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Analysis of geomagnetic field along seismic profile P4 of the International Project POLONAISE'97

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Abstract

This paper presents relative secular variations of the total intensity of the geomagnetic field against a background of results of magnetic anomaly interpretation along seismic profile P4. Profile P4 crosses a Variscan folding zone in the Paleozoic Platform (PLZ), the Trans-European Suture Zone (TESZ), and the Polish part of the East European Craton (EEC). Secular geomagnetic field variations $|\vec{T}|$ measured in 1966–2000 along a line adjacent to seismic profile P4 were analysed. The study of secular variations, reduced to the base recordings at the Belsk Magnetic Observatory, showed that the growth of geomagnetic field at the East European Craton was slower than in the Trans-European Suture Zone and the Paleozoic Platform.

A 2D crustal magnetic model was interpreted as a result of magnetic modelling, in which seismic, geological and geothermal data were also used. The modelling showed that there were significant differences in the magnetic model for geotectonic units, which had been earlier determined based on deep seismic survey data. It should be noted that a fundamental change of trend of the relative secular variations was observed at the slope of the Precambrian Platform. After analysing the geomagnetic field observed along profile P4, the hypothesis that the contact between Phanerozoic and Precambrian Europe lies in Poland's territory can be proven.

Keywords: Relative secular variations; Geomagnetic field; Magnetic modelling; Crustal magnetic model; PLZ; TESZ; EEC

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1. Introduction

Profile P4 is the longest of seismic profiles of the International Project POLONAISE'97 (Fig. 1). In the nearest neighbourhood of profile P4 there runs the magnetic survey line Zgorzelec–Wiżajny (Z–W) (Fig. 2), where measurements of the total intensity of geomagnetic field $|\vec{T}|$ have been conducted since 1966 at regular yearly intervals to evaluate secular variations of the Earth's magnetic field. Both profiles cut through Europe's major geotectonic units including a zone of Variscan folds in the Paleozoic Platform (PLZ) (SW part of the profile), the Trans-European Suture Zone (TESZ) with the Teisseyre–Tornquist Zone (TTZ) (central part of the profile), and the Polish part of East European Craton (EEC) (NE part of the profile).

The area, in which profile P4 and other seismic lines of the POLONAISE'97 project and the

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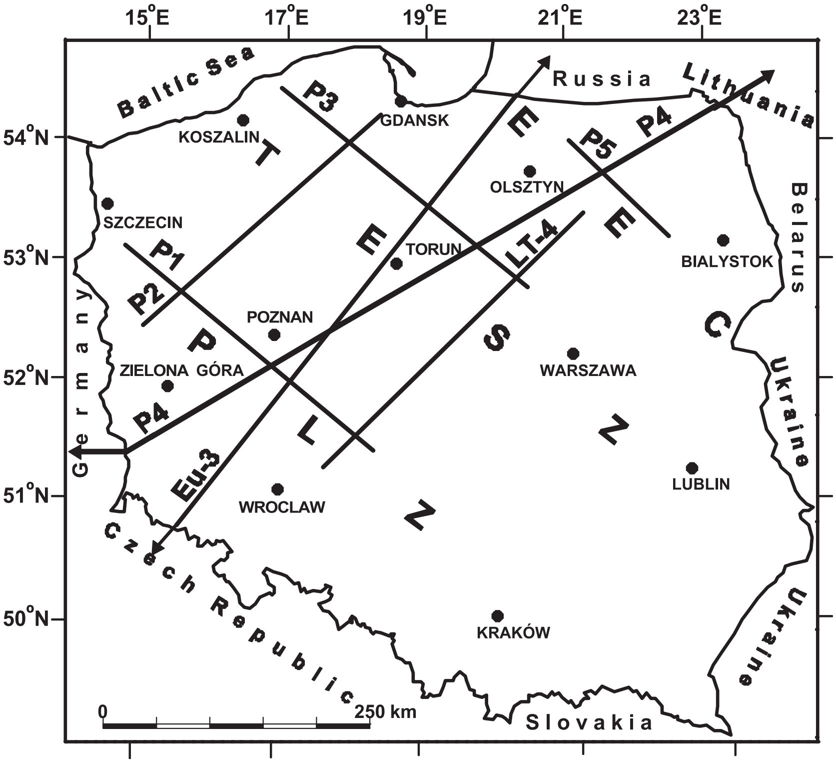


Fig. 1. Location of the POLONAISE'97 profiles P1, P2, P3, P4 and P5 and choice DSS profiles LT-4 and Eurotransect Eu-3 (Geotraverse I). Abbreviations: Paleozoic Platform of the Central and Western Europe (PLZ), Trans-European Suture Zone (TESZ), East European Craton (EEC).

magnetic profile Z–W are situated, has been covered many times by investigations employing potential fields methods (Grobelny and Królikowski, 1989; Grabowska and Raczyńska, 1991; Grabowska et al., 1993, 1998; Grabowska and Dolnicki, 1994; Bojdys and Grabowska, 1996; Królikowski and Petecki, 1997, 2002; Królikowski et al., 1999).

After examining the results of earlier seismic survey (Guterch et al., 1975, 1983, 1985, 1986, 1994, 1996), 2D gravity and magnetic model studies were carried out in the 1990s along some DSS profiles (e.g., profiles Eu-3 and LT-4, see Fig. 1). The objective of the modelling was to construct density models of the Earth's crust and the upper mantle (Grabowska and Raczyńska, 1991; Grabowska et al., 1992, 1993; Chekunov et al., 1993; Królikowski and Petecki, 1997; Krysiński and Grad, 2000) and magnetic models of the crust (Grabowska and Koblański, 1992; Petecki, 2000; Królikowski and Petecki, 2002).

Deep seismic survey data from the POLONAISE'97 project gave new information on the deep structure of the Earth's crust, which encouraged the authors to make another attempt at interpreting potential fields anomalies.

Out of five seismic profiles, P1, P2, P3, P4 and P5 (Fig. 1) of the POLONAISE'97 project, the profile P4 was chosen as the most representative of the region. It runs on Poland's territory over a distance of about 640 km and is almost perpendicular to the direction of the regional horizontal magnetic gradient, which divides Poland and the European continent (Pashkevich et al., 1994; Wonik et al., 2001) into two geomagnetic provinces (Fig. 2). According to many geologists and geophysicists,

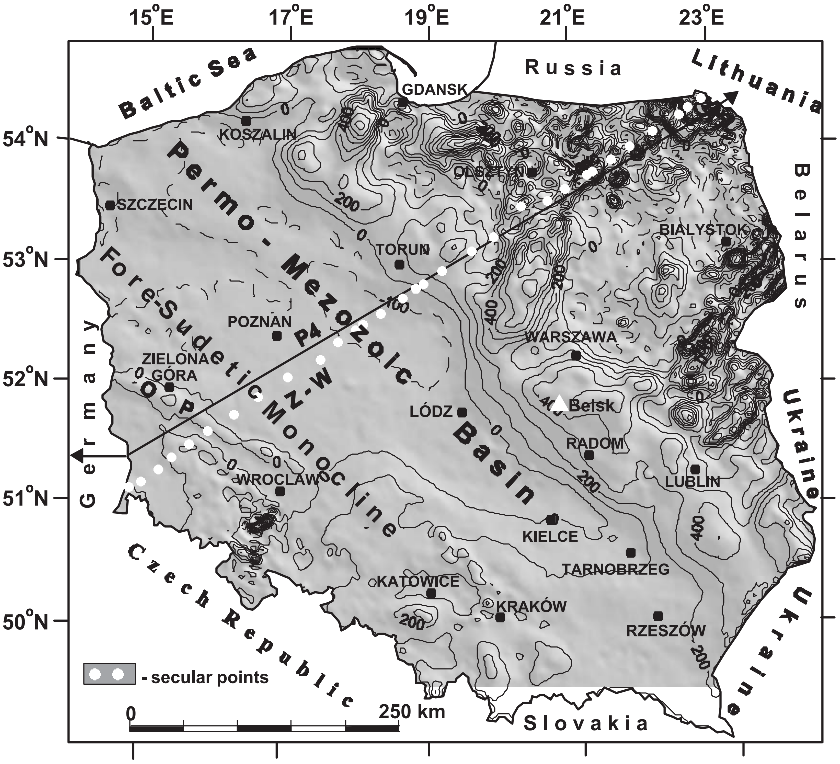


Fig. 2. Shaded Magnetic Anomaly (ΔZ) Image Map of Poland (illumination from NE) with the interpreted profiles P4 and Zgorzelec–Wiżajny (Z–W). Contour interval 100 nT. The map is based on a gridded database with resolution of 5 × 5 km. Data source: Magnetic Anomaly Map ΔZ of Poland, scale 1:500 000 (Karaczun et al., 1978). Measurement accuracy of the vertical component ± 10 nT; measurement sites 0.3–1 km apart. Abbreviations: zone of positive anomalies within Fore-Sudetic monocline (OP).

that gradient defines the edge of the East European Craton (EEC).

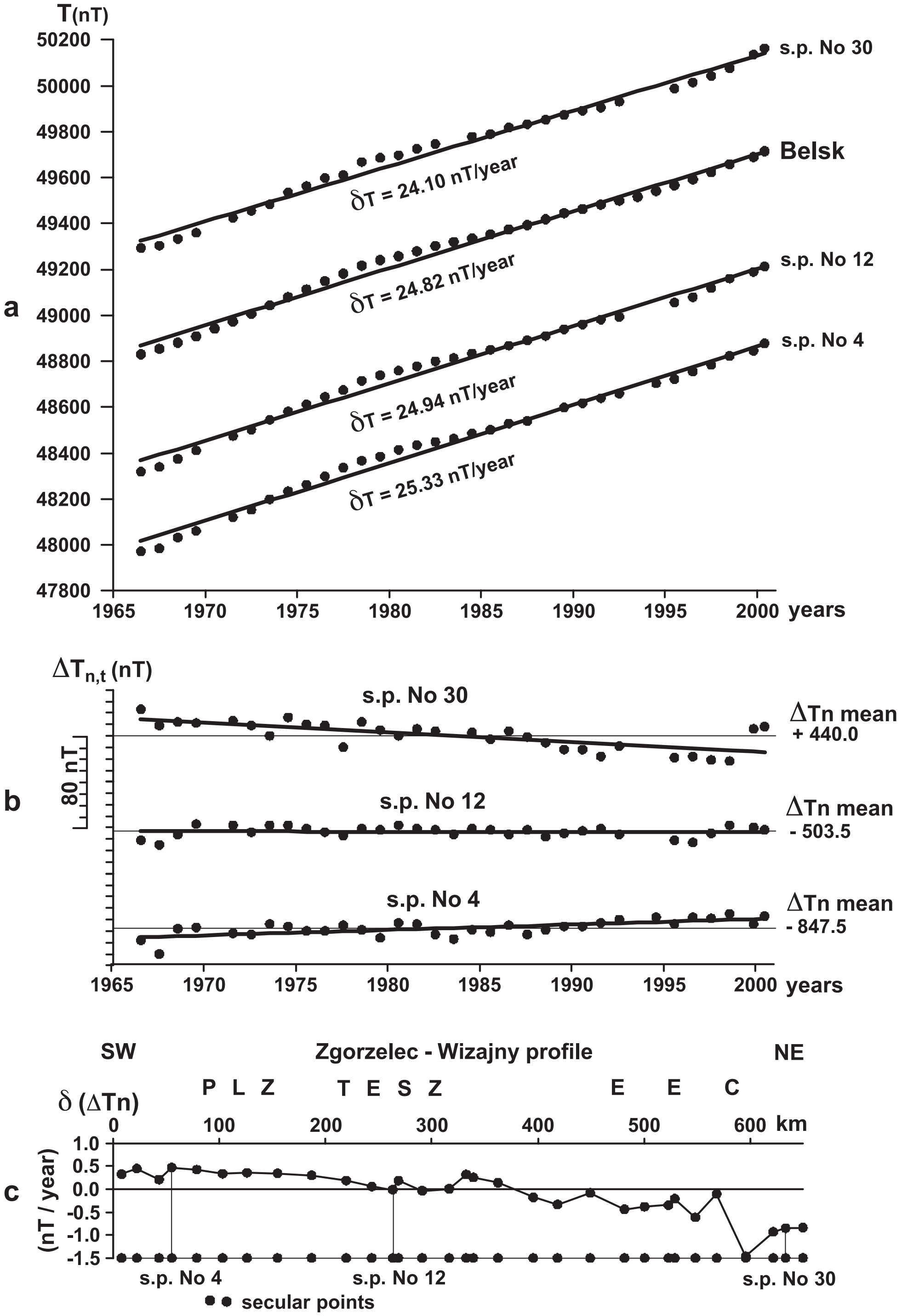
2. Methodology of investigation of geomagnetic field secular variations along the profile Zgorzelec–Wiżajny (Z–W)

The study of the secular variations of the geomagnetic field at profile Z–W was initiated by Małoszewski (1965, 1970). Results of the measurements covering the 30-year interval (1966–1995), as well as data processing and interpretation methods, are presented in the paper by Małoszewski and Jankowski (1997).

A research team of the Institute of Geophysics, AGH-UST, Krakow, has been continuing S. Małoszewski's project since 1996. Measurements are taken with the use of proton magnetometers PMP-7 with a sensitivity of 0.1 nT, produced in Poland. To ensure data credibility, a series of measurements in each of the 31 sites (secular points) of the measurement profile is taken from several to a few dozen minutes (Fig. 2).

Measured every year from 1966 to 2000, the values of the geomagnetic field ($|\vec{T}|_{n,t}$), (Fig. 3) at each measurement site (n) were reduced to the geomagnetic field, observed at the same time (t) at the Magnetic Observatory in Belsk ($|\vec{T}|_{\mathrm{Belsk},t}$). The reduction was made according to the following formula: $\Delta T_{n,t} = |\vec{T}|_{n,t} - |\vec{T}|_{\mathrm{Belsk},t}$, where $\Delta T_{n,t}$ are the relative values of the geomagnetic field.

At each measurement site, values of $\Delta T_{n,t}$ from the 1966–2000 period (Fig. 3b) were approximated by first-order polynomials $W_n(t)=b_n t+a_n$, where $b_n=\delta(\Delta T_n)$ means relative secular variations per year, and $a_n=(\Delta T_{n\ \mathrm{mean}})$ is an average of relative values of the geomagnetic field from the period 1966–2000 for each of the 31 sites (Bojdys et al., 2001).


T(nT)
50200
50000
49800
49600
49400
49200
49000
48800
48600
48400
48200
48000
47800
1965
1970
1975
1980
1985
1990
1995
2000
years
s.p. No 30
Belsk
s.p. No 12
s.p. No 4
δT = 24.10 nT/year
δT = 24.82 nT/year
δT = 24.94 nT/year
δT = 25.33 nT/year
a
ΔTn,t (nT)
80 nT
s.p. No 30
ΔTn mean
+ 440.0
s.p. No 12
ΔTn mean
- 503.5
s.p. No 4
ΔTn mean
- 847.5
b
SW
Zgorzelec - Wizajny profile
NE
P L Z
T E S Z
E E C
δ (ΔTn)
(nT / year)
0
100
200
300
400
500
600
km
1.0
0.5
0.0
-0.5
-1.0
-1.5
c
s.p. No 4
s.p. No 12
s.p. No 30
●● secular points

Reducing the measurements to one base value gives the difference between geomagnetic field secular variations measured at each measurement site and those observed at the Belsk Observatory (Fig. 3a). It should be therefore understood that the curve $\delta(\Delta T_n)$ shown in Fig. 3c reflects the relative secular variations per year of local character.

It is not possible to determine the actual error of calculation of geomagnetic field secular variations at each site. A number of independent factors, especially those associated with the industrialization of the survey area affect the measurement of geomagnetic induction. To approximately evaluate the effects of such factors it is necessary to repeat a series of measurements at selected measurement sites over different time periods. Still, the 35-year span of the studies permits the authors to think that the results shown in Fig. 3c are credible.

The character of local secular variations of the geomagnetic field at profile Z–W, and particularly the drop of their values towards NE (Fig. 3a and c), encourages the detailed study of these variations with regard to the geology of the area and the magnetic anomaly pattern of profile P4, which runs in the vicinity of profile Z–W (Fig. 2).

3. Characteristics of magnetic anomalies and the geological structure

The magnetic anomaly pattern at profile P4 and its neighbourhood (Fig. 2) is characteristic of the central part of the Polish Lowlands. The middle part of the profile runs over a broad depression in the Permo-Mesozoic Polish Basin. In the SW, in the Fore-Sudetic Monocline, this depression neighbours a zone of small positive magnetic anomalies (OP) (Fig. 2) whose origins are not known. It can only be supposed (Dąbrowski, 1969; Koblański, 1989) that the anomalies are generated by Older Paleozoic metamorphosed rocks with magnetic properties (e.g., gneisses, greenstones, amphibolites). Based on magnetic anomaly interpretation, the depth to those rocks was evaluated at ca. 5 km (Dąbrowski, 1969).

It should be mentioned that the zone of small positive anomalies (OP) is a continuation to the East of a belt of positive magnetic anomalies corresponding to the Mid-German Crystalline Rise (Blundell, 1992; Bankwitz, 1993).

A most diversified pattern of magnetic anomalies can be observed in the NE part of profile P4, i.e., in the EEC area. According to recent geological data, this part of the profile crosses the SW part of Fennoscandia, which is one of three main crystalline crust segments forming the EEC (Bogdanova, 1993, 1996).

Poland's Precambrian (Paleoproterozoic) crystalline basement is divided into several minor units with a different lithology, different tectonics (Fig. 4) (Ryka, 1982a,b, 1984) and a different magnetic pattern (Grabowska and Dolnicki, 1994). The oldest units include the granitoid massifs of Pomerania, Mazovia, and Dobrzyn. The massifs are surrounded by the metamorphic fold zones of Kaszuby, Ciechanów and Podlasie. Basic rocks, which occur there, generate strong magnetic anomalies.

At 300–640 km, profile P4 crosses the Dobrzyn Massif, then the Ciechanów Zone and its Warmia branch, and passes through the Mazury complex, which is made of rapakiwi-like granitoids (Figs. 4 and 5). Anorthosites and gabbro rocks (e.g., forming the Suwałki rock complex) are seated in the Mazury complex (Fig. 4).

4. Magnetic modelling along profile P4

A 2D magnetic model was constructed along profile P4 based on ΔZ anomalies (Fig. 5a) and a 2D tomography model of P-wave velocity distribution obtained from the inversion of first arrival travel times. Accord-

Fig. 3. Variations of geomagnetic field intensity $|\vec{T}|$ through the years 1966–2000. (a) At Belsk Observatory and at selected secular points (4, 12, 30) (from Zgorzelec–Wiżajny profile), δT the mean variation in nT/year. (b) Plots of changes in time of the relative geomagnetic fields values $\Delta T_{n,t} = |\vec{T}|_{n,t} - |\vec{T}|_{\mathrm{Belsk},t}$ at selected secular points (4, 12, 30), solid line—linear approximation [$W_n(t)$] of the changes ($\Delta T_{n,t}$). Explanation: $W_n(t)=b_n t+a_n$, where $b_n=\delta(\Delta T_n)$—relative secular variation per year, $a_n=\Delta T_{n\ \mathrm{mean}}$—average (to Belsk) values of the geomagnetic field at selected secular points (4, 12, 30), through the years 1966–2000. (c) Relative secular variations of the geomagnetic field $\delta(\Delta T_n)=b_n$ in nT/year along Zgorzelec–Wiżajny profile (see Section 2). Abbreviations: Paleozoic Platform of the Central and Western Europe (PLZ), Trans-European Suture Zone (TESZ), East European Craton (EEC).

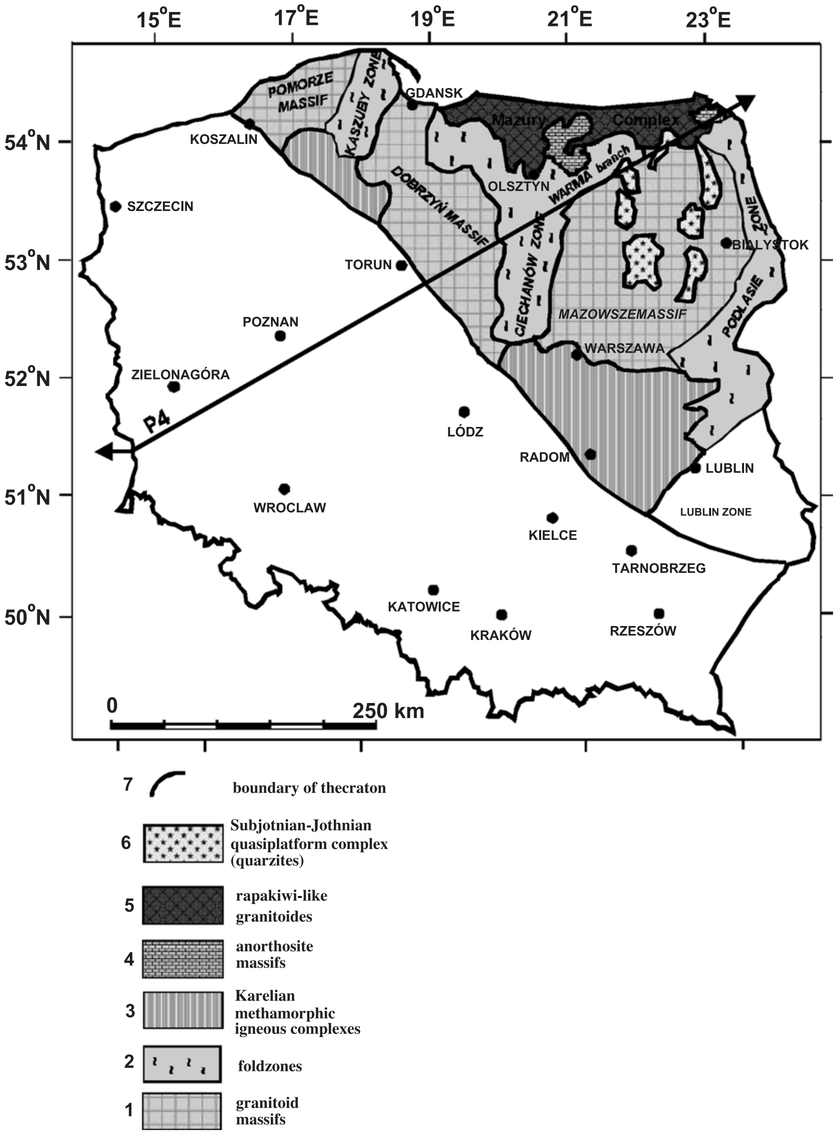


Fig. 4. Tectonic scheme of the crystalline basement in Polish part of the East European Craton, based on geological and magnetic data as compiled by K. Karaczun, S. Kubicki and W. Ryka (according to Ryka, 1982b).

ing to Guterch et al. (1999), velocity contours of 6.0 and 8.0 km/s can be approximately interpreted as the top of the crystalline basement and Moho, respectively.

Based on the results of earlier magnetic modelling for profiles Eu-3 and LT-4 (Grabowska and Koblański, 1992; Grabowska et al., 1993) and spectral analyses of magnetic anomalies of NW Poland (Petecki, 2001) and taking into account magnetic properties of rocks of the EEC crystalline basement (Table 1), it can be accepted that the top of the magnetic active crust coincides with the top of the crystalline basement. Sedimentary rocks occupying the deep, asymmetric Polish Basin in the TESZ were regarded as nonmagnetic.

According to seismic and geological data, the top of the magnetic active crust (Fig. 5c) coincides with the velocity contour $V_p = 6.0$ km/s in the Polish Basin and the SW part of profile P4. In the NE part of profile P4, where it crosses the EEC, the top of

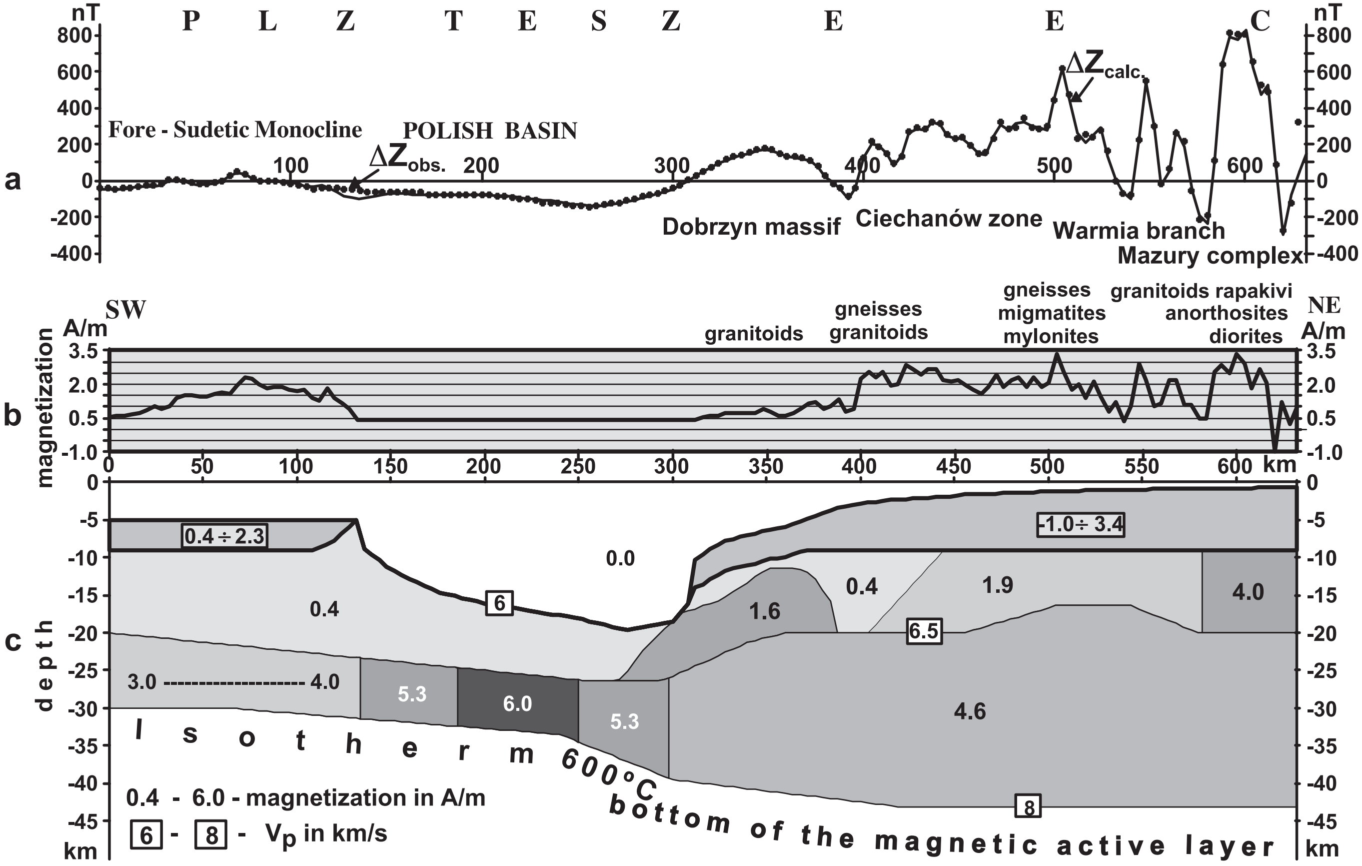


Fig. 5. Two-dimensional model of the magnetic active crust along profile P4 from magnetic modelling. (a) $\Delta Z_{obs.}$—according to Magnetic Map of Poland (Karaczun et al., 1978). $\Delta Z_{calc.}$—summarized magnetic effect calculated for model c. (b) Distribution of induced magnetization in the upper crystalline layer according to 2D magnetic modelling (calculated by iterative program; see Section 4). (c) Magnetic model constructed based on 2D magnetic modelling (calculated by interactive and interative programs; see Section 4). Induced magnetization in A/m. Explanation: the top of the magnetic active crust according to seismic data – velocity isoline of $V_p = 6$ km/s (SW part of the profile) and geological data for NE part of profile. The bottom magnetic active crust according to seismic data – velocity isoline of $V_p = 8$ km/s (NE part of the profile) and geothermal data (Milanovski, 1984; Čermak et al., 1989) (SW part of the profile). Abbreviations: Paleozoic Platform of the Central and Western Europe (PLZ), Trans-European Suture Zone (TESZ), East European Craton (EEC).

Table 1

Age	Lithology	Magnetic susceptibility (κ)	Induced magnetization I_i (A/m)	Remanent magnetization NRM (A/m)
		$\frac{\kappa_{\max}-\kappa_{\min}}{\kappa_{\mathrm{mean}}}$	$\frac{I_{\max}-I_{\min}}{I_{\mathrm{mean}}}$	$\frac{\mathrm{NRM}_{\max}-\mathrm{NRM}_{\min}}{\mathrm{NRM}_{\mathrm{mean}}}$
Precambrian	anorthosites	$n=15$ $\frac{0.004-0.241}{0.068}$	$n=14$ $\frac{0.14-3.42}{0.97}$	$n=15$ $\frac{0.07-11.96}{7.19}$
	migmatites	$n=3$ $\frac{0.005-0.035}{0.017}$	$n=2$ $\frac{0.40-0.70}{0.55}$	$n=2$ $\frac{0.04-0.52}{0.28}$
	granitoids	$n=6$ $\frac{0.030-0.111}{0.078}$	$n=5$ $\frac{1.16-4.49}{2.93}$	$n=5$ $\frac{0.83-2.69}{1.57}$
	gneisses	$n=19$ $\frac{0.001-0.157}{0.045}$	$n=12$ $\frac{0.57-5.44}{2.16}$	$n=13$ $\frac{0.34-11.37}{2.20}$
	granitoids rapakiwi	$n=5$ $\frac{0.059-0.138}{0.100}$	$n=5$ $\frac{1.72-5.51}{3.70}$	$n=5$ $\frac{3.10-9.15}{6.06}$
	gneisses and migmatites	$n=3$ $\frac{0.017-0.065}{0.049}$	$n=1$ 2.47	$n=1$ 2.05

Note: n—number of specimens.
I_i calculated based on the Koenigsberger ratio $Q=\frac{\mathrm{NRM}}{I_i}$ (Wybraniec et al., 1993).

the crystalline basement was identified based on geological drilling data and refraction seismic data (Kubicki et al., 1982).

The base of the magnetic active crust, situated within PLZ and TESZ, was defined after analysing geothermal data (Milanovski, 1984; Čermak et al., 1989). It corresponds to a 600 °C isotherm (T_c~580 °C for magnetite).

In the region of the EEC, the base of the magnetic active layer agrees approximately with the velocity contour $V_p = 8$ km/s at a depth of ca. 43 km, which has been accepted as the Moho (Guterch et al., 1999). The upper part of the crystalline crust in this area was divided into two parts based on available geological data on the lithology of the crystalline basement and a probable depth at which the homogenisation took place (Ryka, 1982b), as well as on results of quantitative interpretation of magnetic anomalies from the EEC area.

The uppermost part of the crystalline crust reaches down to a depth of 8 km and, according to drilling data, has varied magnetic properties resulting from the lithology of the near-top crystalline basement (see Table 1). The lower part comes down to some 20 km; its magnetic properties are less varied. The velocity contour $V_p = 6.5$ km/s was accepted as the top of the lowermost crust and a hypothetical boundary of the lowermost rock complex with strong magnetic properties. This is in agreement with results of magnetic modelling carried out for the EEC beyond Poland's territory (Pashkevich et al., 1994).

2D magnetic modelling was made using two original computer programs. The first program is interactive and computes the magnetic effect from 2D structures with constant induced magnetization. 2D structures are approximated by closed or open polygons (the latter at the ends of the profile). The magnetic effect is then matched by the trial and error method to the regional component of the observed geomagnetic field (ΔZ).

The second program (iterative), based on the residual component of the observed geomagnetic field, $\Delta Z_{res} = (\Delta Z_{obs.} - \Delta Z_{reg.})$, calculates horizontal changes of the magnetization modulus for the layer, under the assumption that the direction of magnetization is constant. In this case, the layer is delimited by two surfaces: the top surface, which is the top of the magnetic active crust, and the bottom surface, which lies at a depth of 8 km within the crystalline crust. The horizontal changes of the induced magnetization for that layer were generated through a series of automatic computer iterations. The results are shown in Fig. 5b.

The final results of the magnetic modelling with the use of the interactive and iterative programs are shown in Fig. 5c as a magnetic model through the magnetic active crust.

We can see that the calculated values of the magnetization of rocks in the uppermost layer of the crystalline crust (Fig. 5b) in the NE part of profile do not oppose the results of laboratory measurements (Table 1).

5. Discussion

The relative secular variations of the geomagnetic field observed along profile Z–W in 1966–2000 show two regular behaviours.

First, the geomagnetic field has a lower growth within the EEC than over the area of the Variscan folding (SW part of the profile). This has been also noted by Małoszewski and Jankowski (1997) in their paper. The lower speed of the geomagnetic field growth at the EEC was also mentioned by Welker and Żółtowski (1993) in their paper dealing with the study of secular variations of the geomagnetic field of Poland observed in 1950–1990 at 21 measurement sites distributed within Poland’s territory.

The lower growth of the geomagnetic field within the EEC is also proven by results of a study on the regional structure of geomagnetic secular variations in Europe conducted by Mundt (1990) in 1950–1975. According to this study, one of the NW–SE course zones, which divide Europe into regions with different dynamics of growth of secular variations, runs through Poland’s territory.

According to W. Mundt, “this phenomenon may be interpreted as regional anomalies of secular variations. Central Europe has a slightly positive anomaly compared with the negative anomalies in Eastern and Western Europe”.

Second, having extrapolated the relative variations of the geomagnetic field from profile Z–W to profile P4, what is evident is the possibility of relating the relative secular variations of the geomagnetic field with major and minor geological units (Fig. 6a, dashed line).

The intense dynamics of secular variations of the geomagnetic field (ca. + 0.4 nT/year) is characteristic of the Paleozoic Platform (Fore-Sudetic Monocline), while relative secular variations typical of the EEC part in Poland’s territory have a rather complex character. A change in the trend of the secular variations is observed at the slope of the Precambrian Platform (the Dobrzyn Massif) and the relative values decrease to ca. − 0.2 nT/year in the Ciechanów Zone. The Ciechanów Zone, formed as a result of Paleoproterozoic folding, is characterized by complex magnetic anomalies, especially in the Warmia branch (Fig. 6b).

Intense dynamics of relative secular variations (ca. − 1 nT/year) is typical of the NE section of the profile (the Mazury complex). Strong magnetic anomalies observed there can be attributed to an anorthosite and gabbro complex in which ilmenite and magnetite ores occur.

As compared to faster relative secular variations of the geomagnetic field for the PLZ and the EEC, the poorer dynamics of the variations (ca. + 0.1 nT/year) is observed for that part of the profile, which crosses the TESZ. It should be mentioned here that Małoszewski (1965) studied secular variations measured during the period 1901–1958 and paid attention to very small values for the Szczecin–Mogilno–Łódź Trough, which extends both in the Polish Basin and TESZ. It should also be noted (see Fig. 6d) that, according to DSS data, the sedimentary crust in that part of Poland has large thickness reaching ca. 20 km (Guterch et al., 1999; Grad et al., 1999).

It is also important to mention that a small dynamics of secular variations of the geomagnetic field was also noted within EEC in SE Poland, NE of Lublin, for regions with sedimentary rocks of great thickness (Bojdys et al., 2003).

The correlation of the dynamics of geomagnetic field variations with minor geological units, especially for the EEC (see Fig. 6a), can indicate some indefinite effects on the rocks of the upper crystalline crust on long-term variations of the geomagnetic field. Indirect evidence of this can be given by small relative secular variations of the geomagnetic field observed for the Polish Basin. There, the crystalline crust rests at a great depth and, according to magnetic modelling, it

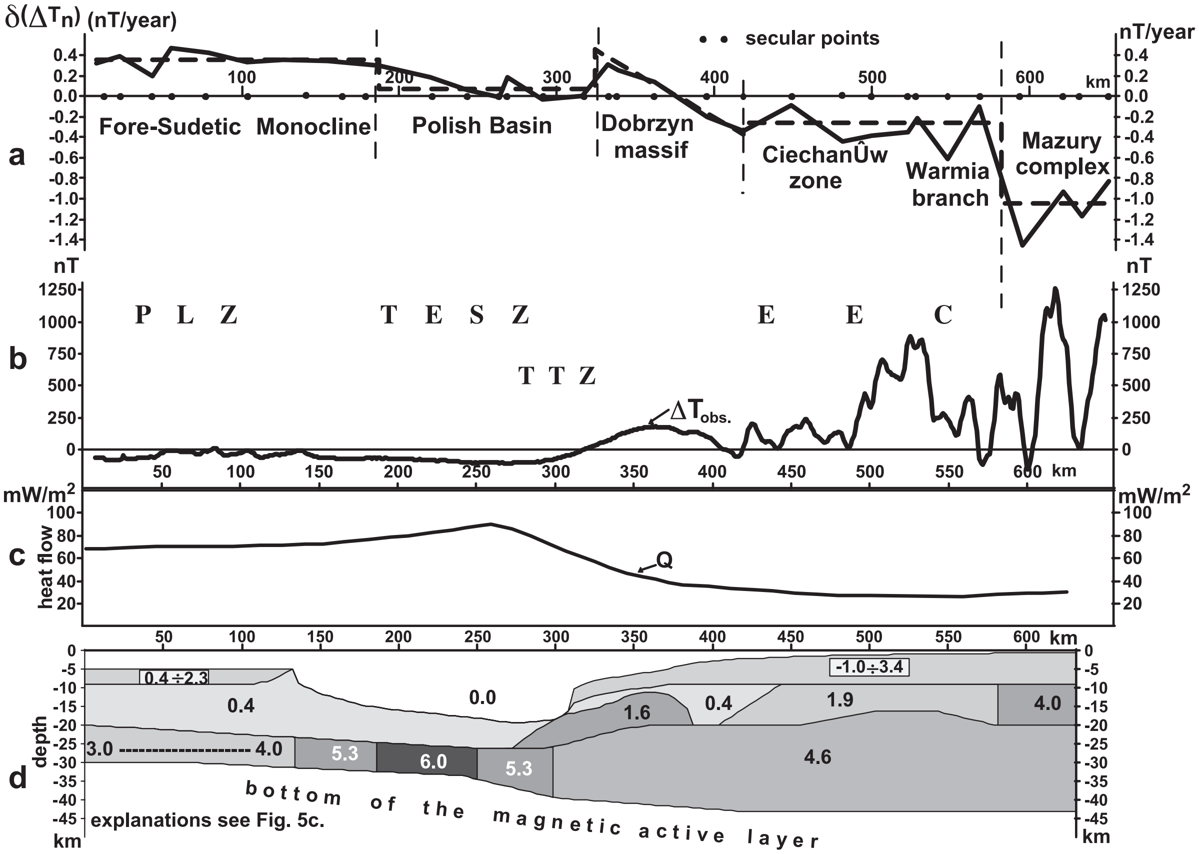


Fig. 6. Relative secular variations of the geomagnetic field (a), with magnetic anomalies (b), geothermal data (c), along profile Zgorzelec–Wiżajny and 2D magnetic model of the Earth's crust along profile P4 (d). (a) Relative secular variations of the geomagnetic field through the years 1966–2000 (Bojdys et al., 2001). Solid line—curve of secular variations $\delta(\Delta T_n) = b_n$ in nT/year (see Fig. 3c and Section 2). Dashed line—simplified lines of relative secular variations per year together with division to sections with different dynamics of the changes in geological units. (b) Plot of total intensity anomalies ΔT (from database of the Geological Institute of Warsaw). (c) Plot of terrestrial heat flow Q (Plewa et al., 1992). (d) 2D model of the magnetic active crust along profile P4 from magnetic modelling (Explanations; see Fig. 5c). Abbreviations: Paleozoic Platform of the Central and Western Europe (PLZ), Trans-European Suture Zone (TESZ), East European Craton (EEC), Teisseyre–Tornquist Zone (TTZ).

has strong magnetic properties while its thickness is reduced to 10 km (Fig. 5c).

Results of magnetic modelling, shown as a crustal magnetic model for profile P4 (Fig. 5c), which can be now extrapolated to profile Z–W (Fig. 6d) show that there are distinct differences in magnetic properties of the crust along profile P4. Magnetic properties for the SW section of the profile, which runs in the PLZ, are less varied. The thickness of the magnetic active crust there reaches 25 km and for the most part its magnetization is small and amounts to 0.4 A/m. In the central part of profile P4, within the TESZ, the crystalline crust is bipartite and its thickness is much reduced (to a dozen or so kilometers). Increased magnetization is observed for its lower, near-bottom part.

The greatest thickness (ca. 40 km) and the most varied magnetic properties are characteristic of the crust within the EEC in the NE part of profile P4. According to magnetic modelling results, the crust is tripartite there, which could correspond to the structure of the crust of old cratons (Bielousov and Pavlenkova, 1985, 1989). Local magnetic anomalies, frequently observed there, are generated by rocks with extremely varied magnetic properties that occur in the uppermost part of the crystalline crust.

The above-discussed crustal magnetic model can explain the origins of the regional magnetic anomalies. That model is not in conflict with average magnetization values and thickness of the magnetic crust for Europe. According to Wonik et al. (2001), those values for Precambrian and Paleozoic Europe are 2.0 A/m and 40 km and 1.5 A/m and 23 km, respectively.

It is also interesting to compare the relative secular variations (Fig. 6a) of the geomagnetic field with the magnetic model of the Earth's crust (Fig. 6d) and the surface heat flow pattern (Fig. 6c). A distinct drop of the heat flow in the EEC, where radiogenic heat sources occur in the thick complex of the crystalline crust, can indicate that there was a small contribution of heat flow from the mantle. According to calculations (Majorowicz, 1978/1979; Milanovski, 1984), the mantle-originated heat flow for the EEC is several times smaller than for the Paleozoic Platform. This can point to different thermal conduction of rocks of the upper mantle, which can affect the long-term variations of the geomagnetic field (Mundt, 1990; Pashkevich et al., 1994).

Seismic survey data prove that physical parameters of the upper mantle rocks are strongly differentiated (Zielhuis and Nolet, 1994). According to these data, shear wave velocity for the upper mantle decreases beneath Phanerozoic Europe while it increases beneath the East European Platform.

It should be added here that 2D gravity modelling in the 1990s along DSS profiles Eu-3 and LT-4 as well as recent gravity survey at profiles P4 and P2 of the POLONAISE'97 project show that the average density of the subcrustal layer increases towards the NE, i.e., from PLZ to EEC.

Seismic survey data from the European Geotraverse (EGT) (Blundell, 1992) and 3D dimensional gravity analysis of the lithosphere below the TESZ (Yegorova and Starostenko, 1999) as well as results of gravity modelling for the Western Carpathians (Bielik, 1999) and Pannonian Basin (Szafian, 1999) suggest that the lowered average density of the upper mantle within the PLZ and increased density in the EEC are associated with the varied depth and thickness of the asthenosphere. Specific physical properties of the asthenosphere (Kearey and Vine, 1990), and especially its high electric conductivity and low viscosity, are propitious to generating processes affecting the character of long-term magnetic field variations.

6. Conclusions

The analysis of the geomagnetic field observed along the neighbouring profiles Z–W and P4, which cross Europe's major tectonic units: PLZ, TESZ, and EEC (Figs. 1 and 2), showed characteristic features of long-term relative geomagnetic field variations as well as differences in crustal magnetic models for those units at profile P4.

Geomagnetic field measurements taken in 1996–2000 along profile Z–W show that:

(1) The dynamics of geomagnetic field growth over the 35-year period of measurements was varied along the profile (Figs. 3 and 6).
   (a) Positive relative secular variations of the order of +0.4 nT/year, pointing to increased dynamics of geomagnetic field growth, are observed in the SW part of the profile within the Fore-Sudetic Monocline at the PLZ.
   (b) The dynamics of geomagnetic field growth is lower in the central part of the profile across the TESZ (the Polish Basin). The sign of relative secular variations of geomagnetic field changes at the slope of the Precambrian craton (the Dobrzyn massif).
   (c) The growth of the geomagnetic field is slower at the EEC. Relative secular variations are negative and reach −1 nT/year. A correlation of secular variations with the lithological and structural units is observed (Ciechanów Zone and Mazury Complex).

(2) A 2D crustal magnetic model along profile P4 is complex (Fig. 5c). It may be divided into three parts:
   (a) The SW part of the model represents the crust with 25 km thickness whose magnetic properties are poor for the most part (magnetization of the order 0.4 A/m). An exception is the near-top layer of the crust with varied magnetic properties (Fig. 5b), which may give rise to small magnetic anomalies observed in the Fore-Sudetic Monocline (Fig. 5a). The

lowermost layer of the crust, the thickness of which does not exceed 10 km, has the magnetic properties of one order higher.

(b) The Polish Basin (central part of the profile) occupies a vast depression in the magnetic anomaly pattern (Fig. 5a). According to the modelling, the depression is associated with the depth and reduced thickness of the magnetic active crust. It consists of two parts: the upper one with poor magnetic properties (0.4 A/m), which forms the basement of the deep-seated basin, and the lower one, probably built of rocks with very strong magnetic properties (Fig. 5c).

(c) The magnetic active crust has the greatest thickness of 40 km in the NE part of the profile within the EEC. The crust there is tripartite and its magnetic properties are extremely varied horizontally and vertically. Diverse magnetic properties are also characteristic of the uppermost part of the crust, which was reached by many drillings. Rocks with strong magnetic properties are responsible for the complex local magnetic anomaly pattern in that area. The regional geomagnetic field pattern is a result of magnetic rocks of the middle part of the crust and the lowermost crust with a great thickness and strong magnetic properties.

To recapitulate, the hypothesis that the main contact between Phanerozoic and Precambrian Europe runs over Poland's territory is proven by the character of long-term variations of the geomagnetic field and differences in crustal magnetic models for the Paleozoic Platform and Precambrian Platform.

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