed by recent 3D MT and gravity modelling of the same area (Fig. 3).

Our methods can clearly identified the crustal segments with contrasting physical parameters and thus contrasting geological composition along this profile. Few different tectonic segments can be identified in the north part of Slovakia (North European platform with overlying Flysch Belt nappes, block of the Pienninic crust with relics of the Klippen Belt complexes, block of the Tatricum unit with typical horsts and grabens structure).

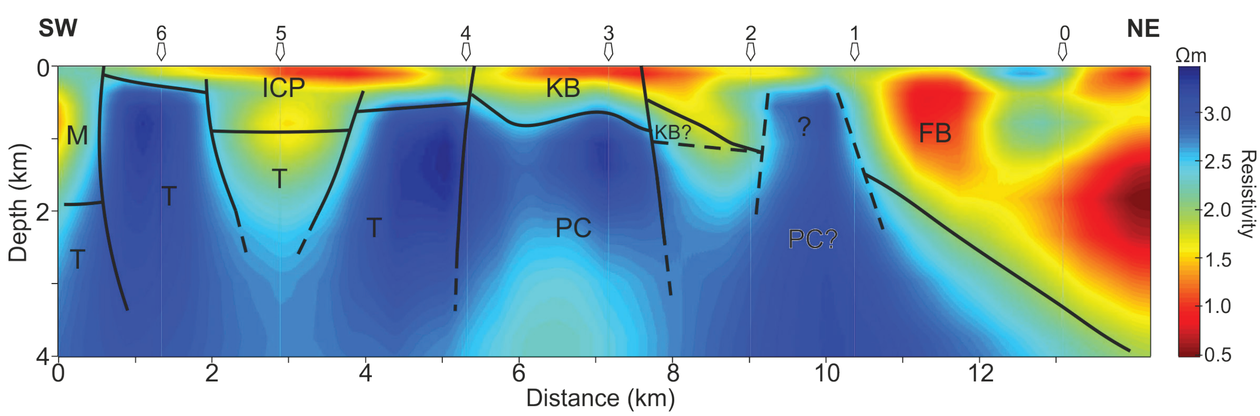

Fig. 2. Interpreted geoelectrical section through 3D MT inversion model along SL-01 profile (area 1 in Fig.1). Structure description: M — Mesozoic complexes, T — Tatricum unit, ICP — Inner Carpathian Paleogene, KB — Klippen Belt, PC — Pienninic crust, FB — Flysch Belt.

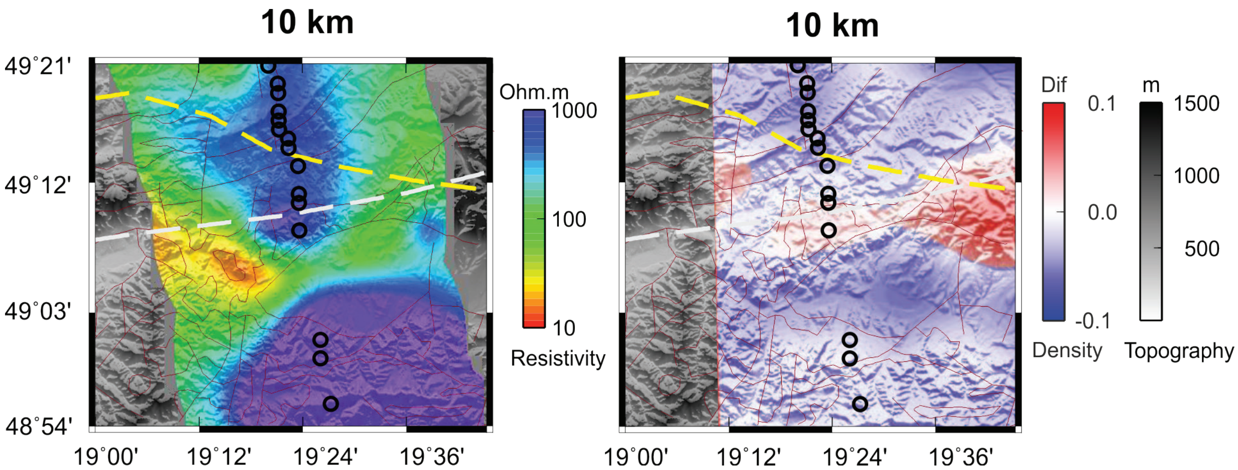

Fig. 3. The horizontal slices through 3-D joint inversion geoelectric and differential density models at depth 10 km in the area of northern part of the seismic 2T profile (area 2 in Fig.1). Thick dashed lines indicate expected position of the CCA based on Jankowski et al. (1985) (white) and Červ et al. (2001) (yellow).

Additionally to these regional and deep studies, the new detailed MT measurements north from the Malá Fatra Mts. have been carried out. They are focused on the nature of the offset in Klippen belt zone in this area, which may also be correlated with the shift in the CCZ in the mid-crustal depths.

Knowledge of the thermal state of the lithosphere is based on the results of direct measurements as well as modelling approaches. An important contribution to the direct research methods for whole Slovakia is also currently completed in the project focused on the hot dry rocks energy utilization (Majcin et al. 2017).

Conclusion

Crustal structures in the northern part of Slovakia were interpreted based on MT data with help of supplementary gravity, seismic and geothermic information. The MT measurements in northern Slovakia along the northern part of seismic profile 2T and MT profile SL–01 were modelled using new processing and inversion methods. Geoelectric model reveals the position and structure of the deep crustal tectonic units and identifies major deep fault zones. The presented northern part of the model exhibits a significant influence of resistive complexes composed of Cadomian crystalline basement of European platform beneath Outer Western Carpathians conductive sediments of Flysch belt. The important contribution of the MT method for the interpretation of the crust structures is the differentiation of high-resistivity and low-resistivity complexes as physically contrasting geological bodies. Young steep shear zones can be well identified by the MT method due to their high conductive properties.

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