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Carbonate complexes underlying Flysch belt and subsurface Neogene volcanic in the NE part of Slovakia – a potential for geothermal energy and raw materials

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Abstract: A positive gravity anomaly was observed in the Flysch belt realm. Based on this fact and available geological knowledge we suppose that the source of gravity anomaly might be carbonate rocks lying perhaps in the footwall of Flysch sediments. The carbonates belong perhaps to the Penninic crust cover (a part of Klippen belt), or to lower structural stage of the Flysch belt. Besides this it is interpreted more volume of Neogene subvolcanic bodies in the frame of the Flysch belt based on the results of the newest magnetic measurements in the NE part of Slovakia (*Kucharič et al.,* in press). These are accompanied by increasing heat flow and hydrothermal alteration within neighbouring rocks what may eventuate into creation of raw materials. These two factors – carbonates and subvolcanic bodies – are important items for appraisal of new perspective in this area not only from hydrocarbon occurrences point of view (a primary intend within this area) but also for enhancement of geothermal potential of Slovak Republic and opening possibilities for prognosis of raw material occurrences as well.

Key words: applied geophysics, magnetometry, gravimetry, geothermics, carbonate complexes, Neogene volcanism, Flysch sediments, Outer Carpathians

1. Introduction

The NE Slovakia belongs mostly to the Outer Western Carpathians in terms of regional geological division. Principal units developed on the surface

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are nappes of Flysch belt and formations of the Klippen belt. The Outer Western Carpathians are overthrusted to the North on the European platform. To the South of the Klippen belt are developed formations of the Inner Western Carpathians – Paleoalpine Cretaceous nappe units (mostly Veporicum, Gemericum) and post-nappes formations of Tertiary sediments and volcanics.

The Palaeogene and Neogene filling of basins and Neogene volcanics in the Inner Carpathians represent complexes formed after nappes activity. The basin creation as well as the volcanic activity was connected with the youngest tectonic development, when it came to asthenolite ascent, thinning of crust and increasing of heat flow. The development of Neogene volcanism both in time and space scales has been described in many articles (e.g. *Csontos et al., 1992; Lexa and Konečný, 1998; Konečný et al., 2002; Pécskay et al., 2009*).

Besides of large volcanic complexes on the surface in the Inner Western Carpathians, there are observed separate intrusive bodies like dikes, sills, and laccoliths in the Outer Carpathians extending from the SE of Moravia *(Krejčí and Poul, 2010)* to the Southern Poland in the Pieniny area *(Birkenmajer et al., 2004, 2008)* and continuing to the Ukraine and Romania area *(Pécskay et al., 2009)*.

The heat flow data and the thermal state of the Carpathian lithosphere in the region under analysis were studied and discussed in the articles *(Plewa et al., 1992; Majcin, 1994; Majcin and Tsvyashchenko, 1994; Franko et al., 1995; Dérerová et al., 2006; Bielik et al., 2010; Kutas, 2011)*, including both the direct measurement methods and the modelling approaches. The surface heat flow density distribution (Fig. 1) is influenced by tectonic activity of the area. Globally the values decrease from more than 100 mW/m^2 in the central part of the East Slovakian basin to 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 heat flow density increase over 75 mW/m^2 inside the region of the Magura group of nappes (in the direction to the Klippen belt). The northern parts of the Flysch (belonging mainly to Dukla unit) are characterized by background values of about 60–65 mW/m^2 but the local anomalies slightly more than 70 mW/m^2 exist in this area. The relatively pure level of the geothermal exploration stage with low number of measured data is the main

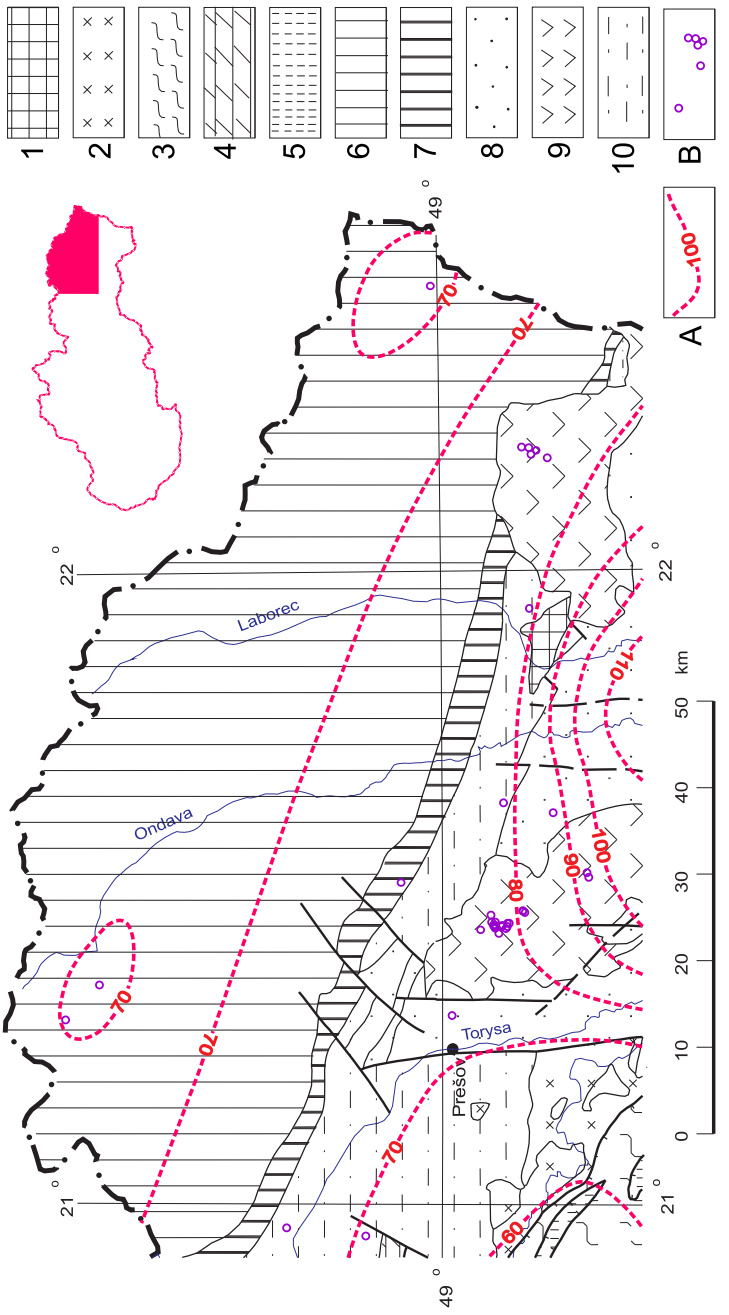

Fig. 1. Surface heat flow density distribution in NE part of Slovakia with geological structure outlines. Inner Western Carpathians: 1 – Fatricum, 2 – Veporicum, 3 – Gemericum, 4 – Hronicum, 5 – Silicicum; Outher Western Carpathians: 6 – Flysch Belt, 7 – Klippen Belt. Post-nappe formations: 8 – Neogene, 9 – Neogene volcanics, 10 – Inner Carpathian Paleogene, locally also Upper Cretaceous. A – heat flow density isolines [mW/m^2], B – positions of boreholes with measured geothermal data.

problem in the determination of surface heat flow density distribution in the region under study. The problem is solved by mathematical modelling methods, by filtration of data and by correlation with data of other geo-scientific branches.

An analysis of new magnetic map of Slovakia *(Kubeš et al. 2008, 2010)* 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 content any magnetic rocks. Due to our utmost interpretations (*Kucharič et al.* in press) it is obvious that such type of anomalies may be caused by products of Neogene volcanism. The increased heat flow has been found by geological methods in this area *(Hrušecký et al., 2003)*. Moreover a positive gravity anomaly which continues from the Inner Western Carpathians realm to the North of the Klippen belt exists in the studied area. This fact reflects an existence of heavy matters in deeper geological structure of this area. These heavy rocks may be potential reflection of carbonates (e.g. *Grinč et al., 2010*), what boosts potential perspective of this area for geothermal evaluation.

2. Analysis of available data and interpretation

Because the seismic investigation in this area has been performed mostly by refraction methods with ambiguous, complicated output, which was difficult to compare with geological knowledge from the boreholes (out of this area), our effort has been concentrated on the results of regional gravity and magnetic mapping.

The magnetic map of the area is depicted in Fig. 2, together with contours of Bouguer's anomalies map for volume density 2.67 g/cm^3 and the course of the Klippen belt on the surface. The expressive and variable anomalies in the bottom part of figure belongs to Neogene volcanics: Slanské vrchy Mts. (left) and the Vihorlat Mts. (right). It is visible that the Klippen belt as one of the most important tectonic units of the Western Carpathians does not limit an extension of magnetic anomalies, which means that volcanic activity to the North of the Klippen belt into the territory of the Outer Western Carpathians is presumable. Volcanics complex of Vihorlat Mts. covers the Klippen belt. This is the known fact, but an expressive negative

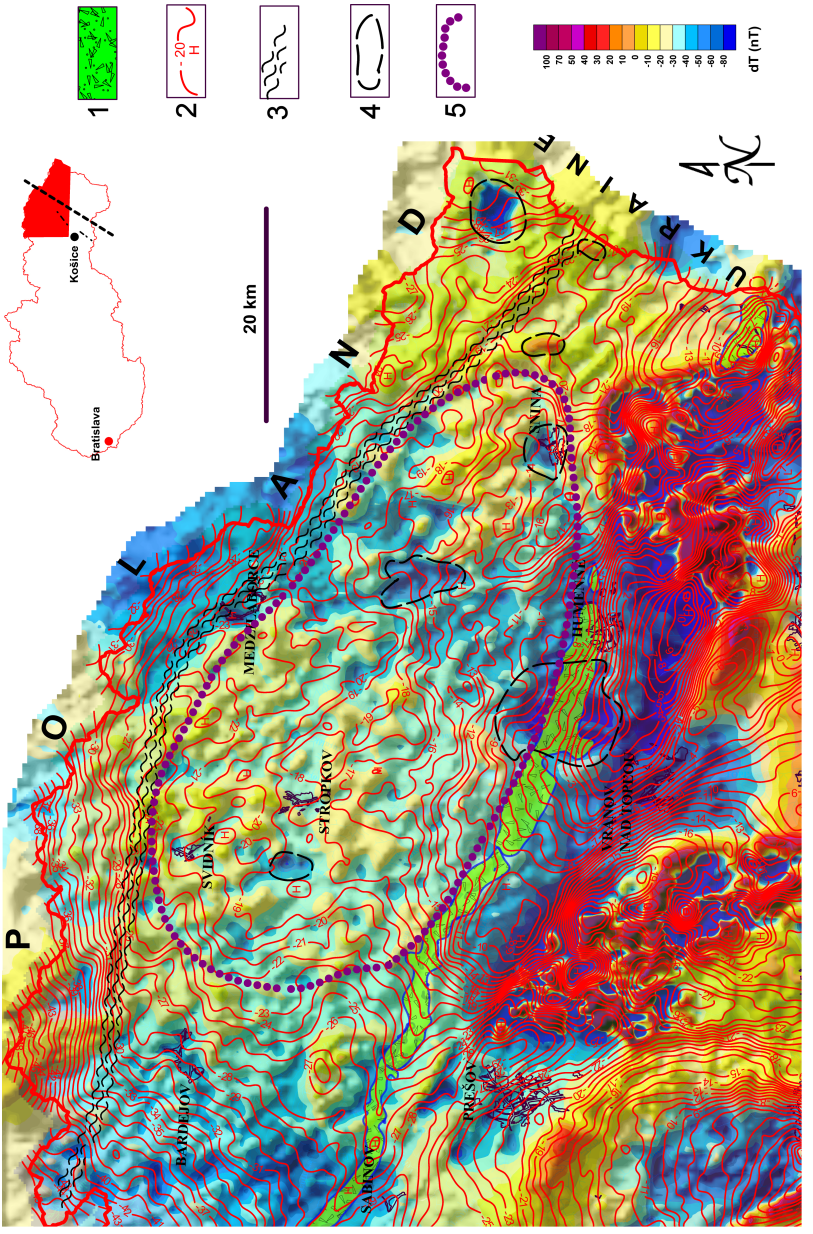

Fig. 2. Magnetic map of the northeast Slovakia with contours of Bouger anomalies and profile position. 1 – Klippen belt on the surface, 2 – isolines and values of Bouger's anomaly (volume density 2.67 g/cm^3) and gravity maximum positions, 3 – Carpathian conductivity anomaly, 4 – single anomalies interpreted as necks, 5 – potentially perspective area for sources of geothermal energy.

magnetic anomaly in the space between towns Humenné and Vranov n.T. is a new discovery, however there are no observations of magnetic rocks on the surface within this area. The course of the Klippen belt does not have any influence on the character of measured magnetic field, what indicates that the range of the Klippen belt to the depth will not be as significant as was regarded up to now. This negative magnetic field tends to the NE in the belts with width 15–20 km and its marginal limitation is relatively marked, what may be interpreted as a manifestation of fault structures. Such type of magnetic field is atypical for non magnetic Flysch sequences and according to current knowledge it is caused perhaps by younger volcanic rock. The magnetic field towards NW of this anomalous belt is a bit different (higher), what might be outline a presence of volcanic products from different volcanic phases. Besides of these inhomogeneities of the magnetic field it is possible to recognize some anomalies with smaller extension (Snina town area, the eastermost part of area). Due to our interpretation (*Kucharič et al.,* in press) the magnetic field in the region to the North of the Klippen belt is caused by subvolcanic bodies of intermediate composition (Neogene age), that did not reach the surface. The larger anomalies belong probably to volcanic field with dense occurrence of volcanic objects, the smaller one is possible to interpret as isolated dikes and necks. These are depicted in Fig. 2. The anomalies are mostly negative, but the changes in magnetic polarity in young volcanic rocks are common feature *(Filo et al., 2003).* From this point of view we suppose that products of Neogene volcanism had penetrated into the Flysch belt environment, but they did not reach the level of nowadays relief of the terrain.

To support of the presence of volcanism within this area it is possible to use results of former works *(Hrušecký et al., 2003)*:

- Rocks samples collected from the area according to results of vitrinite reflectance indicate that these rocks were metamorphosed by the temperature almost 200 °C. The values of vitrinite reflectance hint as a factor that they belong into age interval 10–20 Ma.
- The fission tracks dating was carried out in that area as well and the results of them indicated the age classification into period of the Sarmatian or the Sarmatian–Middle Pannonian with the range 9.9–17.2 Ma.

In such a manner we have obtained indication about potential rise of tem-

perature caused by volcanic activity. Distribution of geothermal field in the Slovak republic territory strongly depends on distribution of deep boreholes from those that have been compiled from the map of geothermal energy *(Franko et al., 1995)*. The presence of volcanic bodies may favourably to affect the heat flow distribution in the area and therefore we suppose that our interpretation precises and may extend the geothermal energy potential of the Slovak Republic supposed in *Franko et al. (1986), Rudinec (1989)* and *Franko et al. (1995)*.

The top of gravity anomaly is located in the Inner Carpathians to the South of Humenné town, where carbonate rocks outcrop on the surface (see Fig. 2). Because the Flysch sequences developed in the Outer Carpathians are known mainly by "light rocks" (sandstones and claystones), it is quite reasonable that on the base of the character of such gravity field we assume a presence of carbonate rocks below the Flysch filling and in its footwall respectively. These rocks are a suitable collector of water and in the depth bellow volcanic complex could possess a temperature potential interesting for geothermal energy utilization.

Our geological imagination towards depth is depicted in the geological cross section (Fig. 3) along the profile determined in Fig. 2.

The peculiarity of this realm is a presence of the long decades known important regional geophysical anomaly – the Carpathian Conductivity Anomaly (e.g. *Berdichevski and Dmitriev, 1976; Červ et al., 1984; Hvoždara*

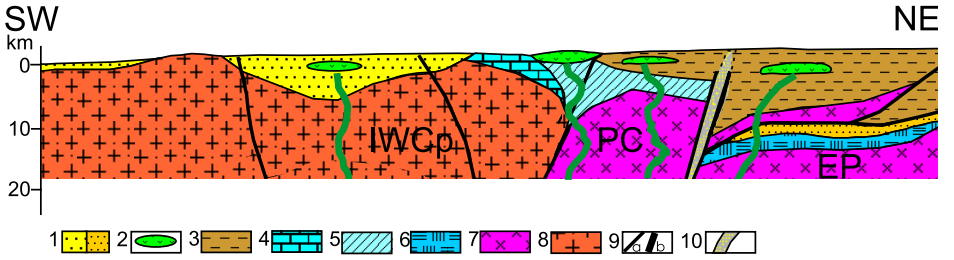

Fig. 3. Geological cross section along profile from Fig. 2. 1 – Neogene sediments, 2 – Neogene volcanic and subvolcanic bodies, 3 – Flysch sediments, 4 – Inner Carpathians Mesozoic sequences, 5 – Klippen belt, 6 – European platform Mesozoic rocks, 7 – European Platform, 8 – Iňačovce-Kričevo unit, 9 – faults, 10 – Carpathian conductivity anomaly. IWCp – Inner West Carpathians, PC – Penninic crust, EP – European Platform.

and Vozár, 2004). This anomaly is in terms of our interpretation (*Kucharič et al.* in press) a real boundary between the European Platform and the Inner Western Carpathian block.

There are three fundamental tectonic segments in the crust depicted in Fig. 3: EP –European Platform (imbricated), PC – Penninic crust with assumed carbonate cover (continuation of the Klippen belt series?) and the block of the Inner Western Carpathians with the Paleozoic complexes, Mesozoic carbonate formations and Neogene sediments and volcanics.

The Klippen belt is situated on the Northern margin of the Inner Western Carpathian as a result of Neogene transpressed activity. Our interpretation is developed on gravity results, when the sequences of Klippen belt perhaps in the development of carbonates are in the position of envelope, laying on the elevated Penninic crust which is interpreted between the European Platform and Inner Western Carpathians on the base of seismic transects from the Celebration project *(Sroda et al., 2006)* as well. These sequences of carbonates create the fundaments of the Flysch belt and are a potential source of geothermal energy. Overheating of this area is highlighted by intrusions of Neogene volcanic bodies.

3. Other outputs from proposed interpretation into sphere of energy and raw materials

Proposed interpretation may be utilized for:

- *Sphere of hydrocarbon investigation.* This area was in the past and also nowadays the subject of hydrocarbon prospecting. Results of some boreholes indicate that some positive signs that were learned would deserve more attention *(Ďurkovič et al., 1982)*. Volcanic rocks are capable to create traps due to suitable porosity even in the bigger depths. Equally the traps may be generated reciprocally between volcanic structures and sedimentary beds. Volcanic activity can rather effectively increase maturity, the velocity of generation, supply abiogenic activation of hydrocarbons and produce migratory ways *(Liu et al., 2010)*. Volcanic liquids and gases influence migration of hydrocarbons in positive manner.

- *Sphere of raw materials.* The squad of diminutive dykes of andesites behind the Klippen belt arc in Pieniny (Poland) causes the contact methamorphosis and alterations not only in neighbouring rocks but also in the andesites by itself, what called into existence small ore bodies in these spaces. These ores were prospected and exploited for gold, silver, and lead for a short time in the beginning of the 18-th century *(Szeliga and Michalik, 2003; Birkenmajer et al., 2004).* It proved the cognate age relationship between andesite intrusion emplacement and subsequent ore mineralization.

- *Sphere of underground CO_2 storage.* Matters connected with underground storage of CO_2 are very close to the hydrocarbon problem. Volcanoes emit larger amounts of volcanic gas than can be dissolved in the volume of erupted magma during a variety of volcanic processes, including explosive and effusive eruption and non eruptive continuous degassing. Degassing of non-erupted magma with a much larger volume than that of erupted magma caused such a large degassing; erupted magma represents only a small portion of the magma that drives volcanic activity *(Shinohara, 2008).* After ending of intrusion activity the magma began to cool down and crystallize. The bubbles of the volatiles will ascent by their buoyancy and be accumulated in the upper part of the volcanic body. Crystallization of magmas will concentrate volatile components in the melt, causing volatile saturation – bubble formation *(Shinohara, 2008).* The space in the upper part intrusion may be permeable (magma foam). Due to fact that this volcanic body stayed unerupted, it is reasonable to suppose that volume of rocks taken by volatile components may be remarkable. This opens up the opportunities for potential spaces suitable for underground CO_2 storage.

4. Conclusions

Based on interpretation of *Kucharič et al.* (in press) we suppose the development of subsurface volcanic rocks of Neogene age within the investigated area in NE most corner of Slovakia. Contrary to the Inner Carpathians the volcanic activity did not reach nowadays relief of terrain and volcanics

are dominantly developed in the form of subvolcanic bodies. The ascent of volcanic bodies into the Flysch sequences has necessitated overheating of the area. Moreover interpretation of carbonates based on gravity results in the footwall of volcanics increases so far at least theoretical potential of this area from geothermal prognosis viewpoint. The deep boreholes in this region are missing and for confirming our interpretation it is necessary to carry out proper technical works.

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