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Regional and local phenomena influencing the thermal state in the Flysch belt of the northeastern part of Slovakia

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Abstract: The locality of the northeastern most part of Slovakian Flysch belt belongs to interesting areas in terms of the interpretation of geothermal conditions in mutual relation with the lithosphere structure and their tectonic development. The evaluation of the geothermal energy sources parameters of this locality is likewise worthwhile. The region under study has the centre in position of the borehole Zboj ZB-1 and spreads out Slovakia also in Poland and Ukraine.

Our contribution provides the analyses of existing geothermal data enhanced by the construction of temperature field models corresponding to the global and local aspects that influence the temperature and heat flow density distributions. The analyses are related to the structures and effects of separate phenomena along as well as across the Carpathian arc. The model calculations were carried out both by analytical and numerical methods of solving the heat transfer equations including their steady state forms and transient cases too.

Besides the regional trend of thermal activity decrease in direction from East-Slovakian Basin to the outer Carpathian units the combined local influences are applied: subsurface thermophysical parameters of rock complexes distributions, non-stationary sources from supposed subvolcanic bodies in close surroundings of borehole Zboj ZB-1, and the effects of the hydrological factors. Considering the observed higher thermal activity in arched zone along the Carpathian structures we discussed the thermal effects of rock complexes supposed as a source of regional Carpathian Conductivity Anomaly and the transfer of heat from East-Slovakian Basin to Outer Carpathian Flysch units. The analysis and the

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modelling results suggest that the mentioned activity is caused by the influences of source type phenomena mainly related to deep fault systems at the margin of the European Platform. That means the anomalies in heat flow density distribution can reach the value 70 mW/m^2 and more in the zone above the thermally active deep-fault system with the presence of volcanism and hydrothermal activities.

Key words: geothermal field, Outer Carpathians, Flysch sediments, Neogene volcanism, Carpathian Conductivity Anomaly

1. Introduction

The aim of this paper is to analyse the thermal conditions in the northeastern most part of Slovakian Flysch belt. For this locality it is worthwhile to evaluate the thermal parameters of prospective geothermal energy sources. Moreover, the locality is interesting for study and interpretation of mutual relations between the geological structures and their tectonic development on one side and the distributions of temperature and heat flow density on the other side. The recently gained geophysical and geological knowledge support the interest in mentioned region.

The northern part of the Carpathians represents a complicated mountain range, which consists of various tectonic units and blocks. The basic division into Outer and Inner Carpathians reflects Neoalpine tectonic evolution during the Neogene when the collision of the Inner Carpathian Block with the European Platform formed the Outer Carpathian Flysch Belt. The Pieniny Klippen Belt makes up the boundary between the Outer and Inner Carpathians.

The main part of studied area (Fig. 1) belongs to the Outer Carpathians. This unit is composed of a stack of nappe sheets extending along the Carpathian arc, which may be up to six kilometres thick. There are various opinions as to the distance of thrusting of the Outer Carpathians nappes over the southern part of the North European Plate (e.g., over 70 km supposed by *Golonka et al., 2005*). The latest paper in which these problems are analysed is *Gagała et al. (2012).* These nappes were detached from the basement during the overthrusting tectonic activity. *Behrmann et al. (2000)* concluded about 260 km shortening in the NE Outer Carpathians. According to the tectonic and geological maps (*Bezák et al., 2004;*

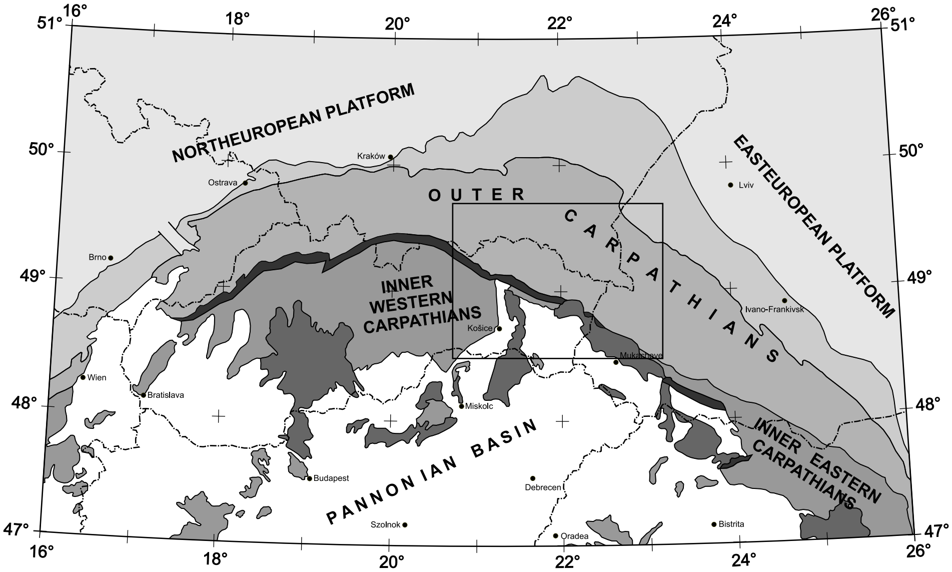

Fig. 1. Position of our region under study in northern part of Carpathian-Pannonian region. Map modified after *Kováč (2000)*.

Lexa et al., 2000) the nappe succession in the territory of West Carpathians from highest to lowest ones comprises Biele Karpaty Nappe, Magura Nappe, Fore-Magura group of nappes, Miková – Snina tectonic unit, Dukla Nappe, Silesian Nappe, Subsilesian Nappe, and Skole Nappe. The last tectonic phase that affected the Outer Carpathians took place in the Miocene. The tectonic mobility in this period occurred during collision between the overriding ALCAPA Block and the North European Plate (*Vass, 1998; Kováč et al., 1998; Cieszkowski, 2003; Oszczypko, 2004*).

There are two nappes of the Outer Carpathians Flysch Belt developed in the central part of the studied area: the Magura Nappe and the Dukla Nappe. The central part of our area (around the Zboj-1 borehole) is entirely located within the Dukla Nappe that contains also the Sub-Menilite, Cisna, Łupków and Zboj beds (*Ďurkovič et al., 1982*).

The southern part of our region under study extends to the Transcarpathian depression area represented here both by the northern part of the East Slovak Basin (ESB) and by the smaller northeastern most part of the Mukachevo basin (MB). The geological structures of subbasins were described by *Sviridenko (1976), Rudinec (1981, 1989b), Soták et al. (1993), Kováč et al. (1995, 1998), Vass (1998), Kováč (2000), Tari and Horváth (2006)* and others.

The Palaeogene and Neogene filling of basins and Neogene volcanics in the Inner Carpathians represent complexes formed after nappes activity. The Transcarpathian basin creation as well as the volcanic activity of the region was connected with the youngest tectonic development, also when it came to asthenolite ascent, local thinning of crust and increasing of the heat flow (*Gordienko, 1975; Kutas et al., 1989; Majcin and Tsvyashchenko, 1994; Bielik, 1998; Tarasov et al., 2005*). The development of Neogene volcanism both in the time and the space scale has been described in many articles (e.g. *Lashkevitsch et al., 1995; Lexa and Konečný, 1998; Csontos et al., 1992; Konečný et al., 2002; Pécskay et al., 2006; Pécskay et al., 2009; Lexa et al., 2010*).

The geophysical works based on data interpretations along the sections crossing the Carpathian arc (*Šefara et al., 1998; Dérerová et al., 2006; Bielik et al., 2010; Janik et al., 2011* and others) significantly contributed to the structural and tectonical knowledge about our region under study. One of the crust models in the area in question (*Bezák et al., 1997*) based on the interpretation of geophysical data assumes a complex imbricated structure (including platform) in the north part of this area and flower structure as a results of strike-slip tectonics in the central part. This tectonic activity resulted into occurrence of various Western and Eastern Carpathian units (Humenné, Iňačovce – Kričevo and Zemplín units, *Bielik, 1998*).

The level of geothermal exploration of region under study is not equable. The most of geothermal data was measured and determined within the Transcarpathian depression parts. The density of existing thermal data in the Outer Carpathian Flysch areas is generally lower.

The region under study has the centre at the position of the borehole Zboj ZB-1 and spreads across Slovakia and also in Poland and Ukraine. The major part of all existing geothermal data related to the analysed region was gained and interpreted to the output maps of temperature and heat flow density distributions separately in above-mentioned countries.

The basic temperature distribution in the Zboj ZB-1 is derived from the interpretation of this deep structural borehole published in *Ďurkovič et al. (1982)*. These geothermal data together with other ones from surrounding boreholes were collected and analysed mainly by Slovak authors *Král et al. (1985), Rudinec (1989b) and Franko et al. (1995).* The Ukrainian heat flow density and temperature distribution data were measured and evaluated in *Kutas and Gordienko (1971), Buryanov et al. (1985), Gordienko et al. (2002), Gordienko et al. (2004).* The set of geothermal data was completed with help of the results from Polish part of Outer Carpathians (*Plewa et al., 1992; Gordienko and Zavgorodnyaya, 1996; Wróblewska, 2007; Górecki, 2013*). Some synthetic works have tried to interconnect the selected geothermal data (most of them was the terrestrial heat flow data) over wider areas containing our studied region (e.g. *Čermák and Hurtig, 1979; Lenkey et al., 2002; Wybraniec, 2008; Majcin et al., 2013*). The modelling results along profiles crossing the studied geological units of the West Carpathians provide very important information about both the temperature and heat flow density distributions in the lithosphere, and moreover, about the relations of geothermal data with structures and tectonics. The models in calculated steady state regime were made by *Bielik et al. (1991)* and *Majcin (1993).* The results of geophysical integrated modelling approaches were presented in *Dérerová et al. (2006).* In addition, there are some transient thermal models that include the influence of main events of the lithosphere tectonic development in the region under study (*Kutas et al., 1989; Majcin and Tsvyashchenko, 1994; Tarasov et al., 2005*).

2. Methods applied

The comparative analysis became the main and primary method for the interpretation of collected measured geothermal data and existing model data within the region under study and in surrounding geological units. The temperature and the heat flow density distributions are analysed both across the Carpathian arc structures and along them. The regional and local geothermal anomalies were interpreted using the temperature field model calculations for heat transfer in steady and transient regime as well. Derived mathematical and physical tasks for the heat transfer equation in bounded areas were solved by means of finite difference methods (*Majcin, 1982*) and/or finite element approaches (using the COMSOL Multiphysics® modelling software with the Heat Transfer Module). In selected geothermal modelling tasks with simple structures, we employed known analytical solutions of heat transfer equation (*Buntebarth, 1984; Kutas et al., 1989*). We used also simple paleoclimatic effects recalculations (*Buntebarth, 1984*) of geothermal data from some selected boreholes, as we have analysed the heat flow density data and maps with paleoclimatic corrections applied as well.

3. Analysis of data and interpretation

The heat flow density distribution became the basic element for our analysis of the thermal conditions within the region under study. The input terrestrial heat flow density (THFD) map (Fig. 2) was constructed from measured data, known interpretations, and modelling results (*Kutas and Gordienko, 1971; Majcin, 1993; Franko et al., 1995; Gordienko and Zavgorodnyaya,1996; Karwasiecka and Bruszewska, 1997; Lenkey et al., 2002; Gordienko, 2004; Dérerová et al., 2006; Majcin et al., 2013* and others). In general, the THFD declines across the structures of Carpathian arc from values greater than 100 mW/m^2 in the Transcarpathian depression subbasins (East Slovakian Basin ESB and Mukatchevo basin MB) to the values of 40–50 mW/m^2 observed in the European platform. The mean value of heat flow density of the East Slovakian Outer Flysch is equal to 65–70 mW/m^2. Hereby the mean values of the heat flow density increase to those higher than 75 mW/m^2 inside the region of the Magura group of napes (in the direction to the Klippen Belt). The northern parts of the East Slovakian Flysch (belonging mainly to Dukla unit) are characterised by background values of about 60–65 mW/m^2 but the local anomalies slightly more than 70 mW/m^2 are supposed in this area. The pattern of the heat flow density distribution map in the neighbouring Ukrainian Outer Flysch is nearly the same with one exception in borehole Chornogolova (CHO-1), where the determined heat flow density value is only 61 mW/m^2. The Skole/Skyba units and Silessian units within our studied region are characterised by THFD values from the interval of 50–65 mW/m^2. The recent results of THFD determination in Wetlina borehole WE-2 (*Górecki, 2013*) confirm the assumption that the THFD values are locally greater than 70 mW/m^2 at the border between the Silessian and Dukla units in the south-eastern

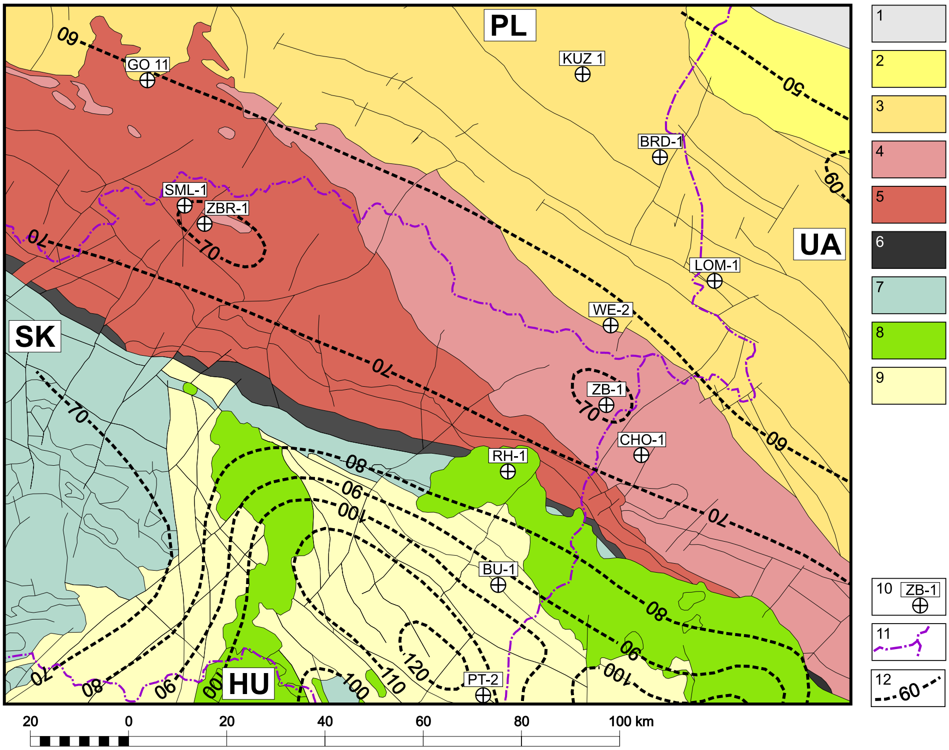

Fig. 2. Input map of the terrestrial heat flow density distribution in NE part of Slovakia with geological structure outlines (from *Lexa et al., 2000*). 1 – Carpathian foredeep molasses, 2 – folded Miocene molasse, 3 – Skola-Skyba, Subsilesian and Silesian Units, 4 – Dukla Unit, 5 – Magura group of nappes, 6 – Pieniny Klippen Belt, 7 – Inner Carpathian Units, 8 – Neogene volcanics, 9 – Neogene sediments, 10 – positions of selected boreholes with measured geothermal data, 11 – state border, 12 – heat flow density isolines [$\mathrm{mW/m^2}$]. Boreholes labels: Zboj ZB-1, Smilno SML-1, Zborov ZBR-1, Remetské Hámre RH-1, Bunkovce BU-1, Ptrukša PT-2, Chornogolova CHO-1, Lomna LOM-1, Wetlina WE-2, Brzegi Dolne BRD-1, Kuzmina KUZ-1, Gorlice GO 11.

most part of Poland (*Gordienko and Zavgorodnyaya, 1996* and *Tarasov et al., 2005*).

The Figure 2 contains also positions of selected boreholes lying closely to lines crossing or running along the Carpathian arc structures near the position of Zboj ZB-1. The downhole temperature distributions (*Ďurkovič et al., 1982; Rudinec et al., 1989a; Franko et al., 1995; Górecki, 2013; Kutas and*

Gordienko, 1971; Gordienko, 2004 and data from the authors) are plotted in Fig. 3. The data serve as the additional information for the geothermal situation analysis. The global trend of the measured temperatures increase from positions in outer Carpathian units to inner ones is evidently perceptible for instance on the set of boreholes Kuzmina, Brzegi Dolne, Remetske Hamre, Bunkovce and Ptruksa (Figs. 2 and 3). It is important for our analysis, that the temperature distributions in Zboj, Wetlina and Remetske Hamre boreholes from area of Dukla and Magura Flysch units are nearly on the same level. Moreover, also the measured temperatures in Zborov and Smilno boreholes laying in the north-western direction are similar to these

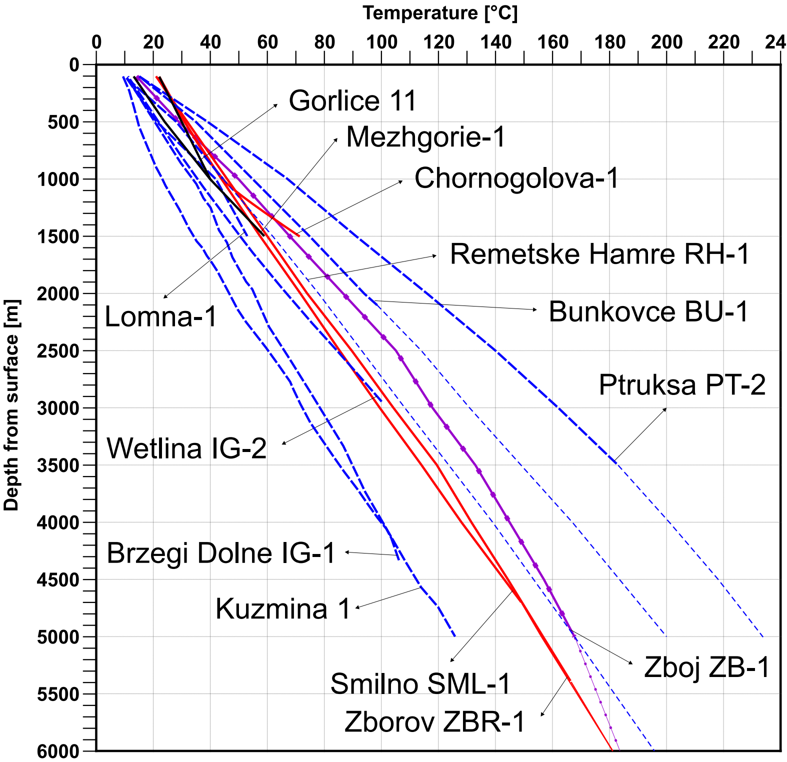

Fig. 3. Collected data of temperature distributions from boreholes in the neighbourhood of Zboj ZB-1 (magenta solid line with dots) along (red solid lines) and across (blue dashed lines) the Carpathian structures. The thick lines denote measured and interpolated temperature data whereas the thin lines are used for extrapolated data.

data. The borehole Chornogolova has relatively smaller gradients in upper parts (the data was used also for determination of THFD) but in the depth of 1500 m the temperatures are greater than those in Zboj borehole. The Ukrainian borehole Chornogolova is relatively shallow but based on the temperature distributions and lithology we suppose that the background heat flow density is there near the level of 70 mW/m^2.

The comparative analysis of the heat flow density and the depth temperature distributions both along and across the Carpathian arc structures as well as the additional modelling refraction effects calculations at the Inner/Outer Carpathians border suggest the existence of the additional regional and/or local sources. These sources increase the heat flow and the deep temperatures closely to arched line between the boreholes Smilno SML-1 and Zboj ZB-1. That is why we checked the influence of various geological phenomena on temperature field by quantitative and qualitative approaches – depending on character and accuracy of input data.

From alternative models approximating both the geological situation and the great change of the thermal conditions at the Inner/Outer Carpathians border we have:

a) The boreholes Zboj, Wetlina, and Chornogolova are too distant from Klippen Belt to be significantly influenced by higher activity of inner Carpathian units (mainly by higher heat flows in Transcarpathian depression subbasins ESB and MB). The effect on the surface heat flow density in mentioned boreholes is smaller than the first few miliwatts per square meter. In some alternative models we took into account also the positive heat transfer influence of the carbonate complexes underlying the Flysch Belt interpreted by *Kucharič et al. (2012).* The effect of horizontal heat transfer from inner Carpathian units is negligible in the region of boreholes Smilno and Zborov.

b) The Mesozoic rock complexes of Humenne ridge with relatively higher thermal conductivities cause the inclination of heat flow vectors towards the body also from the side of the Outer Carpathian Flysch. The smaller geothermal gradients in close surroundings of the Humenne ridge may induce low local anomalies in THFD distributions. These refraction anomalies may be combined also with the effect of infiltration of surface water through the porous Mesozoic complexes of Humenne ridge (i.e. in borehole MLS-1 Podskalka according *Rudinec, 1989a*).

The analysis of new magnetic map of Slovakia (*Kubeš et al., 2008*) within NE part of Slovakia revealed some interesting features, which are not typical for areas with development of the Flysch sediments – disturbances of magnetic field. Flysch sequences do not contain any magnetic rocks. The authors (*Kucharič et al., 2013b*) interpreted the anomalies as subvolcanic bodies of intermediate composition and of the Neogene age. The idea was supported by the evidence of increased thermal activity which has been found out by geological methods in this area (*Hrušecký et al., 2003*). The activisation age was estimated to belong into period of the Sarmatian or the Sarmatian–Middle Pannonian with the range 9.9 − 17.2 Ma.

The larger anomaly lying in the northeastern most part of Slovakian Outer Flysch belongs probably to volcanic field with dense occurrence of volcanic objects, the smaller ones it is possible to interpret as isolated dikes and necks. The contours of the magnetic anomalies are depicted in Fig. 4.

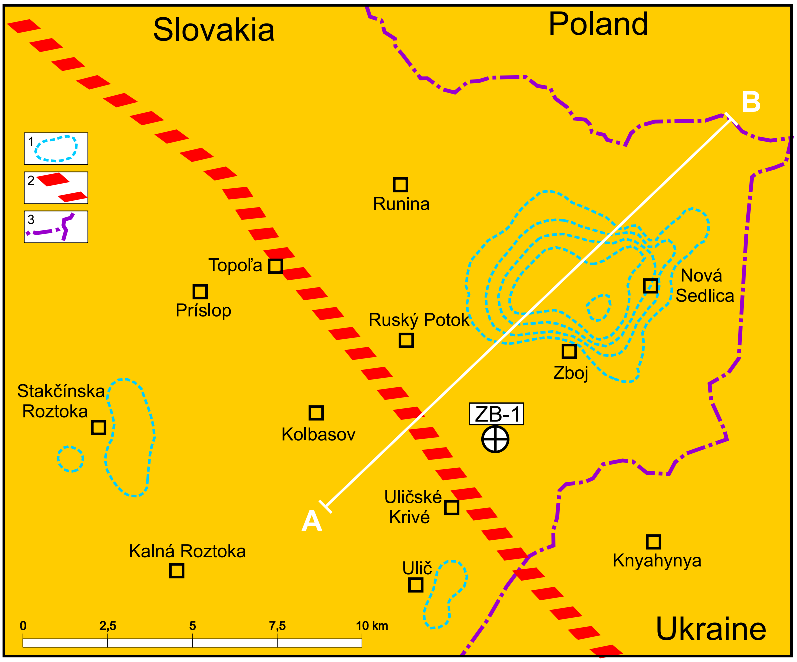

Fig. 4. Map of studied area showing the major geophysical anomalies and position of interpretative profile AB. 1 – contours of magnetic anomalies, 2 – Carpathian Conductivity Anomaly axis position, 3 – state border. (Map modified after *Kucharič et al., 2013a*).

The shape of the main interpreted subvolcanic body is shown within the structure on cross section along the profile AB (Fig. 5).

The ascent of volcanic bodies into the Flysch sequences has necessitated overheating of the area and changed also the distribution of thermophysical parameters. We checked the thermal effects of subvolcanic body both on the temperature distribution of borehole Zboj and on the distribution of surface heat flow density. The calculations of the thermal field changes were carried out separately for the thermal source type component and for refraction type component.

The anomalous temperature distributions caused by igneous body cooling are plotted in Figs. 6 and 7 for volcanic intermediate rock content, for various intrusion ages, and various depth levels of the borehole Zboj. The model data were taken from *Lei (2007)*. We have applied the data and the 2D approximation to receive the upper estimation of effects. From numerical results we can conclude that the shape of supposed subvolcanic body is compatible with observed geothermal data but the amplitudes of the caused temperature distribution anomalies are too small for supposed ages of intrusion and determined intermediate content of subvolcanic body.

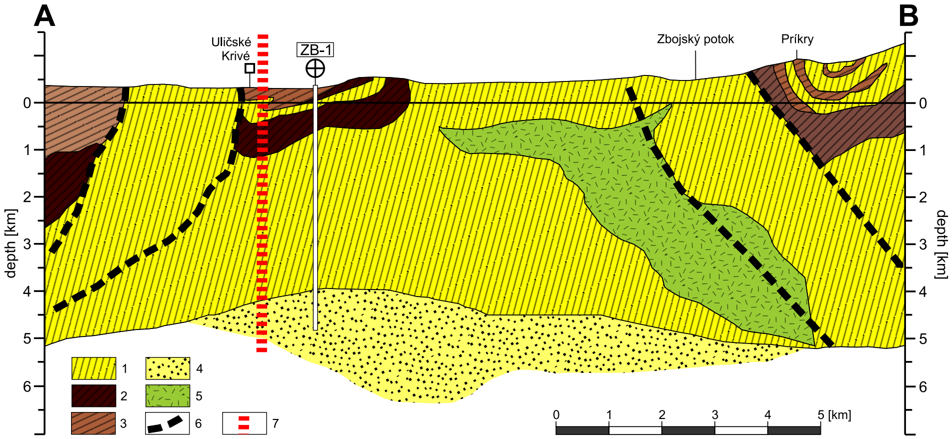

Fig. 5. The interpretative profile for estimation of subvolcanic body cooling and refraction effects with projected position of borehole Zboj ZB-1. 1 – Lupkow Member, 2 – Sub-Menilite Member, 3 – Cisna Member, 4 – Zboj Member, 5 – subvolcanic body, 6 – faults, 7 – Carpathian Conductivity Anomaly axis position. (Map modified after *Kucharič et al., 2013a*).

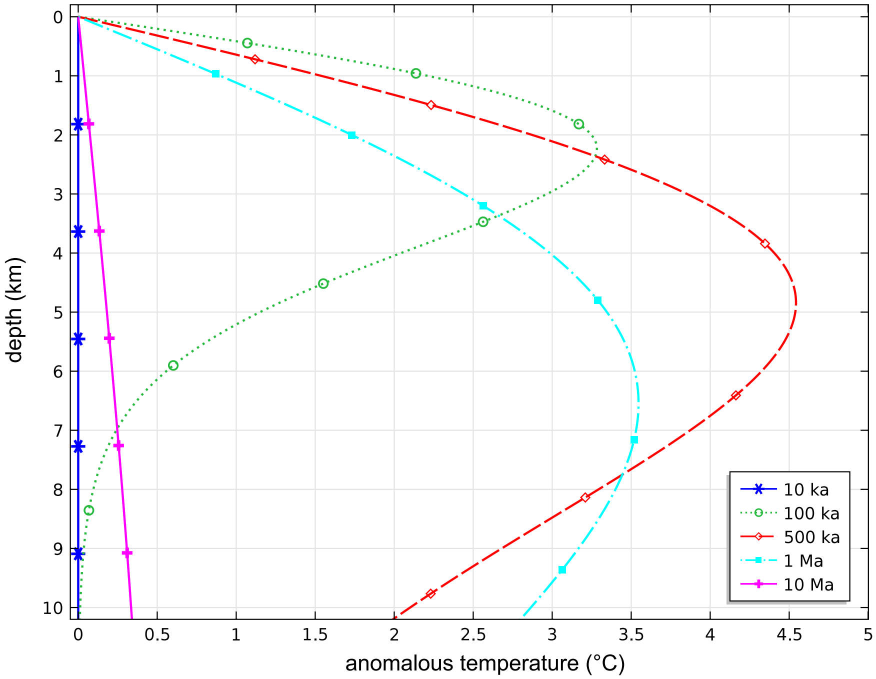

Fig. 6. Anomalous calculated temperature distribution in borehole Zboj ZB-1 caused by cooling of the subvolcanic body of intermediate composition. Distributions in various time levels are plotted.

The local refraction effects on anomalous subvolcanic body are practically negligible for the depth temperature distributions at the position of borehole Zboj ZB-1 for all possible realistic thermal conductivity distributions. We have applied the models with thermal conductivity coefficient $\boldsymbol{k}$ of the anomalous intermediate subvolcanic body from the interval 2.1 – 2.8 W/m·K while taking into account the possible lithology. The surrounding rock complexes were characterised alternatively either by constant thermal conductivity ($\boldsymbol{k} = 2.0$ W/m·K) calculated from the lithological content of Lupkow member (*Ďurkovič et al., 1982*), prevailing in upper parts of the profile geological model, or by the thermal conductivity coefficient linearly depending on the depth $\boldsymbol{z}$ ($\boldsymbol{k} = 1.8 + 0.2\,\boldsymbol{z}$, $\boldsymbol{z}$ in km). This second thermal conductivity model approximates the influence of compactification of Flysch rocks in deeper parts.

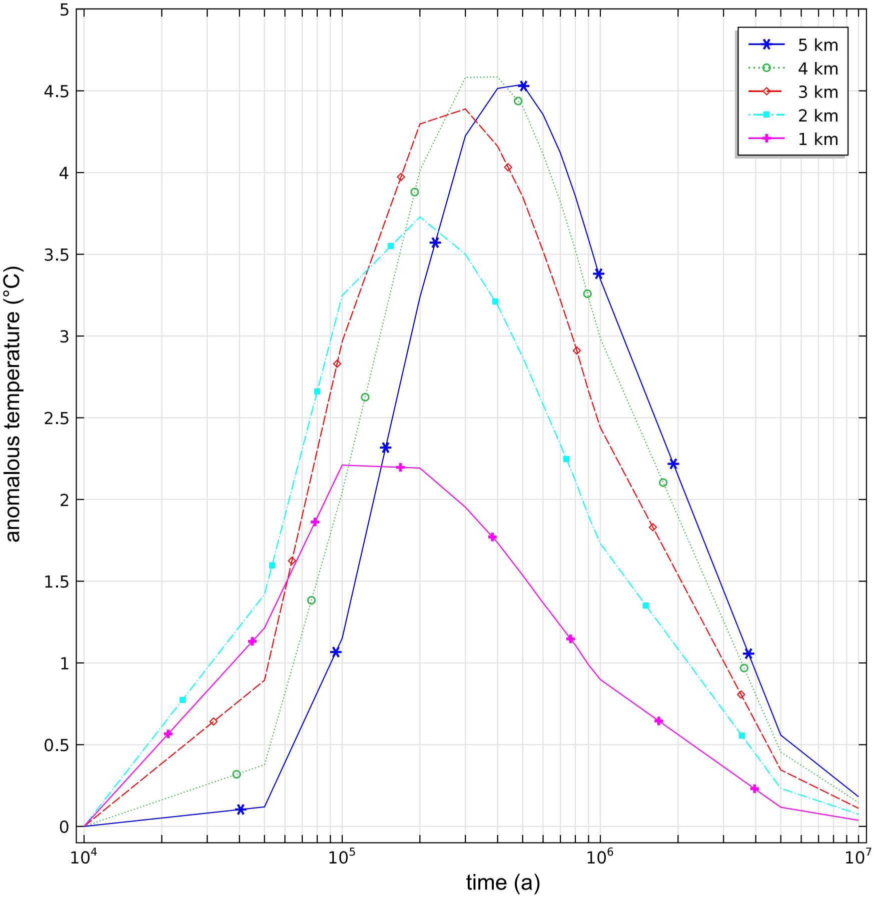

Fig. 7. Anomalous calculated temperature distribution in borehole Zboj ZB-1 caused by cooling of the subvolcanic body of intermediate composition. Distributions for various depths are plotted.

In general, we can conclude that the summary effects are insufficient also for the explanation of differences in temperature distributions related to the deep boreholes along the Carpathian structures such as Smilno SML-1 and Zborov ZBR-1. However, the thermal influence of studied subvolcanic body is relatively great and it may cause the anomaly up to 5–7 mW/m^2 in surface heat flow density distribution in the region of most expressive magnetic anomaly between the boreholes Zboj and Wetlina.

The influence of two supposed small bodies near Stakčínska Roztoka and Ulič (Fig. 4), the distances of which to the borehole Zboj are nearly the same, have smaller influence because of smaller volume and thin shape.

The peculiarity of our region under study is the presence of the important regional geophysical anomaly known for more decades – the Carpathian Conductivity Anomaly (e.g. *Berdichevski and Dmitriev, 1976; Červ et al., 1984; Žytko, 1997; Hvoždara and Vozár, 2004; Jankowski et al., 2008*). The position of the Carpathian Conductivity Anomaly (CCA) axis (Figs. 4 and 5) coincides very well with the arched zone of supposed high thermal activity between the boreholes Zboj and Smilno.

We checked the known nature interpretations of this regional electric conductivity anomaly that is to say the depth, geometry, and petrography of rock complexes as a source responsible for features observed at the Earth's surface.

The electron-type high electric conductivity based on high graphite content (*Jankowski et al., 2008*) is supposed as deep source because the Carpathian Flysch complexes do not contain large graphite-bearing rocks in the scale reflecting the regional character of CCA. Moreover, the thermal conductivity coefficient unlike the electrical conductivity is not so significantly influenced by addition of graphite films in pores (*Hvoždara and Vozár, 2004*). The local refraction anomalies in the temperature field distribution are very small both for intergranular and fissure porosity type. The surface heat flow anomalies are supposed to be practically imperceptible.

The high electric conductivity based on ionic nature is caused by highly mineralized water filling the intergranular space or the connected fissures (*Hvoždara and Vozár 2004*). The saline water becomes the main electric conductor and this increases the electrical conductivity 100–1000 times in relation to dry skeleton. In general, the effects of equivalent changes are smaller for the thermal conductivity coefficient. The thermal conductivity contrasts $\boldsymbol{cc}$ calculated (*Buntebarth, 1984; Walsh and Decker, 1996*) for wet and dry porous rocks typical for deep sources of CCA are $\boldsymbol{cc} = \boldsymbol{k_w}/\boldsymbol{k_d}$, $\boldsymbol{cc} \sim \mathbf{2\text{-}10}$. The thermal conductivity of the compact rock is greater than the same of porous one with air, water, gas, because the matrix rocks are better conductors of heat than the filling liquid. From the model calculations of the refraction effects (*Majcin, 1992; Hvoždara, 2008; Majcin et al., 2012* and others) and from the previous qualitative analysis we conclude that the positive surface heat flow anomalies along the CCA axis can originate only for situations where the CCA source bodies with saline water are enclosed by less conductive dry porous rock complexes. This is a rare situation for known interpretations of the potential source bodies with high electric conductivity of ionic type (e.g. *Ernst et al., 2002; Grad et al., 2006* and *Jankowski et al., 2008*).

The thermal refraction effects caused by the sources with high electric conductivity of ionic or electron type are not sufficient for explanation of increased thermal activity in arched line zone going through the boreholes positions of Zboj and Smilno along the structures of Carpathian arc. However, the petrographic and geometry parameters of all interpretations are supposed in principle as acceptable from geothermal point of view.

The previous interpretations and the modelling results suggest that the higher geothermal activity near the CCA axis within the region under study has to be supported also by higher heat flux from deeper parts underlying here the flysch rock complexes. We consider that the observed geothermal parameters – both the temperature and the heat flow density distribution – are regionally influenced by the thermal phenomena of the deep-seated fault system related to the European Platform margin situated north of the Klippen Belt (*Janik et al., 2011; Kucharič et al., 2013b* and others).

In our interpretation the mentioned fault system at the European Platform margin is:

- the zone of the recent high thermal activation which is also responsible for the origin of melted volcanic rock;
- the highly probable area of the active heat transfer by various liquid media (may be also by mineralized water);
- the controlling structural element for the ascent of the volcanic rocks into the Outer Carpathian Flysch near the Zboj borehole (as supposed recently in *Kucharič et al., 2013b*).

The northeastern part of Slovakian Outer Flysch Belt is characterised by relatively monotonous temperature field distributions (*Franko et al., 1985*). Due to the lack of the geothermal data in Slovak Outer Carpathian Flysch, it is not possible to precise the terrestrial heat flow distribution maps. However, the results of our analyses pointed out that the heat flow density can reach the value 70 mW/m^2 and more in some positions near the CCA axis where the presence of volcanism is supposed (*Kucharič et al., 2012*) and the hydrothermal activities are observed.

The known major high-temperature anomaly of regional importance was noted in the eastern most part of the Flysch Belt – in close surroundings of the borehole Zboj ZB-1. As supposed above, the anomalous temperature distribution in the upper part of the borehole Zboj should be explained partially by influence of supposed subvolcanic body but also by hydrological factors and by smaller thermal conductivity of rock complexes in upper part of Lupkow Beds and overlapping rock complexes. It is important to note that the thermal activity along the zone related to the European Platform margin is not constant. The boreholes Zboj, Smilno, Zborov and others reach the Obidova-Slopnice-Zboj unit supposed as an important regional hydrological collector covered by low permeable rock complexes of Magura (in Slovakia and Poland) and Dukla (in Slovakia and Ukraine) units (*Ďurkovič et al., 1982; Marcin, 2001; Kucharič et al., 2013a*). The waters ascending to the Earth's surface along the tectonic zones influence the local thermal conditions mainly by heat transfer from deeper parts. The temperature anomalies of refraction type are small because the transport ways have fissure character (*Marcin, 2001*). On the other side the refraction on the subsurface structures with thermal conductivity contrast may cause relatively great local anomalies in the surface heat flow distribution (*Majcin, 1992; Majcin and Polák, 1995; Majcin et al., 2012* and others).

4. Conclusions

Based on geothermal modelling results, on the interpretations of known geothermal data and recently gained geophysical and geological knowledge we discussed the regional and local phenomena influencing the thermal field in the northeastern most part of Slovakian Flysch Belt and surrounding region. The higher activity observed in the zone along the arched line running through the positions of Zboj and Smilno boreholes was explained by influence of the thermal phenomena connected with the deep-seated fault system related to the European Platform margin. Great attention was paid to close surroundings of borehole Zboj ZB-1 which is the most thermally active part of region in the study. Our modelling calculations and interpretations suggest that the anomalous temperature distribution is caused by summary effect of more aspects related to the structure and development of area.

Our analysis of the newest geothermal as well as other geological and geophysical data contribute to the knowledge of the temperature and heat flow density distribution also in areas without the measured geothermal data. Additionally, it gives ideas back to study of the structure and the tectonic development of investigated region by other geo-scientific branches. Especially the geothermal results enlarge the information database necessary for the evaluation of the geothermal energy sources parameters of this locality.

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