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Recognition of geological structure of the Carpathians as a result of magnetotelluric investigations

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Abstract. In 1998, the Geophysical Exploration Company and State Geological Institute of Poland started broad-scale magnetotelluric investigations in the Polish Carpathians. The measurements were made by MT-1 magnetotelluric system, designed and produced by Electromagnetic Instruments Inc., over a frequency range of 300 – 0.0005 Hz with remote magnetic reference. The results of data interpretation provided new elements in recognition of the structure of the flysch orogen and its basement and confirmed earlier interpretation of the roof of the high-resistivity horizon.

A considerable resistivity differentiation was observed in the Mesozoic, Paleozoic and Precambrian formations in northern part of the cross-sections, where the high-resistivity platform-type basement occurs beneath the autochthonous Miocene sediments. The zone of low-resistivity rocks occurs in the south-eastern part of the study area. In the western part of the study area, southern parts of profiles run through the Inner Carpathians close to a northern margin of the Tatra Mts. massif. The results of MT data interpretation confirm that the massif has allochthonous character.

Key words: Carpathians, magnetotellurics, basement structure, flysch cover

Introduction

The recognition of the inner structure of the Carpatian flysch cover and its basement is a very difficult problem because of strong tectonics of flysch complexes and rapid changes of its lithological characteristics. As a result, a heterogeneous and anisotropic distribution of physical parameters of geological medium is observed. On the other hand, there is no distinct contrast of physical parameters at boundaries of major tectonic-facies units. Such conditions are unfavourable for using surface geophysical methods since interpretation of the obtained parameters is difficult, and geophysical boundaries often do not coincide with tectonic ones (Stefaniuk et al, 1998). All these factors make a barrier to recognizing the structure of the Carpathian basement.

The seismics is commonly used in structural investigations. However, the flysch orogen generates a complex seismic wave pattern which is very difficult to interpret. Therefore, other geophysical methods are employed. Among them, the magnetotelluric and gravity methods provide the most interesting data for recognizing the Carpathian basement (Stefaniuk, 2001).

The magnetotelluric investigations have been conducted for twenty years in the Polish Carpathians. Most of measurements were made by the Geophysical Exploration Company, Warsaw, for the Geological Institute and Polish Oil and Gas Company (Święcicka-Pawliszyn, 1980, 1984; Molek & Klimkowski, 1991). A number of measurements were conducted by the Institute of Geophysics of the Polish Academy of Sciences, Warsaw (Jankowski et al, 1991) and the Institute of Geophysics of University of Mining and Metallurgy, Krakow (Miecznik et al, 1995).

The main objective of earlier magnetotelluric surveys was to recognize the topography of the high-resistivity horizon related with the top of Mesozoic, Paleozoic or Precambrian basement of the Flysch Carpathians. The surveys enabled the topography of the basement top to be determined (Święcicka-Pawliszyn & Pawliszyn, 1978; Stefaniuk, 1995, 2001). However, because of limited possibilities of measurement systems used, the recognition of the flysch structure was impossible.

In 1998 the Geophysical Exploration Company and the Polish State Geological Institute started a broad-scale magnetotelluric investigation in the Polish Carpathians using state-of-art magnetotelluric system MT-1 designed and produced by Electromagnetic Instruments Inc., Richmond, Ca., USA. The MT-1 system represents major advances in magnetotelluric survey techniques. The measurements were made over a frequency range of 300 – 0.0005 Hz with magnetic field remote reference. The results of data interpretation provided new elements in recognition of the structure of the flysch orogen and its basement and confirmed earlier interpretations of the top of the high-resistivity horizon.

Brief history of magnetotelluric surveys in the Polish Carpathians

First, experimental magnetotelluric survey in the Polish Carpathians, was made by the Geophysical Exploration Company in 1975 along two regional seismic profiles F and V (Święcicka-Pawliszyn & Molek, 1975).

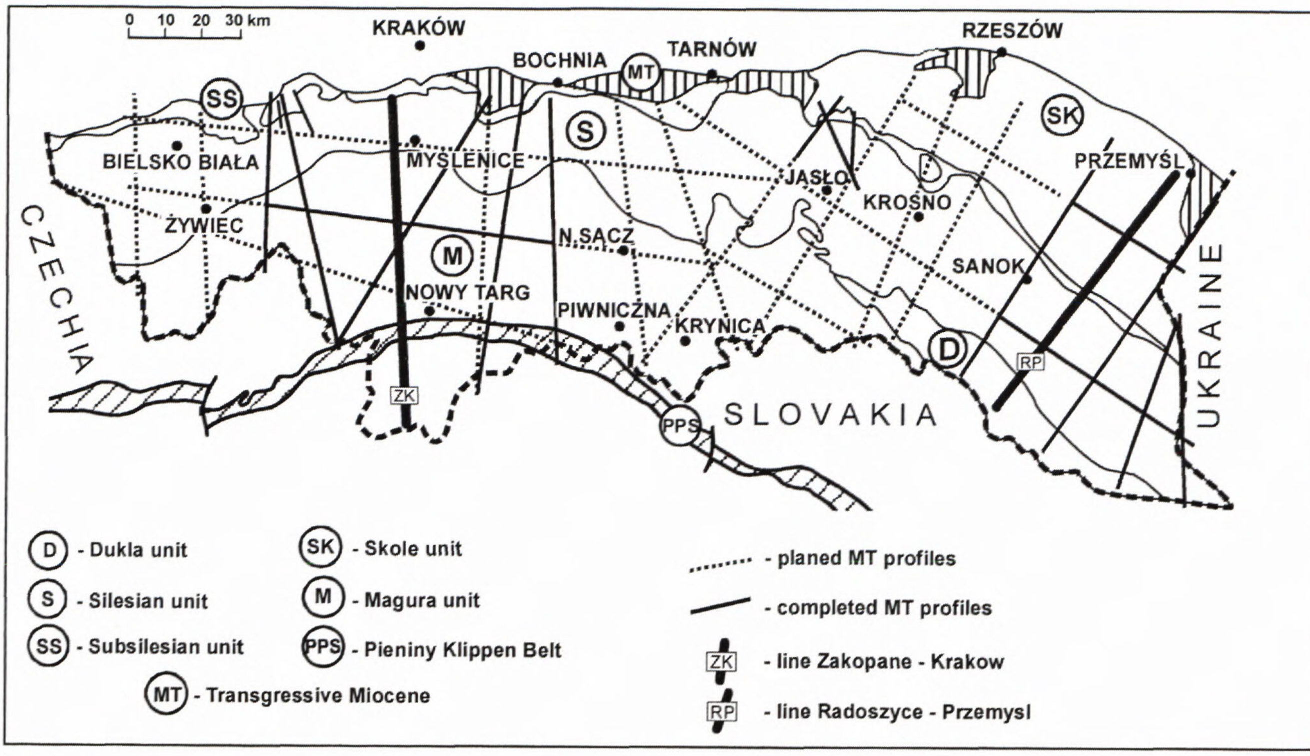


Fig. 1 Location of magnetotelluric profiles

The survey was inspired by the State Geological Institute, Warsaw. The results were most interesting and encouraged to make further magnetotelluric investigations along lines transverse to major orogen axis in 1980s and 1990s. The measurements were made using analog measurement equipment with Bobrov magnetometers as magnetic field sensors. The variations of MT field were recorded over a frequency range of 0 – 1.0 Hz. The analog data were hand processed using a method of apparent impedance of geoelectric medium (Berdičevski 1968).

During this period, magnetotelluric soundings were made on a small scale by the Institute of Geophysics of Polish Academy of Sciences (Jankowski et al, 1991) and Department of Geophysics, University of Mining and Metallurgy (Miecznik et al, 1995, 1996) as well. The measurement system, made by the Institute of Geophysics of Polish Academy of Sciences, was also based on Bobrov magnetometers, but digital recording was employed.

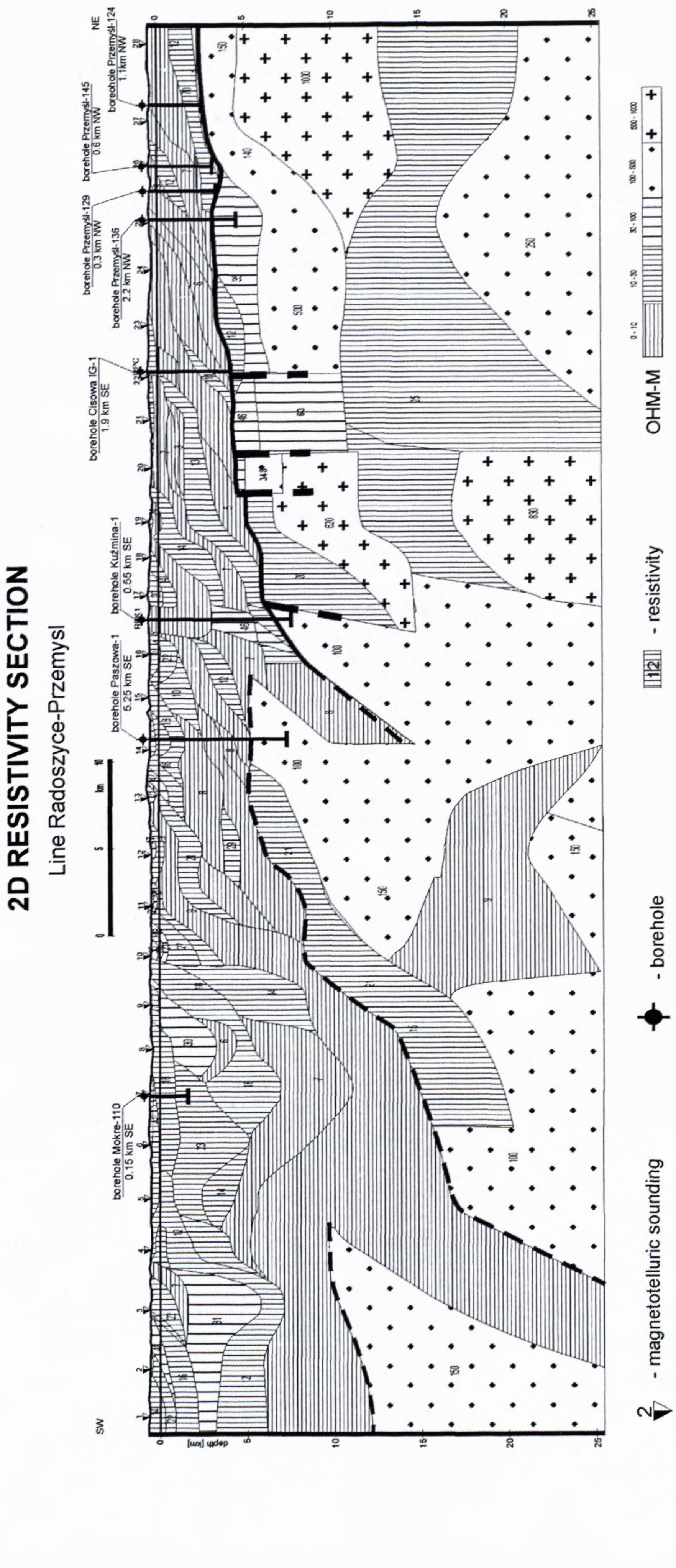
The magnetotelluric data were interpreted and interpretation results were presented by a number of authors (Święcicka-Pawliszyn & Pawliszyn, 1978, 1983; Jankowski et al 1991; Woźnicki, 1985, Ryłko & Tomaś, 1995; Stefaniuk, 1995, 2001).

The main objective of MT data interpretation was to recognize the morphology of the high-resistivity horizon related with the top of sub-Miocene or sub-flysch basement. Four zones of the basement, parallel to the orogen axis, were distinguished based on obtained results. In the outermost zone the basement top rests at a relatively shallow depth (3 – 8 km). It subsides toward the orogen axis, however there occur some local elevations and depressions. South of the outermost zone the high-resistivity basement slopes steeply and depth differences amount to ten to twenty kilometers. Then, the most buried zone occurs at a depth of 15 – 25 km. On the southern margin of the area a zone of the elevated basement is observed at a depth of 8 – 12.5 km. A block of the high-resistivity basement is overthrust to NE onto a low-resistivity complex (Stefaniuk & Kuśmierek, 1986; Stefaniuk, 1995, 2001).

New prospects for magnetotelluric surveys in Poland begun with the application of the MT-1 system which incorporates a measurement equipment together with data processing and interpretation softwares. A major project of magnetotelluric investigations was initiated in 1998. Some results are presented below.

Methodology of magnetotelluric survey

A major project of magnetotelluric surveys has been conducted in the Polish Carpathians since 1998. A network of 25 magnetotelluric profiles was designed. Nineteen profiles are oriented transversely to major axis of the flysch orogen, while other are parallel to it. The goal of the project aimed at recognition of the structure of sub-flysch basement and deep-seated parts of the flysch cover. The measurement lines were about 70 – 90 km long with sounding sites some three km apart. The observations were made over a frequency range of 300 – 0.0005 Hz using the MT-1 system. The remote magnetic referencing was applied to reduce the influence of electromagnetic noise. The field data were processed using MTR15 computer program incorporated in the MT-1 system. The results of data processing were amplitude and phase of MT sounding curves, impedance polar diagrams, and skew. They were then subjected to qualitative and quantitative interpretation. The first stage of inter-



pretation gave apparent resistivity and phase pseudosections. The types of curves, polar diagrams, and skew were analysed in qualitative interpretation. One-dimensional quantitative interpretation was made using Bostick, Occam and LSQ methods. Based on 1D Bostick inversion, pseudo 2D resistivity cross-sections were computed using the kriging method. The results of 1D LSQ inversion were used to obtain a 2D input resistivity section. Additionally, geological information on the flysch orogen, seismic refraction data, and results of 2D inversion with the RRI method were also applied (Stefaniuk et al, 1998b).

Results of magnetotelluric data interpretation

So far, magnetotelluric survey was made along twelve transverse profiles and four linking lines in two areas: between Żywiec and Nowy Sącz, and east of Krosno (fig. 1). Additionally, semi-detailed survey was made along several profiles located between Jasło and Rzeszów. The results of magnetotelluric data interpretation provided new factors in recognition of the structure of the flysch orogen and its basement and conformed earlier interpretations of the top of the high-resistivity horizon Stefaniuk et al, 1998a, b; Stefaniuk & Klityński, 2000).

The magnetotelluric imaging of the basement is quite different for western part and eastern part of the study area. A considerable resistivity differentiation was observed in the Precambrian formations in NE part of the area, where the high-resistivity platform-type basement rests beneath the autochthonous Miocene sediments (Stefaniuk & Klityński, 2000) (fig. 2). In the roof of that complex broad depressions are observed in the high-resistivity horizon. They are filled with relatively low-resistivity deposits and are likely cut by tectonic zones on SW. It is possible that those deposits are younger, however their geological identification is doubtful because borehole data were unavailable there. The zone of low-resistivity rocks occurs to SW of well Kuzmina-1. It is likely connected with a major alpine compres-

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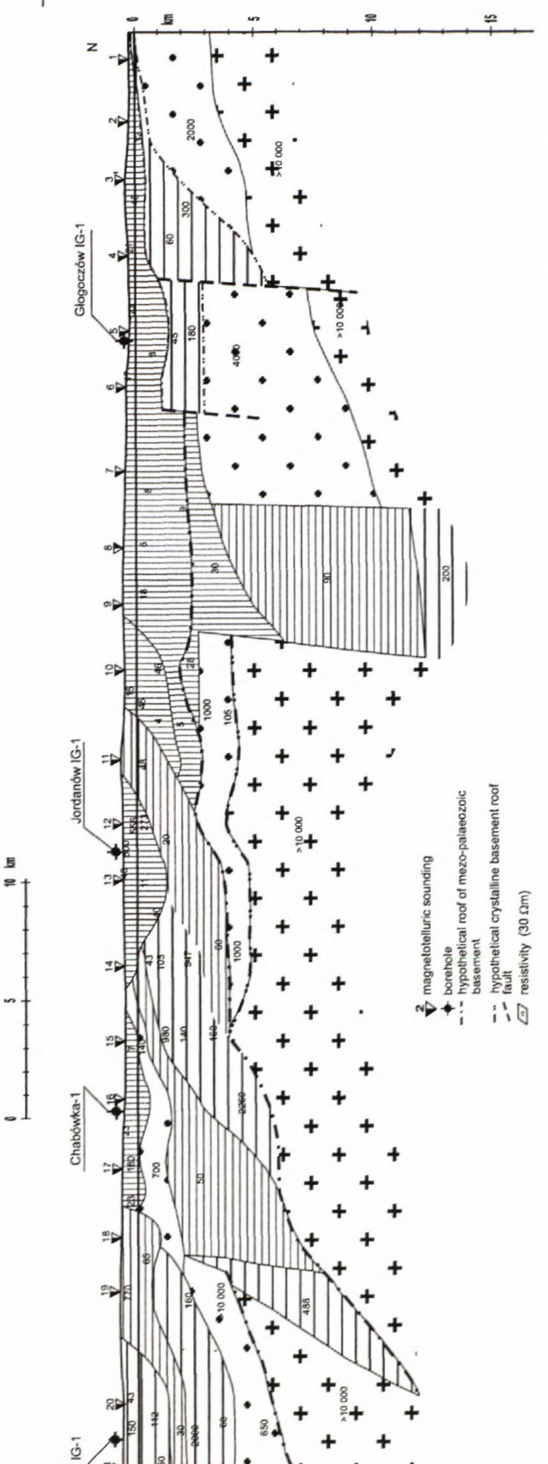

sion structure. That zone tends to close to the west and open to the east. In SW part of the area the high-resistivity horizon is buried deep under a thick low-resistivity complex. In the southern margin of the sections, close to the state border, a thick high-resistivity block is overthrust onto those low-resistivity deposits. Its top is interpreted to rest at a depth of 8 – 10 km. The arrangement of those high- and low-resistivity complexes suggests that an overthrust zone is present where low-resistivity deposits are impressed under a high-resistivity block overthrust from the south. It is probably an element of the deep-seated basement, uplifted in front of the subduction zone, which is generally related with the Pieniny Klippen Belt. Investigations made by Slovak geologists and geophysicists (Bielik, 1999) and a team the Institute of Geophysics Polish Academy of Sciences (Jankowski et al, 1991) prove this.

The great differences in resistivity distribution are observed in the deep basement along the general axis of the flysch orogen in the southern part of the study area. Strong undulations of the roof of the high-resistivity horizon, probably related with deep-seated tectonic zones, are observed. The low-resistivity complexes dominate in the resistivity cross-section. A thick block of the high-resistivity basement occurs in eastern margin of the area. The resistivities of the flysch orogen differ over a narrow range in that part of the study area. They tend to increase towards south and east. In southern part of the sections the flysch is underlain by thick, low-resistivity complexes whose geology is not clearly identified. The position of the surface of the Carpathian overthrust is not clear as well. The results of the presented study show that the magnetotelluric method provides new possibilities for recognition of the geology of the Carpathian orogen and its basement.

Quite different situation is in western part of the study area. Some general features of resistivity distribution are observed in that region. The geoelectric cross-sections may be divided into two parts (fig. 3). The uppermost part, with relatively low resistivity, is related with the flysch cover and Miocene sediments of the flysch basement. The resistivity distribution is much variable in that part of the cross-section. The low-resistivity rock complexes dominate in the Silesian and sub-Silesian units, while a high-resistivity formation occurs within the Magura unit. The lower part of the cross-section, with relatively high resistivity, is related with sub-Miocene and/or sub-flysch substratum. After results of magnetotelluric data interpretation the tectonics of the Carpathian basement can be recognised there. In northern part of the area, the continuation of structures of the European platform is observed. In central and southern part of the area, the major structural directions in the basement generally agree with those in the flysch cover.

Fig. 3 2D resistivity section. Line Zakopane-Krakow

Two measurement lines run across the Pieniny Klippen Belt and reach the northern border of the crystalline massif of the Tatra Mts. A zone of relatively low-resistivity complex, associated with the Pieniny Klippen Belt, dips rapidly to south beneath the Tatra massif. This confirms an earlier hypothesis on the allochthonous character of that massif.

Some remarks on geological interpretation of magnetotelluric data

The great importance of magnetotelluric data interpretation represents geological identification of geoelectric horizons. The high-resistivity horizon corresponds to the top of the Mesozoic, Paleozoic or Precambrian basement (Stefaniuk, 1995, 2001). This holds for the outermost zone and has been proved by deep borehole data and refraction seismics.

Still, geological identification of the low-resistivity rock complex is a key problem. There are different interpretations and hypotheses on the origin of that complex. And so, it is thought that the complex is associated with deep oceanic sediments saturated with mineral water (Jankowski et al, 1985; Woźnicki, 1985), partial melting of crystalline rocks (Lebiediev & Chitarov, 1964), or graphitized shales or graphites (Żytko, 1997).

The analysis of resistivities of flysch complexes and basement for some twenty boreholes located near the orogen margin shows that resistivity of Miocene clayey sediments falls in a range of 1 to 5 omm, thus being the same as that of the low-resistivity layer (Miecznik et al, 1993, 1995). W. D. Stanley (1989) states that conductivity anomalies in the Western Carpathians are generated by black shales similar to those Miocene sediments. It may be concluded that a depression in southern part of the study area is a foredeep filled with molasse-type sediments and covered by the Carpathian overthrust. It is possible that the conductivity anomaly is generated by thick complex of deep marine sediments as well. The geophysical data are insufficient to confirm this, however the hypothesis may be verified by analysis of the tectonic development of the Carpathian orogen (Stefaniuk, 2001).

Conclusions

The magnetotelluric method may be effectively applied to recognize the structure of the Carpathian orogen. Especially, its role in studying the basement structure should be emphasized. The results of magnetotelluric data interpretation are much more general than good seismic data, however seismic data are non-interpretable in many cases. On the other hand, the magnetotelluric method can support seismic data interpretation.

The general features of the Carpathian basement interpreted from magnetotelluric sounding data are different for eastern and western part of the study area. The low-resistivity complex and overthrust zones are characteristic of the eastern part of the area. The geological identification of the low-resistivity layer is still not clear. The great interest evokes a high-resistivity block occurring near the Polish-Slovak border, likely overthrust onto a low-resistivity complex to north. Based on MT data from profiles, located in the Polish territory alone, it is not possible to recognize the genesis and the structure of that block. Hence, MT profiles should be extended to southwest beyond the Pieniny Klippen Belt. Generally, the length of regional profiles is too short to recognize the structure of the deep-seated basement. Therefore, the profiles should be extended south to Slovakia, and north to North-European Platform and East-European Platform. More detailed magnetotelluric survey is needed to resolve problems of recognizing the flysch structure.

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References

Berdičevski M. H., 1968: Električeskaja razvedka metodom magnitotelluričeskogo profilirovania. Nedra. Moskwa, 255.

Bielik M., 1999: Geophysical features of the Slovak Western Carpathians: a review. Geol. Quar., 43: 251-262.

Czerwiński T., Klityński W. & Stefaniuk M., 2000: Some results of magnetotelluric survey in Polish Western Carpathians. Vijesti Hrvatskoga Geoloskog Drustva, 37, 3, 31.

Jankowski J., Pawliszyn J., Jóźwiak W. & Ernst T., 1991: Synthesis of electric conductivity surveys performed on the Polish part of the Carpathians with geomagnetic and seismic data.

Lebiediev J. B. & Chitarov N. J., 1964: Načalo plavlenia granita i elektroprovodnosti ego rasptava v zavisimosti od vysokogo davlenia paroc vody. Geochimia, 3: 195-201.

Miecznik J., Stefaniuk M. & Klityński W., 1995a: The methodology of magnetotelluric investigation in heterogenous media. Bull. Pol. Ac. Sci., Earth Sciences, 43: 99-112.

Miecznik J., Stefaniuk M. & Klityński W., 1996: Badania magnetotelluryczne w Karpatach fliszowych. Kwartalnik AGH. Geologia, 22: 39-48.

Molek M.& Klimkowski W., 1991: Dokumentacja badań magnetotellurycznych. temat: badania wgłębnej budowy geologicznej Karpat: Karpaty, lata 1988-1990. PBG Warszawa. Arch. Oddziału Karpackiego PIG Kraków.

Ryłko W. & Tomaś A., 1995: Morphology of the consolidated basement of the Polish Carpathians in the light of magnetotelluric data. Geol. Quart. 39: 1-16.

Stanley W. D., 1989: Comparison of geoelectrical/tectonic models for suture zones in the western USA and eastern Europe: are black shales a possible source of high conductivities ? Physics of the Earth and Planetary Interiors, 53: 228-238.

Stefaniuk M., 1995: Selected problems of the basement tectonics of the Polish Carpathians in the light of magnetotelluric sounding interpretation. XV Congress CBGA. Special Publications of the Geological Society of Greece, Athens: 1155-1160.

Stefaniuk M., 2001: Główne elementy strukturalne podłoża wschodniej części Karpat polskich w świetle badań magnetotellurycznych. Kwartalnik AGH, Geologia, 1.

Stefaniuk M. & Kuśmierek J., 1986: Interpretation of the basement roof of the eastern part of Polish Carpathians in the light of magnetotelluric survey and geological premises. Proc. 31 Intern. Geoph. Symp., Gdańsk: 221-232.

Stefaniuk M., Czerwiński T., Wajda A. & Mrzygłód T., 1998: First results of high-frequency magnetotelluric investigations in Poland. Book of Abstracts, the 14th Workshop on Electromagnetic Induction in the Earth, Sinaia.

Stefaniuk M. & Klityński W., 1999: Interpretation of magnetotelluric data along the Radoszyce – Przemyśl line – eastern part of the Polish Carpathians. Mat. Konf. EUROPROBE, Romanian J. Tect. and Reg. Geol., 77, Suppl. 1: 32.

Stefaniuk M. & Klityński W., 2000: Selected results of magnetotelluric data interpretation in eastern part of the Polish Carpathians. Vijesti Hrvatskoga Geoloskog Drustva, 37, 3, 121.

Stefaniuk M., Czerwiński T., Wajda A. & Mrzygłód T., 1998: Perspektywy i problemy wykorzystania badań magnetotellurycznych do rozpoznawania utworów fliszowych na przykładzie przekroju Zawoja-Potrójna. XIX Konnf. Teren. Sekcji Tektonicznej PTG – Magura '98.

Święcicka-Pawliszyn J., 1980: Dokumentacja badań geoelektrycznych, temat: Karpaty. Profile regionalne F i V rok 1975 i lata 1978-79. Arch. PBG Warszawa.

Święcicka-Pawliszyn J., 1984: Dokumentacja badań magnetotellurycznych, temat: Karpaty cz. wschodnia, rok 1975 i lata 1978-79, 1981-83. Arch. PBG Warszawa.

Święcicka-Pawliszyn J. & Molek M., 1975: Dokumentacja badań geoelektrycznych, temat: Profile regionalne. Profil F (Baligród-Przemyśl). Arch. PIG.

Święcicka-Pawliszyn J. & Pawliszyn J., 1978: Zastosowanie badań magnetotellurycznych do rozpoznawania złożonych struktur geologicznych. Biul. PBG Warszawa, 2: 16-25.

Święcicka-Pawliszyn J. & Pawliszyn J., 1983: Magnitelluričeskoe modelirovanie karpackoj anomalii elektroprovodnosti na territorii Polszi. 18 Meždunarodnyj Geofizičeskij Simpozium. Trudy II: 848-859.

Woźnicki J., 1985: Low-resistivity element in the Carpathians. Kwar. Geol., 29: 153-166.

Żytko K., 1997: Electrical conductivity anomaly of the northern Carpathians and the deep structure of the orogen. Ann. Soc. Geol. Polon., 67: 25-43.