EFFECT OF THIN NEAR-SURFACE LAYER ON THE GEOMAGNETIC INDUCTION ARROWS: AN EXAMPLE FROM THE EAST EUROPEAN PLATFORM

Jerzy JANKOWSKI, Tomasz ERNST and Waldemar JÓŹWIAK

Institute of Geophysics, Polish Academy of Sciences
ul. Księcia Janusza 64, 01-452 Warszawa, Poland
e-mail: jerzy@igf.edu.pl

Abstract

Nineteen deep geomagnetic soundings were made in NE Poland which belongs to the East European Platform. The calculated transfer functions show that the induction vectors are quite large, achieving 0.8. The maximum length of the vectors is at the period of about 300 s. Comparing the directions of the induction vectors with the map of the thickness of sedimentary cover we found a striking correlation with the crystalline basement depth isolines. An auxiliary 2D modelling and a thin-sheet model support the statement that substantial part of the vectors is due to induction in the sedimentary cover.

Key words: geomagnetic induction, East European Platform, deep geomagnetic sounding, induction arrows.

1. INTRODUCTION

The regional induction studies have nearly fifty years long history. During these years, much progress has been made in the methods of magneto-telluric and geomagnetic soundings. The progress was achieved in instrumentation, data processing, as well as direct and inverse modelling. Many regional studies all over the world were made, giving interesting results but sometimes below the optimistic expectations assumed many years ago.
In Poland there are three major geological units. Western Poland lies on a platform of Paleozoic folding. Eastern Poland is on an old platform of craton-type, extending far eastwards. A relatively young Carpathian arc, folded in the Alpine orogenesis, is situated on the south. On the Paleozoic Platform there is a profound sedimentary Permian Basin (Guterch et al., 1999), up to 20 km thick. The depth of sediments reaches 20 km also in the Carpathians (Ernst et al., 2002).

Geomagnetic induction studies have been initiated by the Institute of Geophysics, Polish Academy of Sciences, in the early 1960s. We collected and interpreted data mainly in the two geotectonic units: the Permian Basin in Central and NW Poland (prolongation of the North German conductivity anomaly) and in the Carpathians where we worked together with Czech colleagues (Jankowski, 1965; Jankowski et al., 1985; 1991). After so many years of field measurements we were convinced that we know geomagnetic induction arrows distribution on the majority of the Polish territory. In many areas, the distribution of induction arrows is very regular, in the sense that the their lengths and directions are not changing rapidly at two neighbouring points; the maximum length of arrows is about 0.5 at the period of about 1800 s. The interpretation models showed that the induction effect is connected with large sedimentary synclines. In both areas under study, the thickness of sedimentary cover exceeds 15 km and its conductance is several thousand Siemens (see the papers cited above). We were not making regular studies of NE Poland because the geometry of contact between the sedimentary cover and the crystalline basement is simple and conductance of the sediments is low. The sediments are rather thin, less than 1 km thick in the eastern part of East European Platform (EEP) in Poland. The dip of the crystalline basement from east to west is about 2 degrees. Basing of these facts we were expecting rather short induction arrows and magnetotelluric curves close to the 1D situation. In the years 1999-2000 we made 19 geomagnetic and magnetotelluric soundings in the area and the results were quite different from our expectations. This paper shows the possible influence of the thin conductive layer situated on the high resistivity basement on the length and azimuth of the induction arrows.

2. MEASUREMENTS

In the summer seasons of 1999 and 2000 we collected data from two profiles crossing NE Poland. The locations of measurement sites are shown in Fig. 1. For field measurements we used seven long-period magnetotelluric stations. The magnetometers used were of two types: one with photoelectric conversion – PSM type (Marianiuk, 1977) and the other of fluxgate type made in Lvov (Korepanov et al., 1998). The first instrument has a better resolution (few pT) but it is heavier and more difficult to install. The fluxgate resolution is 0.1 nT. Before measurements, all stations were carefully calibrated at Belsk observatory. A new set of algorithms was developed for optimal determination of frequency responses of these instruments (Marianiuk, 2000;
Nowożyński (2001). Because we were interested in collecting data for long-period variations, we kept every magnetotelluric station on the measurement site for three weeks. The main difficulty was to obtain good quality data with high signal to noise ratio. This is especially difficult for long periods, because Poland has a dense net of electric railway connections. The amplitude of disturbances in magnetic vertical component at a distance of 20 km from the railway line is about 1 nT. The noise in the electric components is as a rule higher, due to electric railway and local human activity. For getting good quality data it is necessary to select the recording place very carefully and wait for a period of comparatively high magnetic activity. To illustrate the quality of our data we show in Fig. 2 an example of simultaneous recordings of all five components. Additionally we made recordings of horizontal components using induction coils which allowed us to construct the MT curve up to 25 Hz.

Fig. 1. Location of the two induction soundings profiles on the generalised tectonic map of Central Europe (northern profile 1999; southern profile 2000).
Fig. 2. An example of the simultaneous recordings of the five components as recorded at seven sites of profile 2000.
3. DATA PROCESSING AND BEHAVIOUR OF INDUCTION ARROWS

In our laboratory we have different numerical programs for magnetotelluric data analysis. We use algorithms in time domain (Wielądek and Ernst, 1977) and in frequency domain (Semenov, 1985), and generally the results of both methods are nearly the same. The results of all geomagnetic induction arrow computations are presented in Fig. 3a and Fig. 3b.

Figure 3a shows the results from profile 1999. Geomagnetic sounding curves differ from each other, but one can observe some common features. The amplitudes of real and imaginary parts change with periods and with location but the directions computed from the real parts are rather stable. The maximum length is achieved at about 300 s. For this period we observe a reversal of directions calculated from the imaginary parts. The amplitudes of the real part are rather large, achieving 0.8.

A similar pattern can be seen on profile 2000 (see Fig. 3b). In this case, the length of arrows is smaller and the picture is more complicated. The typical errors are between 5 and 10%. The results, as mentioned in the introduction, are rather surprising for us, because at old platforms of simple geology we got so meaningful geomagnetic induction arrows. Normally, so large arrows are connected with a large lateral conductivity contrast. Only part of the observed phenomena can be explained by induction in the Mid-Polish Trough.

To illustrate the spatial pattern of the arrows we have plotted the distribution of real induction arrows on simplified tectonic maps of the area, see Fig. 4 (Znosko, 1998). We have made computation of all magnetotelluric curves (Figs. 3a and 3b) and we present, here one example of the curves to demonstrate that a very good conductive layer exists in the lower part of the sedimentary cover. The complex interpretation of magnetotelluric data is not made in this work – it will be the subject of additional publication in the future.

The long period branch of the curves together with neighbouring observatory data were used for the determination of the upper mantle conductivity (Semenov et al., 2002). The information from the very short period was used for construction of 2D model of the induction arrows’ lengths (see the next section).

In Fig. 5 we show one magnetotelluric sounding curves.

4. CORRELATION WITH GEOLOGICAL STRUCTURE AND NUMERICAL EXPLANATION OF THE OBSERVED FEATURES

While starting the measurements we hoped to discover a conductivity anomaly in the lower crust, but after processing of data the main goal became to explain the observed geomagnetic arrows distribution. On both profiles, the arrows have similar directions. There is no reversal of the vector directions, as we have observed in the Carpathians or the Permian Basin. The maximum arrow length was observed at the period about six
Fig. 3a. Geomagnetic sounding curves for profile 1999 (real part – solid line; imaginary part – dashed line).
Fig. 3b. Geomagnetic sounding curves for profile 2000 (real part – solid line; imaginary part – dashed line).
times smaller than for anomalies in other areas. The directions of arrows show that the electric current concentration is increasing in the SW direction. At the beginning, we tried to explain the observed features by induction in the marginal structure of the East European Platform. The big sedimentary basin does affect the induction arrows observed on the platform but the data cannot be explained by EM induction in this basin. Analyzing the tectonic map, especially on the profile 1999, we have found a striking correlation between the direction of the crystalline basement depth isolines and the direction of the geomagnetic induction arrows (see Fig. 4). They are perpendicular to each other. Furthermore, whenever the isolines turn, the arrows rotate in the same manner. This correlation suggests that the observed behaviour of the arrows

Fig. 4. The real induction arrows for periods of 300 s, plotted on the map of the crystalline basement depth isolines taken from the tectonic map of the area (Znosko, 1998).
may be connected with the near-surface layer. At the beginning it was difficult for us to adopt the idea that the induction connected with such a thin layer can generate so large arrows.

To explain the arrows’ lengths and directions it was necessary to do some modelling. We believe that it is more justified to adopt simplifications for geomagnetic than for magnetotelluric soundings because magnetic signals are due to integrated current distribution. We decided to construct a 2D model to explain the length of arrows and a thin-sheet model to explain their rotation. For direct and inverse modelling, we used finite difference method with program designed by Nowożyński (Nowożyński and Pushkarev, 2001). The model of resistivity distribution which explains the length of arrows for four periods on profile 1999 is shown in Fig. 6. The geometrical parameters of the model are mainly based on the tectonic map. To get a reasonable agreement between the observations and model results it was necessary to distinguish in the sedimentary cover (in its part in which the profiles are situated) the following two layers: the top layer with a resistivity of several tens of ohmmeters and the other one with a very low resistivity of 1 Ω·m. The existence of this low resistivity layer is marked on some magnetotelluric curves (see Fig. 5); moreover, an independent borehole logging shows a low resistivity connected with strongly mineralized waters (Szewczyk, private communication). On the East European Platform, a similar layer was also found (Modin et al., 1998). It was also necessary to adopt a very low conductivity of the crystalline basement (10 000 Ω·m.). To check whether the morphology determines the rotation of vectors too, we applied the thin-layer model, making use of Weidelt’s algorithm. We should keep in mind, though, the strong limitations associated with this approximation, so the model is of rather qualitative nature. Still, we see that even such a simplified model explains the magnetic arrow directions observed on profile 1999 (Fig. 4). The results of the thin sheet modelling

Fig. 5. An example of magnetotelluric sounding curves for the site 2/1999.
Fig. 6. The two dimensional conductivity model used for the explanation of the length of the geomagnetic vectors on profile 1999 for four periods.
show rotation of the vectors (see Fig. 7). One can see that vectors rotate on profile 1999 in a similar manner as the experimental ones. On profile 2000, the regularities are similar but the shape of isolines is more complicated. On profile 2000 the isoline of crystalline basement shown much more complicated “pattern” and in many cases its determination is uncertain (Ryka, 1964). Due to this fact, the correlation between directions of induction arrows and isolines of basement is not so clear. Now we are convinced that the induction vectors in the studied region of Poland are mainly due to induction in the relatively thin sediments. There is some coupling of induction in the big sedimentary basin in the marginal zone of the EEP west of the profiles and induction in the thin sedimentary cover on the platform.

5. CONCLUSIONS
The fact that the observed magnetic arrow values can be explained, for fairly long periods, as being due to the thin sedimentary cover, seemed very interesting to us, and, to our knowledge, never reported in the literature. We think that this fact can be important for other authors carrying out sounding surveys in similar geological situations.

We do not claim that the above-mentioned correlation is present everywhere on the East European Platform. For instance, Fainberg and co-workers (1998), who made electro-magnetic soundings on the same platform nearby our study area (some 100 km away), have not observed the long induction arrows. Rokityanski (1972), who
analyzed the data from the Ukrainian part of the platform (some hundred kilometers from our study area) tried to interpret the observed features as being due to inhomogeneities in the lower crust.

We think that results of this study clearly show that it is very misleading to use depth of penetration for establishing the depth of the anomaly. The depth of penetration determines only the thickness of layer in which the sources of anomaly are located.

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