SELF-REPORT

I) NAME: Waldemar Jóźwiak

II) OBTAINED DIPLOMAS AND SCIENTIFIC DEGREES

- Diploma and the Ph.D. degree in physics, 2000, Institute of Geophysics, Polish Academy of Sciences (specialization: geophysics), Warsaw.

  Title of the Ph.D. thesis: A new inversion method of global electromagnetic data and its application to studies of conduction in the Earth's mantle.

  Supervisor of the Ph.D.: prof. dr hab. Jerzy Jankowski

- Diploma and the M.Sc. title, 1978, Physics Faculty, University of Warsaw (specialization: geophysics), Warsaw.

  Title of the Master thesis: *Thermal convection in the upper mantle of the Earth.*

  Supervisor of the Master thesis: prof. dr hab. Roman Teisseyre

III) EMPLOYMENT HISTORY

Since 1977 until now I have been employed at the Institute of Geophysics in the Department of Magnetism, as:

December 1977 - Trainee
August 1978 - Assistant
December 1982 - Senior Assistant
August 1986 - Geophysicist position
December 2000 - Adjunct position
December 2009 - Senior Specialist

May 2007 - Head of Magnetic Department

IV) SCIENTIFIC ACHIEVEMENT DESCRIBED IN ART. 16 PARAGRAPH 2 OF THE LAW ACT OF THE POLISH MINISTRY OF SCIENCE AND HIGHER EDUCATION FROM 14TH MARCH 2003 ABOUT DEGREES AND TITLES IN SCIENCE AND ARTS (Dz. U. nr 65, poz. 595 ze zm.)

MAGNETOVARIATION STUDIES OF THE STRUCTURE OF THE LITHOSPHERE IN THE MARGINAL ZONE OF THE EAST EUROPEAN CRATON

– NEW METHODS AND RESULTS

Monothematic series of publications entitled:

1. Semenov, V.Yu., Jankowski, J., Jóźwiak, W., 2002. New evidence of the anomalously conductive mantle beneath the Tornquist-Teisseyre zone in Poland, Acta Geophys. Pol., 50, 4, p. 517-526.

2. Semenov, V.Yu., Jozwiak, W., Pek, J., 2003. Deep electromagnetic soundings conducted in Trans-European Suture Zone, EOS Transactions, AGU, 84 (52), p. 581, 584.

3. Semenov, V.Yu., Jóźwiak, W., 2005. Estimation of the upper mantle electric conductance at the Polish margin of the East European Platform, Izv. Phys. Solid Earth, 41 (4), p. 326-332.

4. Jóźwiak, W., Neska, A., 2005. Electromagnetic sounding in SW Baltic Region: Significant induction anomaly indicated by perturbation vectors, Publs. Inst. Geophys. Pol. Acad. Sc., C-95 (386), p. 97-106.

5. Semenov, V.Yu., Jozwiak, W., 2006. Lateral variations of the mid-mantle conductance beneath Europe, Tectonophysics, 416, p. 279-288.

6. Brasse, H., Cerv, V., Ernst, T., Hoffman, N., Jankowski, J., Jozwiak, W., Korja, T., Kreutzmann, A., Neska, A., Palshin, N.A., Pedersen, L.B., Schwartz, G., Smirnov, M., Sokolova, E.Yu., Varentsov, I.M., 2006. Probing electrical conductivity of the Trans-European Suture Zone, EOS Transactions, AGU, 87, No 29.

7. Pushkarev, P.Y., Ernst, T., Jankowski, J., Jozwiak, W., Lewandowski, M., Nowożyński, K., Semenov, V.Yu., 2007. Deep resistivity structure of the Trans-European Suture Zone in central Poland, Geophys. J. Int., 200, p. 926-940.

8. Ernst, T., Brasse, H., Cerv, V., Hoffman, N., Jankowski, J., Jóźwiak, W., Kreutzmann, A., Neska, A., Palshin, N.A., Pedersen, L.B., Smirnov, L., Sokolova, M., Varentsov, I.M., 2008. Electromagnetic images of the deep structure of the Trans-European Suture Zone beneath Polish Pomerania, Geophys. Res. Letts., 35 (15), p. DOI:10.1029/2007GL034610.

9. Semenov, V.Yu., Pek, J., Adam, A., Jóźwiak, W., Ladanivskyy, B.T., Logvinov, I.M., Pushkarev, P.Y., Vozar, J., 2008. Electrical structure of the upper mantle beneath Central Europe: Results of the CEMES project, Acta Geophys., 56 (4), p. 957-981.

10. Jozwiak, W., 2012, Large-Scale Crustal Conductivity Pattern in Central Europe and Its Correlation to Deep Tectonic Structures, Pure Appl. Geophys., 169, 10(2012), p. 1737-1747, DOI 10.1007/s00024-011-0435-7.

11. Jóźwiak, W., 2013, Electromagnetic Study of Lithospheric Structure of Marginal Zone of East European Craton in NW Poland. Acta Geophys., 61, 1101-1129.

INTRODUCTION

The subject of the proposed homogenous set of works is research on the structure of the lithosphere in the marginal zone of the East European Craton by means of magnetovariation methods. The works in question present an original development of those methods, which allows for efficient study of the structure of the upper mantle and tracking of deep well-conducting complexes in the crust. They also present the results of application of the proposed methods in studies of the marginal zone of the East European Craton.

The magnetovariation (MV) method, just as the magnetotelluric (MT) method, uses, as a source, natural variations in the magnetic field and is based on the phenomenon of electromagnetic induction. In the rocks of the Earth's interior, electrical currents are induced whose directions and intensities depend on the distribution of electrical conductivity. The analysis of relationship between the values of particular components of the electromagnetic field recorded on the surface allows us to draw conclusions about the values of electrical conductivity of the basement. It is an extremely important physical parameter as it allows us to identify geological structures with different petrophysical characteristics. Electromagnetic methods can detect fault or overthrust zones with porous rocks saturated with mineralised waters, graphites and metal sulphides, and – at a greater depth – zones of partial melting, which is important for understanding of the tectonics of a given area. In stable regions, those methods make it possible to track the traces of ancient tectonic processes, collisions of continental plates or their fragments, and locate the suture zones or foreland basins.

In the present series of works, two new methodological approaches were proposed to interpretation of the results of MD soundings. First of all, the series presents the method for the study of deep conductivity distribution by design, then a common interpretation, of sounding curves consisting of global (MV soundings), regional (MV soundings), and local (MT soundings) branches. Interpretation of such curves involves application of the stochastic inversion algorithm to the spherical Earth model (Jóźwiak 2001).

Another method developed and implemented in the presented works is the use of invariant analysis of the Horizontal Magnetic Tensor (HMT) to determine the parameters of the great, extensive well-conducting complexes present in the crust. The spatial distribution of some HMT invariants, in particular, the maximum eigenvalues, can very effectively locate the position of well-conducting structures, including three-dimensional ones (Jóźwiak 2011). Direct determination of the HMT requires synchronous recording of the magnetic field variations throughout the study area, which requires a large amount of equipment and is very expensive. However, having a sufficiently large amount of data (induction arrows or tippers) from points spread fairly evenly across the study area, we can make their transformation to the HMT. Such transformation uses the properties of potential fields, for which there is a relation between the vertical component and the horizontal components of the field through the Hilbert transform. In the subsequent works forming the cycle, a new, efficient algorithm for this transformation was proposed.

In the publications included in the presented series, MV data interpretation was performed in the region of the East European Craton by means of both of the two proposed methods. The obtained results, on the one hand, provided a lot of interesting information about the structure of the lithosphere in that region, and on the other hand, confirmed the usefulness and effectiveness of the proposed methodology in the study of the crust and the upper mantle.

The forefield of the East European Platform is a unique area in the tectonic structure of Europe, and identification of its structure is the key to understanding the geotectonic history of our continent. Our recognition of the geological structure varies from region to region. On the East European Craton, the basement is well recognized by numerous drillings and reflection seismic surveys. The Proterozoic basement, composed of metamorphic and h rocks, is overlaid by relatively shallow and rather flat sedimentary rocks. The basement is not homogeneous, giving rise to numerous magnetic anomalies. In the other regions, it is only the Mesozoic-Zechstein cover, whose thickness reaches 9-10 km in the central part of the Polish Basin that is recognized in detail. Information on sub-Zechstein structures in this region comes mainly from the seismic surveys. It is to be kept in mind, however, that the recognition of deeper structures is difficult, since the salt complexes provide a very effective screening for reflection seismics.

The results of deep seismic sounding (reflective and refractive) and tomography point to a very complex structure of the Earth's crust, which is divided onto numerous blocks of different thicknesses. Physical properties of the blocks vary drastically, which reflects the differences in their geology. West of the T-T zone, the tectonic movements, of greater or lesser intensity, have been occurring in the Paleozoic, giving rise to folding deformations.The folded Paleozoic rocks are overlain by flat sediments, starting from the Lower Devonian or Permian. The folded Paleozoic (and older) rocks constitute the basement, while the overlying non-folded sediments are the young platform's cover. The Earth's crust thickness changes substantially, from 35-45 km under the Precambrian Platform to 40-55 km in TESZ and 28-32 km under the Paleozoic Platform of Western and Southern Europe (Guterch et. al 1986, Guterch et al. 1999, Grad et al. 2002, Janik et al. 2002, Grad et al. 2003a, Grad and Guterch 2006). Also, a distinctive drop of seismic velocities (by 2-3%) is observed in the upper mantle, at 100-200 km depths, while going from the Precambrian Platform to the Paleozoic Platform (Zielhuis and Nolet 1994). Besides, the lithosphere changes its thickness: from 150-200 km under the craton to 80-120 km under the Phanerozoic Platform (Wilde-Piórko et al. 2010). Of greatest interest for our further discussion are the results from profiles LT7, P2 and P4 (Guterch et al. 1994, Grad et al. 2002, Dadlez et al. 2005, Guterch and Grad 2006). The latter paper contains also some geological implications of the obtained seismic models. A very interesting result of seismic studies was the finding that in the Polish Basin the rocks of relatively low P-wave velocities, of less than 6.0 km/s, may reach as deep as 20 km. This corroborates the supposition of a very large thickness of the sedimentary cover, along with the probable occurrence of strongly metamorphosed or volcanic-origin rocks in the basin's basement. As we already mentioned, the main source of information is seismic survey.

Yet the seismic models, based on the ray theory as well as tomography, although very helpful for solving many important problems, do not provide answer to all the hitherto unresolved questions. The main unsettled issues are localizations and mutual positions of the southwestern margin of the East European Craton and the Caledonian Deformation Front as well as position of Variscian Deformation Front. Therefore, it seems very advisable to apply other geophysical methods, notably electromagnetic ones, which enable us to construct electric conductivity distribution models in the crust and upper mantle. The joint knowledge about the seismic wave velocities and electric conductivity distributions gives chance to make complementary geophysical interpretations, leading to a better recognition of the deep basement structure

DESCRIPTION OF THE WORKS FORMING THE CYCLE

The first group of works forming the cycle, to which [1, 2, 3, 5, and 9] belong, is dedicated to the proposed method of simultaneous inversion and interpretation of global MV studies, regional MV soundings, and local MT soundings, and its application to the regional studies of the structure of the upper mantle. I have started working on the possibility of application of this method together with dr hab. Vladimir Semenov in 1998. The new element was the use of an algorithm for the spherical Earth model (Jóźwiak 2001) for inversion of data, while other studies used classical algorithms for horizontally layered structures, which were widely used to interpret short-term MT data, but did not take into account the effect of the Earth's sphericity even though, starting from the depth of 400 km, it begins to be a significant factor (Srivastova 1966).

The newly developed methodology was applied for the first time to interpret the results of long-term electromagnetic soundings on the profile crossing the Polish part of the East European Platform, similar to the seismic CEL 01 profile, and the results were presented in [1]. The measurements were carried out for approximately three weeks. The magnetic field variations were recorded for a range of periods from 0,05 to 10.000 s. To process the data, two different numerical programs were used: one operating in the time domain, and the other – in the domain of frequency. In order to limit industrial noise, statistical methods of the robust type were used (Chave et al. 1987), as well as the method of the reference station (Gamble et al. 1979). In order to estimate the parameters of the sedimentary cover and of the upper crust, classic methods of interpretation of MT and MV soundings were used.

It was found that the conductivity of the sedimentary layer ranges from 30 to 100 omm on the platform and from 20 to 30 omm on its edge. Knowledge of the sedimentary layer parameters allowed us to more accurately assess the distribution of conductivity in the Earth's mantle. To determine the distribution of conductivity in the deep structures, we also used data from the observatories in Belsk and Pleszczenica. On this basis, the apparent resistivity curves were determined for periods from 8 hours to 300 days, using the methodology described in the work of Semenov (1998). MV curves were supplemented with short-term branches obtained from the results of MT soundings. They were subsequently inverted using stochastic inversion program for the spherical Earth model (Jóźwiak 2001) and, for comparison, the classical 1D OCCAM algorithm (Constable et al. 1987), with the latter results being converted to spherical coordinates (Weidelt 1972). An original approach analogical to that used in seismic tomography was used to present the results. It was assumed that the model of the geoelectrical structure for the platform is the reference model, and deviations from this model were set for all points and depths. Electrical conductivity of the rocks of the Earth's interior can vary by up to several orders. This is why logarithmic scale is often used for presentation of conductivity distribution. Therefore, parameter v was proposed, which was constructed as a logarithm of the S_i/S_0 coefficient, where S_i is the value of integral conductivity at a given depth at the measuring point and S_0 – at the reference point. The integral conductivity of subsurface layers was eliminated from these considerations, which was made possible by estimating those values using routine MT soundings. The obtained results indicate that the upper mantle in the region of the TT zone is more conductive than the one located under the East European Platform. In the area of the TT zone and further in the direction of the Palaeozoic platform, a well-conducting layer is visible at the depth of 200–250 km and its integral conductivity is relatively high. This is new, previously unknown information about the structure of the upper mantle in the region of the marginal zone of the East European Platform.

The study was then continued along the (750 km) long seismic profile similar to the POLONAISE'97 profile. The results of that study were published in [3]. Ultra deep MV and MT soundings were conducted in two points located on the East European Platform, in two points located in the Trans European Suture Zone (TESZ), and in one point on the Palaeozoic platform. A big experimental challenge was to obtain good records of electrical fields for periods up to 40.000. In connection with this, special tests of the apparatus and electrodes were carried out (Semenov et al. 2001). On the basis of their results, the equipment was adapted. For long periods (from daily to secular variations), the data from observatories in Belsk, Niemegk and Pleszczenica were used, and the determined transfer functions were supplemented with values for the longest periods of up to 11 years calculated for Europe and Asia (Semenov and Jóźwiak 1999). Then, the issues related to combining various branches of the transfer function were discussed, since it requires special care. For short periods, the main directions of MT tensors are dependent on the presence of horizontal (often shallow) heterogeneities or anisotropies of the medium. For long periods, the directions of MV sounding curves are dependent on the nature of the sources in the ionosphere and magnetosphere. Thus, the currents induced by storms (D_{st}) have a meridional direction and we can estimate the transfer functions only in this direction. The directions of currents generated by daily variations (S_q) depend on the configuration of ionosphere vortices. Thus, the various branches of the curves can be connected only on the assumption that the deep layers of the Earth in the observation region are homogeneous and isotropic. Such an assumption is true in most cases, which confirms the consistency of all segments of the phase curves obtained by different methods, while the observed discontinuity in the amplitude curves is caused by the presence of local inhomogeneities. This is why we give more weights to phase curves during inversions, as they are more resistant to the presence of displacement currents. Also in this paper, modelling was carried out using stochastic inversion for the spherical model (Jóźwiak 2001), and the D+ inversion algorithm (Parker and Whaler 1981) was used for comparison with correction of the results to spherical coordinates (Weidelt 1972). The result was a model of integral conductivity distribution along the profile. For presentation purposes, the previously introduced parameter *v* was used, describing the deviation from the reference distribution of conductivity (on the East European Platform). In the approach proposed by us, the anomalous well-conducting area under the TT zone is clearly visible: *v* reaches 0,5 at a depth of 150–200 km (relative to the structure of the East European Platform). The resulting model was then compared with a 2-D tomographic model of seismic velocities in the lithosphere along the P4 profile (Guterch et al. 1999). It was found that both the geoelectric model and the seismic model clearly show the difference in the deep structure under the East European Platform and under the TT zone in Poland. Interestingly, the position of the deep zone of reduced velocities visible in the seismic model (probably a basin filled with metamorphosed sediment) in the upper crust correlates very well with the location of the highly conductive area in the upper mantle as discovered by us.

The above results of electromagnetic soundings at selected profiles showed that the conductivity of the mantle under the East European Platform and the TT zone is different. However, those results did not let us determine whether the phenomenon is local or rather regional. We decided to undertake further works so that we can decide on the nature of the anomalous zones observed in the mantle. The methodology developed by us and presented earlier had proven to be an effective research tool and we applied it to the diagnosis of conductivity distribution in the middle mantle. The data from regional MV soundings, which can be obtained on the basis of long-term records performed in the observatories, are sufficient for those estimates. The results of these studies are presented in [5]. The study was possible because Europe is the region with the highest density of geomagnetic observatories with many-year series of records, which allowed the development of transfer functions for a very wide range of periods from 6 hours to 5,5 years. A unique collection of MV sounding curves was created in this way for 35 observatories, which was then supplemented with the data from global soundings. Both branches of the curves were interpreted jointly by means of the above-described methodology. When interpreting, much attention was paid to the assessment of the potential impact on the obtained results of large well-conducting subsurface areas (oceans, seas and sedimentary basins). To estimate this potential impact, the spherical Earth model was used in which conductivity is a function of the radius, with the additional assumption of existence of an additional external inhomogeneous surface layer. The theoretical values of the transfer function for 35 points, which were determined by means of this model, were then inverted by the inverse algorithm in the same manner as the experimental data. Then, the assumed and calculated values of the depths at which integral conductivity reaches 100 kS were compared. Results for the 28 observation points showed that, through theoretical data inversion, we “recover” with high accuracy the assumed structure model with a several per cent error. Only for the seven southern coastal observatories, the error reached 9%. As a result of inversion, we obtained conductivity distributions for all 35 observatories. Then, we created, by means of averaging, a European map of integral conductivity in the middle mantle to a depth of 770 km. This depth was chosen for presentation of the integral conductivity distribution, because it is the average depth of deposition of the conductive layer in the middle mantle in Europe and Asia (Semenov and Jóźwiak 1999). If the conductive layer is located closer to the surface, we will obviously observe high values of integral conductivity at the depth of 770 km. If it is located deeper, the values will be low. The resulting image shows that the observed differences in conductivity correlate well with the location of the main European tectonic units: the East European Platform, TESZ and Palaeozoic platform. Analysing the obtained results, it was found that the distribution of conductivity in the mantle is regular, and that in the middle mantle we can very clearly see a layer of increased conductivity. However, the depth at which this layer is located depends on the region: from 600 km under the East European Platform up to 900 km under the Palaeozoic platform. Let us recall that, for the upper mantle, we observe the opposite picture (the conductive zone under the East European Platform is located clearly deeper than under the Palaeozoic platform), which is also seen in seismic data and satellite gravity data.

In 2001, an international experiment on a regional scale under the name of CEMES (Central Europe Mantle geoElectrical Structure) was organised for the first time in Europe. It was our (Vladimir Semenov’s and mine) initiative, joined by research teams from nine countries of the region. Its main objective was to study the distribution of electrical conductivity in the upper mantle based on a common interpretation of long-term MT and MV soundings data. Assumptions and preliminary results of the project were presented in [2], and the final results in [9]. The project included ultra-deep (several months’ long) electromagnetic soundings in 11 geomagnetic observatories in Central and Eastern Europe. The observations were carried out, to the extent made possible by technical and human capabilities, synchronously in as many points as possible, so that in the processing of the data it was possible to use reference methods. The processing of experimental data was conducted separately by five teams from different countries using three different procedures. Impedance tensors were calculated, as well as resistivity curves and phase curves, polar diagrams, induction arrows and the magnetic tensor. The directions of induction arrows were also determined for long periods because they reflect the regional directions characteristic of deep structures. To assess the impact of the conductive subsurface layers, a spherical Earth model was constructed with an outer heterogeneous layer simulating distribution of shallow conductive structures in Central Europe (Vozár et al. 2006). Then, using an advanced algorithm (Kuvshinov et al. 2005), theoretical transfer functions of MT soundings were calculated for several different sources of field generation. The results of the model clearly showed a strong “displacement effect” on the amplitude curves, while the phase curves are undisturbed and must be treated with priority at interpretation. The combined MT and MV curves were inverted independently by research teams in Kiev, Moscow, Warsaw and Prague, using various one-dimensional inversion algorithms. The obtained integral conductivity distribution models up to the depth of 300–400 km that were obtained by different groups were consistent within the error limits. An averaged integral conductivity distribution model in the upper mantle was then created for the region of Central Europe. The results were presented in the form of three-dimensional maps presenting the distribution of integral electrical conductivity for the upper mantle (the layer of 50–200 km) and the distribution of depths at which the integral conductivity reaches the value of 1 kS, which is equivalent to reaching a well-conducting layer corresponding to the asthenosphere and which shows its depth of deposition. As written above, the regional MV soundings allow us to evaluate the parameters of the well-conducting layer in the middle mantle. However, the addition of short-period sounding branch allows us to evaluate the properties of the well-conducting layer at depths of 100–300 km, where you can expect the presence of asthenosphere, known from seismic studies. The results of the CEMES project provided evidence for presence of these two well-conducting zones in the mantle, differing both as regards the values of conductivity and the depth of deposition. There is a close correlation between the depths of deposition of the layer corresponding to the asthenosphere and the boundaries of the main tectonic units present in Central Europe. The asthenosphere lies deep (about 250–300 km) under the East European Platform and at a significantly smaller depth under the Palaeozoic platform (80–150 km), reaching the lowest depths under the Pannonian Basin. This is a picture opposite to that seen in the position of the well-conducting layer in the middle mantle (Semenov and Jóźwiak 2006). These properties of the structure are also observed in seismic velocity distribution models.

The next three works – [6, 7, and 8], developed by teams composed of many authors – were devoted to a comprehensive interpretation of regional results of MT and MV soundings. My contribution to these works was focused mainly on estimating the distribution of conductivity in the upper mantle. For this, I took advantage of the technique described above, which uses long-term records of neighbouring observatories along with data recorded on the profiles. I also participated in the preparation of the concept of both of these works and implementation of their experimental part. It is important as much as I used the data collected in these projects to later assess conductivity in the marginal zone of the East European Platform [10 and 11].

Article [7] presents a comprehensive interpretation of the results of MT and MV soundings on a 400-kilometre profile crossing the Małopolska Massif, Świętokrzyskie Mountains, TESZ and the Polish part of the East European Platform. The main objective was to diagnose the morphology of the top of the crystalline basement and to identify tectonic elements of the crystalline basement and the sedimentary Palaeozoic complex. An important element was the diagnosis of the geoelectrical properties of the Earth’s upper mantle. Construction of the models of conductivity distribution involved the use of data from deep electromagnetic soundings, data from MT and MV soundings carried out at 20 points on the profile and data from the nearest magnetic observatories. To determine the transfer function, the previously described methodology was used. A crucial step in the study was inversion of all the collected data using two different 2D algorithms (Rodi and Mackie 2001; Nowożyński and Pushkarev 2001). Numerical modelling was conducted taking into account the estimates of the upper mantle conductivity made on the basis of the results of MV soundings performed in Belsk and Hel observatories for periods from several days to several months. On the determined model of conductivity distribution, in the south-western part of the profile, we can see conductive sedimentary rocks of the Małopolska block. Below, we can see less conductive metamorphosed rocks reaching the depth of 8 km. Under Łysa Góra block, these complexes have a more complex structure, and the south-western part is more conductive than the north, particularly at the depth of about 5–8 km. This may be the result of various factors, such as differences in petrological composition, presence of mineralised water, metamorphism or differences in anisotropy of the basement rocks (more horizontal nature in the south-west and more vertical in the north-east). On the obtained model, at the north-east side of the Łysa Góra block, we can clearly see a deep conductive fault, known as the Holy Cross dislocation. Very high conductivity values point out to graphitisation or presence of rocks soaked with mineralised water. Under the TESZ, at a depth of 3–8 km, we identify a complex of rocks of high conductivity, presumably of sedimentary origin. Further to the north-east, the tectonic structures become more complex, and the estimated thickness of sediments are similar to those obtained in other geological and geophysical studies. The Lublin graben, probably filled with Silurian-Carbonian sediments, is also clearly visible. The high conductivity of rocks in the central part can be explained by a high content of mineralised water or graphite. These rocks are covered with Permian and Cretaceous sediments, which continue further into the East European Platform. They consist of two layers: the lower is more conductive, probably because it contains mineralised water. Between 250 and 270 km of the profile, we can see deep, almost vertical anomalous structures in the crust, which can be interpreted as faults. The presence of two such faults is typical of the TESZ. Their presence was confirmed also in the south-eastern Poland (Ernst et al. 2002) and in Sweden (Smirnov & Pedersen 2005). The rocks lying below the upper crust are consolidated and high-resistance rocks (with resistivity of the order of 10.000 Ωm), which is consistent with the estimates for Belarus (Fainberg et al. 1998). Below the depth of 10 km, conductivity of rocks gradually increases. In the upper mantle, at depths of 150–210 km, we observe a zone of increased conductivity under the TESZ. This well-conducting layer, clearly visible in the model, corresponds probably to the asthenosphere, and the observed decrease in its conductivity towards the East European Platform can be caused by decreasing the conductivity of the rocks composing it or by progressive immersion.

Subsequent works – [6 and 8] – show the first results of the large, international electromagnetic research project conducted in the north-western part of Poland and the north-eastern part of Germany. It was carried out by teams from Poland, Germany, Finland, the Czech Republic, Russia, Sweden, and Ukraine. The main objective was to study the deep geoelectrical structure of the TESZ. Measurements were carried out in the years 2001–2005, primarily along the seismic profiles P2, LT-7, and LT-2. Later, in the years 2005–2007, the area of research was extended to the north-west with points lying near the Baltic Sea in Poland and by additional profiles in the north-eastern Germany and south-eastern Sweden. The experimental works were conducted using broadband and long-term stations (Polish, German, Swedish and Czech). Importantly, the interpretation of the data also relied on data from Hel, Belsk and Niemegk observatories, located in the vicinity of the study area. Many years of recordings performed in those observatories made it possible to evaluate the conductivity of the upper mantle and also helped to determine the interstation transfer function for MV soundings. Data processing and analysis were conducted independently by all participating groups, using various algorithms. Interstation impedance tensors, tippers and magnetic tensors were determined for periods of 10–15.000 s for long-term stations and 0,003–2.000 s for short-term stations with the help of advanced algorithms, including multireference ones. Parameters pointing to dimensionality of the structure were calculated and diagrams of the directions of the main impedance tensors were built. It was found that 2D modelling can be used to interpret the data both for the P2 profile and LT-7 profile. Conductivity distribution models were then determined using a variety of 2D inversion algorithms (NLCG – Rodi and Mackie 2001; REBOCC – Siripunvaraporn and Egbert 2000). Many attempts were made in which initial models were changed and *a priori* data were introduced or not in relation to the subsurface layers and the distribution of conductivity in the mantle determined on the basis of short-term simultaneous inversions of MT data from the profile and long-term data of MV soundings in nearby observatories. The presence of well-conducting sedimentary Cenozoic-Mesozoic layer with a maximum conductivity (1 S/m) at a depth of approximately 1 km is also visible in the subsurface zone on the obtained models. Its thickness reaches 4–5 km and is the largest in the south-western part of the profile, near the German-Polish border. This layer disappears in the central part, in the area of the Czaplinka block, where we can observe non-conductive salt domes with very high resistivity values. Below, there is a non-conductive layer of Zechstein, very well visible across the profile. The most striking feature is the presence of a very well-conducting layer with minimal resistivity of about 2 Ωm and values of integral conductivity of the order of 1000–1500 S, which is located under the entire TESZ at a depth of 10–12 km. It is identified on the basis of seismic refraction data analysis as a pre-Variscan consolidated crust (Dadlez 2006) and is characterised by low values of P wave velocity (5,85 km/s). We cannot state clearly what the mechanism of electrical conductivity is. It can be mineralised waters (ionic conductivity) or graphites or conductive slates (electronic conductivity). In the south-eastern part of the profiles, at a depth of about 100 km, there is a well-conducting layer which may correspond to the asthenosphere observed on the results of seismic and geothermal studies (e.g.: TOR Working Group et al. 2002). In the central zone, under the TESZ, we can see a conductive region at depths of 60–120 km. In conclusion, it was found that the obtained conductivity distribution models for both profiles show three different fragments of the crust. First of them, lying in the NE part of the profile is highly resistant and is undoubtedly part of the East European Platform. Its structure appears uniform, indicating that the changes that had taken place since its creation in the Precambrian were relatively small. In the second, middle fragment, the resistivity values are much lower. Due to the complicated structure of its upper floors, this area must have undergone numerous changes. It was subject to tensions and compressions, which together with subsidence and sedimentation led to the creation of a deep basin, which underwent inversion in the Triassic. However, we cannot see division into terrans in the lower crust. The lower crust appears to be quite homogenous and lower resistivity values may indicate a higher temperature. The anomalous well-conducting region visible in the upper mantle correlates well with the thermal anomaly observed there (Majorowicz 2004). The third region adjacent to the former from the south-west is not as homogeneous as the East European Platform and it is undoubtedly the Palaeozoic platform. Contacts between the platforms indicate very deep rooting of the sutures observed in the shallower layers. In the obtained conductivity distributions, we do not see the typical image of subduction in the lower crust, even though it is possible to find some elements of this model in the upper stages.

The next three articles, namely [4, 10, and 11], present the methodologies and results of MV research of the crust structure. The research started with a project implemented under my leadership and entitled “Magnetovariation soundings on the Rügen-Bornholm profile”, which was a natural continuation of the research described above, carried out as a part of the EMTESZ-Pomerania project. Article [4] shows the initial interpretation of those results, and in the conclusions, we suggest continuation of the work, which later came true. The project of research on the Baltic had two main objectives. The first was to develop numerical models for the distribution of electrical conductivity for the Southern Baltic region. The second, no less important, concerned the methodical aspect, namely implementation of a new research method based on the use of offshore magnetic measurements. Both of the objectives were fully achieved. As a part of the experimental works, long-term geomagnetic recordings were carried out at two points located in the Southern Baltic region between Bornholm and Rügen, and long-term MV and MT soundings in ten points located on land (Bornholm, Rügen and Western Pomerania). Terrestrial measurements were performed by standard, long-term stations of the fluxgate type by Polish and German groups, and the marine measurements – by a sea-bottom station (Marianiuk 2005). At selected points, short-term measurements were also carried out (using induction coils), which allowed us to evaluate the electrical conductivity of the shallower layers. Based on the collected experimental material, magnetic transfer functions were determined for MV soundings, and impedance tensors – for MV soundings for periods from 0,003 s to 12 h with the help of advanced algorithms using reference stations. Interpretation of MV data involved the use of the so-called perturbation tensor (Schmucker 1970), which is a relation between the anomalous and normal field. The results were presented in the form of the so-called perturbation vectors, whose real parts describe the anomalous currents induced in the basement and flowing to the north and east. Large values of these parameters indicate the presence of well-conducting complexes. The obtained preliminary results are very interesting and shed new light on the structure of the deep basement of the TESZ in the studied region. They provide evidence for the existence of a large, not yet described magnetic anomaly on the west coast of the Baltic Sea. It runs from Koszalin and along the Baltic coast in the direction of Świnoujście, Usedom Island and Rügen, where we can observe a double increase in the value of the horizontal component of the magnetic field. This anomaly is probably caused by the presence of well-conducting sedimentary rocks at a depth of 11–20 kilometres, but it is difficult to say whether we are dealing with ionic conductivity, and thus porous rocks filled with mineralised waters, or with electronic conductivity, which requires presence of conductive slates with high graphite content. At the end, it should be added that by implementation of the project, we wanted to extend our research methodology and introduce geomagnetic soundings on seas to routine regional works. We managed to achieve this objective in full. The equipment worked perfectly and quickly we were able to solve all the technical problems associated with foundation of the station at the bottom and with its subsequent ascent. As expected, the recorded data were of very good quality, and in contrast to terrestrial recordings, there were virtually no interferences as the thick layer of water above the magnetometer significantly reduced the harmful impact of artificial interferences.

These very interesting results of preliminary interpretations led me to deal with the methodology of interpretation of regional MV soundings. I was encouraged also by our many years of experience showing that MV soundings are the most effective method of studying the distribution of conductivity in the crust, especially where the structure is of a three-dimensional nature. The works undertaken resulted in a new method of interpreting the data from MV soundings, which together with the first results of its application is presented in [10]. The results of MV soundings are usually presented in the form of tippers or the so-called induction arrows. For two-dimensional structures, these transfer functions are the starting point for numerical modelling, but we do not have efficient algorithms for three-dimensional structures and we can only draw qualitative conclusions. The Perturbation Tensor technique, proposed by Schmucker (1970) and used in the previous article, has many limitations as well and is not effective. However, it is possible to present the results of MV soundings in the form of HMT. It is the relation between the magnetic field at the point of observation and the magnetic field registered by the reference station (Schmucker 1970; Berdichevsky 1968, 2008; Varentsov 2005, 2007). This method of presentation is much more informative. It makes it possible, in particular, to map the course of deep conductive structures in the crust and Earth's mantle. The spatial distribution of some of its invariants corresponds to the distribution of amplitudes of the magnetic field induced in the Earth. This means that in areas where those values are large, there are complexes of well-conducting rocks. However, this way of interpreting the results of MV soundings is used very rarely since direct determination of HMT is possible only if the observations are carried out in the whole study area synchronously. Moreover, the reference point must be selected in such a way that the structure is similar to a normal one, i.e. it must be placed far enough from the places of occurrence of anomalies in the distribution of conductivity. Fulfilment of those conditions is quite difficult and greatly increases the cost of the research. However, it turns out that it is possible to reconstruct all components of the magnetic field and define HMT values based on the knowledge of tippers, or induction arrows within a certain area. This technique takes advantage of the fact that the Earth's magnetic field is a potential field and its vertical component is associated with the horizontal component by Hilbert transformation (Weaver 1964; Bailey et al. 1974; Becken and Pedersen 2003; Jóźwiak et al. 2009). In [10], a new efficient iterative algorithm was presented for determination of HMT based on the distribution of surface tippers (geomagnetic vectors). It uses approximation of tipper components on the area of a rectangle with the use of two-dimensional splines with separate variables and the algorithm for calculating the three-dimensional Hilbert transform for the vertical component of the magnetic field. The method presented above is very effective as it allows the use of archival data and the systematic extension of the set of data for the area of interest. The proposed methodology was applied to a great set of induction arrows for the period of 1800 s from the Central Europe region, gathered over the last 50 years. The greater part of them comes from published studies and additional values were obtained thanks to the courtesy of colleagues carrying out our joint EMTESZ-Pomerania project. The results of transformation of this data set in HMT is presented in the form of a map showing the spatial distribution of the most informative invariant of HMT, maximum specific values that correspond to large values of the induced magnetic field. The resulting image is much more structured than the classical distribution of induction arrows. We can clearly see large, stretched anomalous areas where amplitudes of the induced magnetic field are twice higher than in normal areas. This means that those places contain very well-conducting rocks. The large period of the field variations for which the computations were performed suggests that these are deep, crust complexes. In order to better define the depth of those changes, it would be necessary to know HMT for a large set of periods. It is currently not possible, because for many years – in the initial period of application of MV studies – induction arrows were determined only for long periods. More precise determination of the depths of the conductive structures identified by HMT is possible by comparison with the results of 2D modelling conducted on profiles crossing the structures in question, making it possible to evaluate the depth of depositions of those well-conducting complexes at 10–20 km. The structures identified on the basis of the analysis of the spatial distribution of HMT invariants are probably deep sedimentary basins with large conductivity values reaching 10000 S. It is impossible to determine the nature of those well-conducting rocks. These can be either porous (fractured) rocks filled with mineralised waters or metamorphosed sedimentary rocks containing graphite or metal sulphides. An extremely suggestive image is obtained after marking on the above-mentioned map the hypothetical locations of the Caledonian (Berthelsen 1992) and Variscan (Pożaryski and Karnkowski 1992; Dadlez et al. 1994; Narkiewicz and Dadlez 2008) Deformation Fronts. In analysing this picture, we find a strikingly good correlation between the position of those fronts and the position of the deep conductive complexes in the crust, as identified by us. This demonstrates, in my view, that the origin of those basins is closely related to the orogenies present in the past on the study area: Caledonian, Variscan and Alpine. They are probably subsidences before the mountain ranges emerged as a result of those orogenies. On the basis of the obtained results, we can infer the location of the Caledonian Deformation Front (CDF), in particular in the area between Rügen and Koszalin, where we do not have any data from drillings. It seems that on the north of Koszalin, CDF turns west and runs along the coast of the Baltic Sea up to the Usedom Island, where it turns north towards Rügen. It can be also concluded that the position of the Variscan Deformation Front (VDF), proposed by Pożaryski and Karnkowski (1992) and later modified by Narkiewicz and Dadlez (2008), is closer to the truth.

[11], the last work of the cycle, is a monograph. It summarises the results of many years of research on the deep basement in the marginal zone of the East European Platform with the use of electromagnetic methods. It also presents the latest results of research on the structure of the crust and the upper mantle beneath the East European Platform, TESZ and the Palaeozoic platform. Then, it makes a comparison with the results of seismic research and formulates conclusions concerning the geotectonic history of the region. In the introduction, it was pointed out that electromagnetic methods can detect fault and overthrust zones with

porous rocks saturated with mineralised water, graphites and metal sulphides, and – at a greater depth – zones of partial melting, which is important for understanding of the tectonic structure of a given area. In stable regions, they make it possible to track the traces of ancient tectonic processes, collisions of continental plates or their fragments, and locate the suture zones or foreland subsidences. Then, the monograph briefly presents the methods of electromagnetic soundings, both MV and MT. It discusses their origin, conditions of use, data processing procedures and methods of interpretation. It was stressed that the MT method, initially used for diagnosing layered structures, does not give satisfactory results in areas of heavy horizontal heterogeneity. In this case, the method of MV soundings is of special significance. It was underestimated for a long time in the West, while it was widely used in the countries of Central and Eastern Europe with very interesting results. It was recalled that that it was thanks to this method that the Carpathian anomaly – one of the largest anomalies in the world – was described already at the beginning of the 1960s. It is not advisable to cite all the results presented in the article and discuss the methods of obtaining them since they were already indicated during the presentation of previous works of the cycle. Let us mention, however, that the work presents the previously unpublished results of HMT tensor distribution analysis for the region of Pomerania for periods from 128 s to 4000 s, compiled in the form of "pseudo-sections". The analysis of those results showed that both anomalies are visible in a large range of periods of field variations, so their thickness is very large and may reach up to 20 kilometres. They are located at the depths of 10–20 km. The anomaly that runs along the Baltic coast, identified by us as the limit of reach of the Caledonides, is already visible for shorter periods, which means that its top is located at shallower depths than the top of the second anomaly, in our opinion related to Variscan orogeny. A more precise determination of the depth will be possible only as a result of 3D modelling, which is currently underway. The next paragraph shows the new results of conductivity distribution modelling in the upper mantle in the marginal zone of the craton. For the selected points of the P2 profile, where – as a part of the already discussed EMTESZ-Pomerania project – the Polish team performed long-term soundings, combined transfer functions were calculated. The MT sounding curves were supplemented by long-term branches calculated on the basis of data from the nearest magnetic observatories located in places where the parameters of deep structures are similar (Semenov and Jóźwiak 2006). The very behaviour of the apparent resistivity distributions showed that there are differences in the distribution of conductivity in the deep basement for those three tectonic units. On the basis of functions determined in this way, a 1D distribution of conductivity in the upper mantle was constructed for each point using inverse algorithm for a spherical Earth model (Jóźwiak 2001). Then, on the basis of 1D models, a pseudo 2D conductivity distribution was developed for the P2 profile to obtain a unique, very interesting picture of the lithosphere in the transition zone between the two platforms. The last part of the paper presents conclusions that can be drawn from the analysis of the results of all the discussed electromagnetic studies, which will be referred to now in several points:

- the obtained conductivity distribution models suggest that the magrinal zone of the East European Platform is an area of a very complex and diverse geological structure. They also show that the TESZ is a lithospheric border, which is reflected not only in the sedimentary layer, but also – and probably above all – in the crust and upper mantle of the Earth;
- the results of shallow EM soundings helped to determine the parameters of the sediment layer and determine the presence of rocks impregnated with mineral waters in the lower parts of this layer. The results are consistent with the results of other geophysical methods and drilling;
- significant horizontal heterogeneity can be observed in the crust. We can clearly isolate the area of the high resistivity Precambrian platform, Palaeozoic platform with slightly lower resistivity values and the transitional TESZ with a complex structure. We can observe there

the presence of large, stretched well-conducting complexes at depths of 10–20 km and possibly reaching even deeper. Huge integral conductivity values reaching 10.000 S and large thickness suggest that they are probably porous (fractured) rocks soaked with mineralised water, which does not exclude the presence of slates and metal sulphides. The location of those crust complexes is very well correlated with the location of Caledonian and Variscan Deformation Fronts. The relationship seems obvious. However, we are not able to clearly describe the process of their formation. It can be assumed that it is a sedimentary material accumulated during orogenic movements, which as a result of subsequent processes sunk to such great depths. Presence of similar conductive zones is observed in other regions of plate contact, including those that are inactive. The obtained results indicate that the CDF running northeast of Rügen and further to the SE, near Koszalin, and in Central Poland, approaches the TT line, which cannot be determined beyond doubt due to lack of data from this region. However, the position of the VDF line is similar to the one proposed by Pożaryski and Karnkowski (1992) and modified by Narkiewicz and Dadleaz (2008);

- conductivity variation seen in the crust continues in the upper mantle. We can observe a more resistant lithosphere block corresponding to the Precambrian platform, and the lithosphere of the Palaeozoic platform is a little bit more conductive. The depth of the LAB reaches 250 km under the Precambrian East European Craton and 150 km under the Palaeozoic platform. The properties of the lithosphere in the transition zone, under the TESZ, are clearly different. There is no clear visible high-resistivity block, and in the upper mantle, we can see two anomalous areas of a clearly higher conductivity values, whose positions correlates well with the thermal anomaly. The inclined edge of the Precambrian lithospheric plate suggests that it is the passive edge of the platform created as a result of Neoproterozoic rifting (Early Cambrian);
- electromagnetic soundings are a very effective tool to diagnose the lithospheric structure. They provide information complementary with respect to seismic information on the physical parameters of the Earth, which facilitates learning about the construction and understanding of the geotectonic history of the study area.

V) DISCUSSION OF OTHER SCIENTIFIC AND RESEARCH ACHIEVEMENTS

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Studies on the geoelectrical structure in the marginal zone of the East European Platform, which were presented as the habilitation achievement, were the main area of my research in recent years. In addition, I participated in all the routine regional MT and MV soundings carried out by our group. I also participated in development of the concept of both of these projects, implementation of the experimental part, as well as in the interpretation of the results. I will discuss only the most important of them – those whose results were published in leading journals. However, at the beginning, I will present the results of the research on the mantle structure, which began even before the doctorate and were its basis, and then – after an extension and modification – the object of two publications.

STUDIES ON THE DISTRIBUTION OF ELECTRICAL CONDUCTIVITY IN THE EARTH'S MANTLE

As mentioned in the discussion of the works constituting the habilitation achievement, an important element of the proposed method of research of the deep conductivity distribution is the stochastic inversion algorithm for a spherical Earth model. This algorithm was the basis of my doctoral thesis and was intended to be used for inversion of global data. Those data for periods of field variations of up to 11 years, make it possible to estimate conductivity in the mantle up to a depth of 2100 km. I considered that inversion of global data is only possible with the help of the spherical model as, starting from a depth of 400 km, the effect of Earth's sphericity begins to be of significance (Srivastova 1966). Even before presentation of my doctoral thesis, together with dr hab. Vladimir Semenov, I tested the possibility of applying this algorithm to the inversion of regional data. After some modifications, it proved to be a very useful and effective tool, and since then we routinely use it for long-term MV and MT data inversion. This modified version of the algorithm, together with examples of the results of its applications, was presented in [1]. Due to poor conditioning of the inverse task for the conductivity distribution function, the algorithm assumes that the searched function is the distribution of integral conductivity. Since, in practice, inversion involves the use of a relatively small number of observations, it was necessary to adopt additional assumptions about the task. It was assumed that the differences between the model searched for and the half-space are stochastic and can be described by a combined process of moving average and autoregression. Then, the total error consists of proper errors from the formulation of the inverse task and approximation errors in the stochastic process. An attempt to solve this task by the nonlinear method of least squares leads to peculiarities. Therefore, the maximum likelihood method was used. It is difficult to solve for numerical reasons, but in this case, the task can be converted into a form corresponding formally to the nonlinear method of least squares. A comprehensive approach to the task made it possible to use the Marquardt's (1963) method. The results of many years of research on the global geoelectrical structure of the Earth's mantle with the use of the described algorithm were presented in [3]. The article emphasises that the obtained models do not confirm presence of a layer of high conductivity at a depth of 400 km, which for many years was considered an essential feature of the global distribution of conductivity. However, it very strongly emphasises presence of a well-conducting layer at a depth of the order of 600–900 km. Some of the models give indications of the possible existence of a second conductive layer at a depth of about 1600 km. It should be noted that the unique result of the stochastic method is the estimation of conductivity of the lower mantle and determination that the increase in conductivity is clearly visible from the depth of 2100–2200 km to the border of the core, which shows that, at the core-mantle boundary, there is an interface layer with different properties (equivalent of the D’’ layer in seismology). Moreover, examples were presented of regional models. They show that the obtained regional distributions of conductivity are generally similar in nature, but the depth of the visible well-conducting layers changes, which is likely to reflect the regional differences in the structure of the mantle. Part of the obtained results correlate well with the results of seismic studies, but some seismic results are not confirmed, perhaps because the changes in the mechanical properties of rocks do not always translate easily to changes in conductivity. It is significant that the conductivity distribution models suggest (perhaps in a way not entirely sure yet) the existence of anomalous layers not previously documented by seismology. It is obvious that, in this situation, the results of electromagnetic studies should be considered as independent and complementary with respect to the seismic data. This approach expands interpretation possibilities and will make it possible to better understand the construction of the Earth’s interior and the physical processes occurring inside.

MT AND MV SOUNDINGS IN THE CARPATHIANS

[4] presents a new interpretation of the results of soundings from the Polish part of a long international profile from Ukraine to Hungary (PREPAN 95) crossing the Carpathians, TT zone and East European Platform in South-Eastern Poland, supplemented with data from two new MV and MT soundings. Particular attention was paid to data from Pawłówka, where additional short-term MT soundings were performed next to long-term MT soundings. Inversion of combined sounding curves showed that the upper mantle, at a depth of 100–200 km, contains a conductive layer whose integral conductivity is about 3 kS. We can also note the presence of a conductive layer in the middle mantle at a depth of about 800 km with integral conductivity values of about 800 kS, which is a global feature. A 2D numerical modelling was then carried out. The obtained model of conductivity distribution in subsurface layers basically confirms the already known information about the morphology of the top of the crystalline basement and parameters of the Palaeozoic sedimentary complex. The most important, original and interesting conclusion was proving the existence of two deep conductive faults in the area between the Carpathians and the East European Craton. The first one can be interpreted as an extension, towards the south-east, of the well-known Holy Cross dislocation. The second fault can be interpreted as the south-western border of the East European Platform.

Article [6] is a monograph and it discusses the results of long-term MV and MT soundings carried out in the Carpathian Mountains, mainly by a team of the Institute of Geophysics in collaboration with partners from the Czech Republic and Slovakia, but also from Ukraine, Russia and Romania. It was recalled that the anomaly in the Carpathian Mountains was discovered in 1967 (Jankowski 1967) on the basis of an analysis of induction arrows. Their distribution is typical of two-dimensional structures, for which vectors rotate 180 degrees when passing through the zero line located over the axis of the anomaly. The following section discusses the results of further works carried out by various groups until recent years. The methods of interpretation and the obtained models of conductivity distribution were compared. It was found that the obtained models are varied and can be divided into two groups. The first is composed of those that locate well-conducting areas which are the source of anomalies in two depth ranges: in shallow layers of up to 5 km and deep in the crust at depths of about 20–30 km. In the second group of models, we have only one conductive region at depths of 8 to 18 km and it is just this picture of the structure that our studies support. The models of conductivity distribution were then compared with the results of seismic studies (Guterch et al. 2003; Grad et al. 2006; Środa et al. 2006) and it was found that the position of the well-conducting area documented by us correlates surprisingly well with the position of the low seismic velocity zone. In conclusion, it was found that: the shape of the zero line of the anomaly is well documented and it locates the axis of the anomaly; the depth of deposition of the well-conducting complex does not exceed 30 km, and it is probably located at a depth of 8–18 km; it has not been settled yet beyond doubt whether good conductivity of the rocks is the result of saturation with mineralised water (ionic conductivity) or of the presence of graphites and slates (electronic conductivity).

The last paper, [10], concerning the Carpathians, was devoted to the discussion of the geometry, depth of deposition and petrography of a well-conducting rock complex responsible for the existence of the anomaly. It was found that both mechanisms are theoretically possible. However, in the case of the Carpathians, the mechanism of ionic conductivity is much more likely. In the case of graphite, there is a serious problem of galvanic connections between the individual grains. Moreover, extremely high integral conductivity values indicate that it must be a layer of big thickness, since graphite rarely takes the form of a solid rock in nature. We can only find the additive of graphite in various rock complexes, such as black slates, and then the conductivity of such a complex is less than 10 S/m. However, no such complexes have been found in the Carpathians, although it is of course conceivable that such rocks exist at greater depths. The situation is different with the version involving mineralised waters. Many such waters can be found in the Carpathian Mountains and they are also found in boreholes at depths of 5–6 km, for example, in Orava and in the Krynica region. It is therefore likely that they occur at greater depths. The article goes on to discuss the problem of tectonic disturbances of the conductive complex and their impact on the observed induction effects. The Carpathians are a young mountain range and they have a block structure. Therefore, we can expect tectonic disturbances also in the complex of conductive rocks. However, the observed anomaly has a length of about 600 km and is very regular. Based on the three-dimensional models I developed, it was found that the introduction of tectonic disturbances involving fracture of the conductive channel causes a significant reduction in the amplitude of the observed vectors and such an effect could be expected in the case of electronic conductivity. In the case of the ionic conductivity, fluids will migrate through a gap in the good conductor, given that the gap would probably be composed of fissured rocks. This effect causes "gluing" of fragments of the fractured well-conducting rock complex and, as a result, there would not be much difference in the current density and amplitude values of induction arrows. In the conclusion, it was stated that all of our analyses suggest ionic conductivity and this means that the source of the Carpathian anomaly are deep complexes of porous rocks soaked with mineralised waters.

RECONNAISSANCE ELECTROMAGNETIC SOUNDINGS ON BORNHOLM

[2] presents the results of MT and MV soundings conducted by our group in collaboration with Danish partners on Bornholm. Recordings were performed for two weeks in 1998 in two points: Rutsker (RUT) and Louisenlund (LUI), located about 20 km away from each other. Magnetic and telluric recordings were virtually free from interference, which made it possible to calculate the transfer function for periods from 10 s to several hours. Polar diagrams were characterised by a very complex structure. It was not possible to determine on their basis the direction related to the regional structure. The attempt to use the algorithm of Bailey and Groom (1989) and Bahr (in 1991) also failed, as might be expected in the case of strong current channelling (Bahr 1991). The data pointed to a complex, three-dimensional nature of the distribution of conductivity, and the strong current channelling, which had no justification in the character of the subsurface structures, is evidence of anisotropy of the complex of the crystalline rocks forming Bornholm. The situation was less complicated in the case of MV soundings, as this method is not as sensitive to local inhomogeneities. The induction arrows determined for the period of 1800 s have the length and direction similar to

those observed in Poland in the East European Craton, which confirms the structural affiliation of Bornholm to the craton (Berthelsen 1993). The directions and lengths of the vectors indicate also that, perpendicularly to them, there is the axis of a well-conducting structure, possibly a deep sedimentary basin, running along the southern coast of Bornholm. For short periods, of the order of 20–50 s, the directions of vectors in Rutsker indicate that there is also a good conductor located along the west coast of the island. It is difficult to say whether this is the same conductive complex, which only changed the course of its direction, or whether it is another anomaly. Vector directions in Bornholm are similar to those in Rügen, which means that they cannot be caused by the presence of a symmetric sedimentary basin between them. There are two possible explanations: either there is a plateau of the crystalline basement in the sedimentary basement between the islands, or there are two clearly visible thresholds. The latter should then be placed to the southwest of Rügen, as this is where a good conductor responsible for the observed vectors should be sought. It was stressed that the resolution of this issue will be possible only on the basis of data from measurements carried out at the bottom of the Baltic Sea.

STUDIES OF THE IMPACT OF THE HETEROGENEOUS SUBSURFACE LAYER ON THE NATURE OF INDUCTION ARROWS ON THE EXAMPLE OF THE EAST EUROPEAN PLATFORM

[5] presents very interesting and quite unexpected results of deep MV and MT soundings carried out in the Polish part of the East European Platform. The recordings were made in nineteen points, and on their basis, sounding curves were established. The most surprising result was that the amplitudes of the real part of the induction arrows are very large and reach 0,8, which was not expected in the case of an old platform. Large amplitudes of induction arrows can be rather expected in areas with large horizontal gradients of conductivity.

The vectors reach their maximum length for periods of about 300 s, and it is for this period that we can observe inversion of the directions of the imaginary part of the vectors. All vectors calculated for the period of 300 s were applied to a tectonic map (Znosko 1998). It is easy to notice a striking correlation between the directions of the isolines of the depths of deposition of the crystalline basement and the directions of induction arrows – they are perpendicular to each other. Such correlation suggests that the reasons for the observed behaviour of the induction arrows should be sought in the subsurface sedimentary layer. A two-dimensional conductivity distribution model was then developed based on the results of MV soundings (vector amplitudes). This model points to diversity of the sedimentary cover, in which we can distinguish two conductive layers: the subsurface layer, whose resistivity can be estimated at several tens of omm, and the other, at the border of the crystalline basement, where we can observe resistivity values of the order of 1 omm. To clarify whether the morphology of the sedimentary overburden actually affects the directions of vectors, we developed a pseudo 3D model of a thin layer, assuming distribution S on the basis of geological data up to the depth of the crystalline basement. It turned out that even such a simplified model explains the observed directions of induction arrows. The results of modelling confirmed that the morphology of the sedimentary cover has a decisive impact on the nature of induction arrows. It was a new conclusion, not yet found in the literature. However, there was another important conclusion of methodological nature. Our results clearly show that it is impossible to estimate the depth of deposition of anomalies only on the basis of the depth of wave penetration. In fact, this parameter indicates only the possible maximum depth of their occurrence.

MAJOR ANOMALIES IN THE DISTRIBUTION OF ELECTRICAL CONDUCTIVITY IN POLAND IN RELATION TO THE GEOLOGICAL STRUCTURE

[7] was created in 2005 and had the form of a review. It was a preface to a special monographic number of Publications of the Institute of Geophysics Polish Academy of Science: “Study of geological structures containing well-conducting complexes in Poland”, of which I was a co-editor. The paper discusses the results of many years of electromagnetic research conducted in Poland since the 1960s, focusing on presentation of the results of research on the deep basement. It was stressed that the main result of the geomagnetic soundings conducted in Poland since the early 1960s was determination of the presence of two large magnetic anomalies. The first, related to the Permian basin, turned out to be an extension of the great North German-Danish anomaly, the largest in Europe, discovered in the 1950s in Germany. The second one, the Carpathian anomaly, was discovered in the 1960s and was then thoroughly investigated as a result of several years of joint work of Polish and Czechoslovak teams. It was further found that it is now almost certain that both of these anomalies are associated with the presence of large sedimentary basins. More detailed studies have shown, however, that in both cases the anomalies are deeply rooted and the well-conducting rocks may reach a depth of 15–20 km. The nature of those “deep roots” is still subject to controversy. For many reasons, it seems that the cause of high values of electrical conductivity of these complexes is the presence of mineralised waters, and this hypothesis seems to us to be the most plausible. However, some authors point to the possible presence of graphite complexes (black slates). The results of many MV and MT soundings carried out since the discovery of those anomalies provide us with more and more information, but the final resolution of this problem is difficult without performing deep drillings. Nevertheless, even the location of those well-conducting areas is very helpful in formulating geotectonic hypotheses since the position of the main magnetic anomalies in Poland reflects its geotectonic situation.

[9] was of a similar, review-like character. It summarised the results of the current ultra-deep electromagnetic soundings conducted in Poland. I will not repeat them here as they have been successfully presented in the discussion of previous publications. Let me just remind that the main result of this research was the discovery of a well-conducting anomaly in the upper mantle at the depths of 150–250 km under the TESZ. Moreover, the analysis of the results of MV soundings for the entire Central Europe indicates that there are heterogeneities in the middle mantle, or possibly that it changes its structure under Europe, in the TESZ area.

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