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A new magnetic anomaly map of Poland and its contribution to the recognition of crystalline basement rocks

Zdzisław PETECKI[1] and Olga ROSOWIECKA[1, *]

[1] Polish Geological Institute – National Research Institute, Rakowiecka 4, 00-975 Warszawa, Poland

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Magnetic total field measurements acquired in Poland between 1974 and 2011 have been compiled in a new digital database that provides a complete picture of magnetic anomalies of the country. The data compilation and further processing procedures used to create the magnetic anomaly database and maps that accompany this article are briefly summarized. The reduced-to-the-pole and pseudogravity anomaly maps were computed to accurately locate anomalies above their causative bodies as well as to simplify anomaly patterns and emphasize principal magnetic domains within the basement. An interpretation of the magnetic maps reveals a lot of magnetic basement provinces and domains indicating basement division into blocks and structural elements, which are important for understanding the regional tectonic setting of Poland.

Key words: magnetometry, Earth's total magnetic field map, pseudogravity, crystalline basement, Poland.

INTRODUCTION

A number of high-resolution magnetic surveys have been conducted in Poland over the last three decades. Unfortunately, the large amount of magnetic data has not been compiled into a map that covers the whole country (Petecki et al., 2003). It was therefore difficult to interpret these magnetic data on a regional scale and to compare with neighbouring countries.

To obtain a consistent magnetic anomaly map of the Earth's total magnetic field intensity for the whole Polish territory, the magnetic data have been compiled into a 1 km grid. The map is based on 10 semi-detailed (2–4 pts/km^2) ground- and shipborne surveys (Fig. 1).

The present paper includes a short description of the history of magnetic surveying in Poland, new magnetic data used in the compilation of the maps, and reduction and processing methods. Furthermore, a brief discussion of the regional anomaly pattern and its relationship to the tectonic elements of Poland is given.

HISTORY OF MAGNETIC SURVEYING IN POLAND

Magnetic field investigations in the area of Poland have been conducted for more than hundred years. The first measurements, executed in the former East Prussia (present NE Poland), resulted in the discovery of a distinct boundary between a magnetic region east of the Wisła River and a non-magnetic region west of it (Tornquist, 1908), which eventually became to be known as the Teisseyre-Tornquist Zone (Dąbrowski, 1971; see also the review in Narkiewicz et al., 2015). A systematic regional magnetic survey started before the Second World War and was finished in the mid-1950s. It was characterized by a low data point density (0.06–0.7 pts/km^2) and low accuracy of measurements of the vertical component *Z* of the geomagnetic field. On the 1:2,000,000-scale map, constructed on the basis of this regional survey (Dąbrowski and Karaczun, 1958), the two above-mentioned separate magnetic regions were more precisely determined: NE and E Poland being part of the East European Craton (EEC), with the strongly differentiated magnetic field, and the remaining part of Poland being characterized by the weak or very weak magnetic field. More intense anomalies in the latter region were detected only in the Sudetes, the Fore-Sudetic Block and along the NE boundary of the Upper Silesian Block.

Initially, various formulas for a normal field have been applied when reducing the data obtained from separate magnetic surveys. In order to process the data in a uniform way, the analytical formula for a normal field of the area of Poland has been calculated based on the Taylor's formula in consideration of the second degree expressions (Karaczun, 1965). It became the basis for the development of a new version of the magnetic anomaly map of Poland by Karaczun et al. (1978).

Numerous measurements of the *Z* component were made in the area of NE Poland, especially during the 1960s and 1970s. Two kinds of surveys have been applied: a survey with the irregular point distribution with density of 4–6 pts/km^2, and a profile survey with the point spacing of a few tens of metres. In both cases, the measurement accuracy was ~6 nT. All these measurements were unified applying a magnetic reference

* Corresponding author, e-mail: opol@pgi.gov.pl

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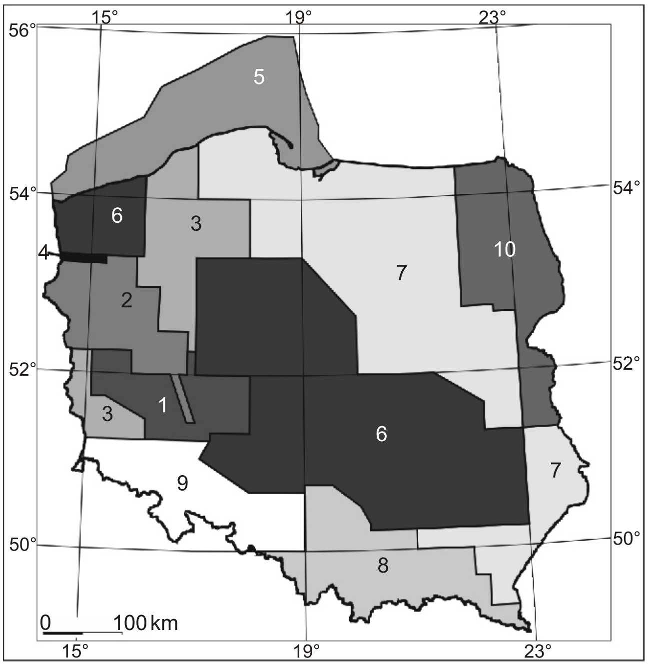

Fig. 1. Location of semi-detailed surveys used during map construction

1 – Fore-Sudetic Monocline; 2 – Szczecin Trough and Fore-Sudetic Monocline; 3 – Western, central and southeastern Poland; 4 – NW Poland; 5 – Baltic Sea; 6 – western, central and southeastern Poland; 7 – margin zone of the Precambrian Platform; 8 – Carpathians and their foreland; 9 – Sudetes; 10 – NE Poland

point network, reduced to epoch 1957.5 using *DGRF* (Definitive Geomagnetic Reference Field) and organized in a database. The weakly differentiated magnetic field in western and central Poland, with only regional anomalies of relatively small amplitudes, discouraged subsequent, more detailed investigations in this area.

In the early 1960s, researchers from the Geophysical Department of the Polish Academy of Sciences constructed the first Polish proton magnetometer, which was able to measure the absolute total magnetic field *T* value. It allowed a radical increase in the accuracy of magnetic measurements (0.1 nT) as well as simplification of further data processing. These new techniques together with more detailed survey layouts led to the second generation of magnetic mapping programs in Poland.

The first semi-detailed ground survey in the western part of Poland, executed using proton magnetometers, was carried out in the southern part of the Fore-Sudetic Monocline between 1972 and 1974 (Table 1, No. 1). This study began acquisition of the present semi-detailed survey covering the whole area of Poland.

The magnetic *T* offshore surveys in the southern Baltic Sea have been carried out by several companies. The largest offshore survey (with respect to the area and the number of data points) was completed between 1976 and 1982 by the Inter-Union Research Institute of Marine Geology and Geophysics WNIMORGEO, upon a commission from the international group PETROBALTIC, Gdańsk. Results were reprocessed by the Geophysical Exploration Company (PBG) in 1993–1994, and a computer database was created. Totally, a dataset of 490,000 marine measurements was acquired (Table 1, No. 5).

Aeromagnetic measurements were acquired between 1977 and 1981 in the area of the Sudetes, the Fore-Sudetic Monocline, and the Carpathians and their foreland. Measurements were collected along 1 km spaced flight lines intersected perpendicularly by 10 km spaced tie lines. Unfortunately, the whole original dataset was affected by a strong noise mainly of industrial origin. As a result of works aimed at the elimination of those disturbances, the magnetic field was radically smoothed.

For a long time, strong artificial noise, caused by electrified railways, posed a serious obstacle for the acquisition of uniformly distributed data points. A fieldwork method enabling the elimination of the described noise was developed by Kosobudzka (1988). The so-called differential method comprises the measurement of magnetic field variations in two measurement points, simultaneously with the use of two synchronized magnetometers, working at an accuracy of 0.1 nT. Using this method there is still a lack of measurements right at railway lines and the characteristic "zebra" pattern of magnetic stations in the 8 km wide zones on both sides of them (Fig. 2).

Table 1

Magnetic surveys of total field, used to compile the present total intensity magnetic map (for more details refer to Petecki et al., 2003)

No.	Area of survey	Year	Point density [pts/km^2]	Purchaser	Contractor
1	Fore-Sudetic Monocline	1974	1.0	AGH University of Science and Technology	PBG Geophysical Exploration Company
2	Szczecin Trough and Fore-Sudetic Monocline	1989	4.0-4.5	Polish Oil and Gas Company (PGNiG)	
3	Western, central and southeastern Poland I	1992	2.0-3.0	Polish Geological Institute	
4	NW Poland	1994	1.0	State Committee for Scientific Research	Polish Geological Institute
5	Baltic Sea	1994		Ministry of the Environment	PBG Geophysical Exploration Company
6	Western, central and southeastern Poland II	1997	2.0		
7	Margin zone of the Precambrian Platform	2002	2.0		
8	Carpathians and its foreland	2005	2.0		
9	Sudetes	2007	4.0–13.0		
10	NE Poland	2011	3.7		

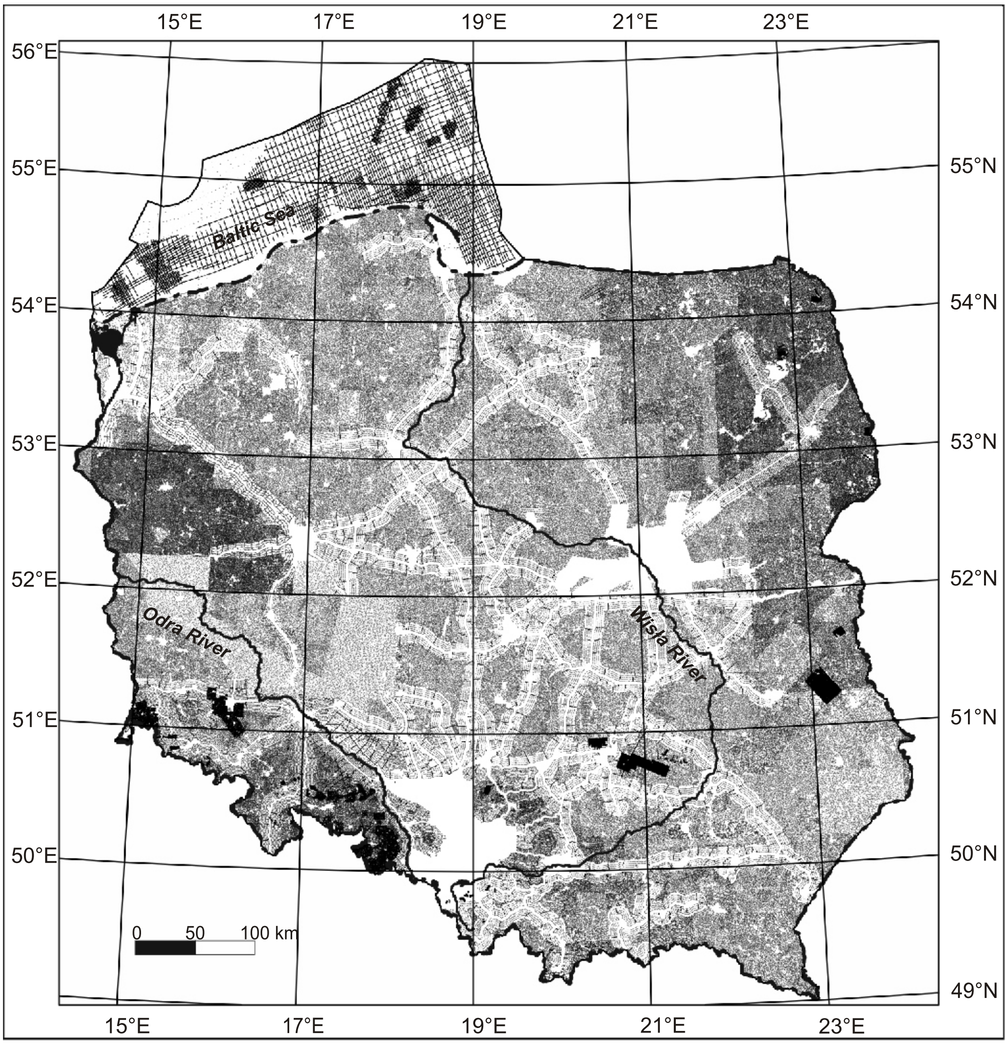

Fig. 2. Distribution of all magnetic stations (black dots) used for the present map compilation

Routine magnetic measurements, with the application of the differential method, started in 1981 in the northern part of the Fore-Sudetic Monocline and the southern part of the Szczecin Trough (Table 1, No. 2). The results appeared to be so promising that a decision to expand measurements across the whole area of western and central Poland (1985–1992) was made (Table 1, No. 3). The project was supplemented by research in the Szczecin area as part of a grant financed by the State Committee for Scientific Research (Table 1, No. 4). Between 1995 and 1997, the project was continued in the area of south-eastern Poland (Table 1, No. 6).

A next stage in the magnetic data acquisition was made by expanding the survey into the area of the EEC marginal zone (Table 1, No. 7). All the so far mentioned semi-detailed surveys of *T* were compiled into a map at a scale of 1:500,000 presenting the northern part of Poland (Petecki et al., 2003). The southern part had to wait until completion of lacking surveys in the Carpathians and Sudetes. Since 2002, a semi-detailed survey covering the Carpathians and their foreland has been acquired (Table 1, No. 8). The coordinates of measurement points were based on the direct field measurements using GPS receivers. A similar survey in the Sudetes was performed between 2005 and 2007 (Table 1, No. 9).

In order to complete a homogeneous anomaly dataset for Poland, a magnetic survey in NE Poland was conducted between 2008 and 2011 (Table 1, No. 10). The resulting magnetic database has been supplemented with the archival data from the years 1967–1992, covering selected anomalous areas.

DESCRIPTION OF SOURCE DATA AND PROCESSING

For the present compilation, 10 ground- and ship-borne surveys were used, which were conducted between 1974 and 2011. The characteristics of individual surveys are summarized in Table 1. The reader is also referred to Figure 1 for more detailed account of survey location.

Data processing of ground magnetic data included removal of the effects of time-varying external fields such as micropulsations, magnetic storms and diurnal variations, removal of the International Geomagnetic Reference Field, and gridding. Diurnal removal was achieved by subtracting the time-synchronized magnetic field, recorded at a stationary base-station magnetometer, from the survey data. After the base-station correction and adjustment to the 1982.5 geomagnetic epoch, the total-field magnetic anomaly *T* was obtained by subtracting the magnitude of an appropriate DGRF 1982.5 regional field from the total field measurement to obtain the crustal anomaly field. Notably, the DGRF 1980 model was selected as the best reference model for Europe (Wonik et al., 2001), which was recently used by Gabriel et al. (2011) during compilation of the magnetic anomaly map of Germany. Finally, the data were gridded at 1 km spacing using a minimum curvature method. Nearly 1.4 million data points were used to prepare the grid (Fig. 2).

To produce a magnetic anomaly map of Poland, some *Z* measurements were used as well. In two regions, the environs of Warsaw and large part of Upper Silesia (Fig. 2), where new measurements were not achievable because of strong industrial noise, the data selected from the *Z* regional survey (Karaczun et al., 1978) were used to fill gaps in the data point distribution. Since magnetic anomalies were calculated in that case in reference to the local geomagnetic level, they were recalculated to the DGRF, epoch 1957.5 reference field. The vertical-component data have been converted to the total-field data by means of 2-D filtering (Gunn, 1975). It was performed in the wavenumber domain using the *MAGMAP*™ software of Geosoft Ltd., and assuming that sources of magnetic anomalies are magnetized parallel to the Earth magnetic field direction. As a next step, the magnetic total intensity grid has been used as the "master grid" for merging with *Z* converted to *T* grid, applying another tool (*GridKnit*™) of the *Geosoft Oasis montaj* software. Finally, a combined grid was edited for manual elimination of remaining errors. Figure 3 shows the total intensity magnetic anomaly *T* map of Poland.

MAGNETIC DATA FILTERING

Utilization of magnetic data during geological interpretation is difficult in Poland since magnetic anomalies usually do not lie directly above their causative sources. Displacement between anomalies and their sources results from directions of the geomagnetic field and source magnetization, which are not vertical beyond the magnetic poles (Blakely, 1995). To correct for this distortion, the magnetic data should be reduced to the pole or transformed to the pseudogravity field by the application of mathematical filters to observed data (Baranov, 1957; Baranov and Naudy, 1964).

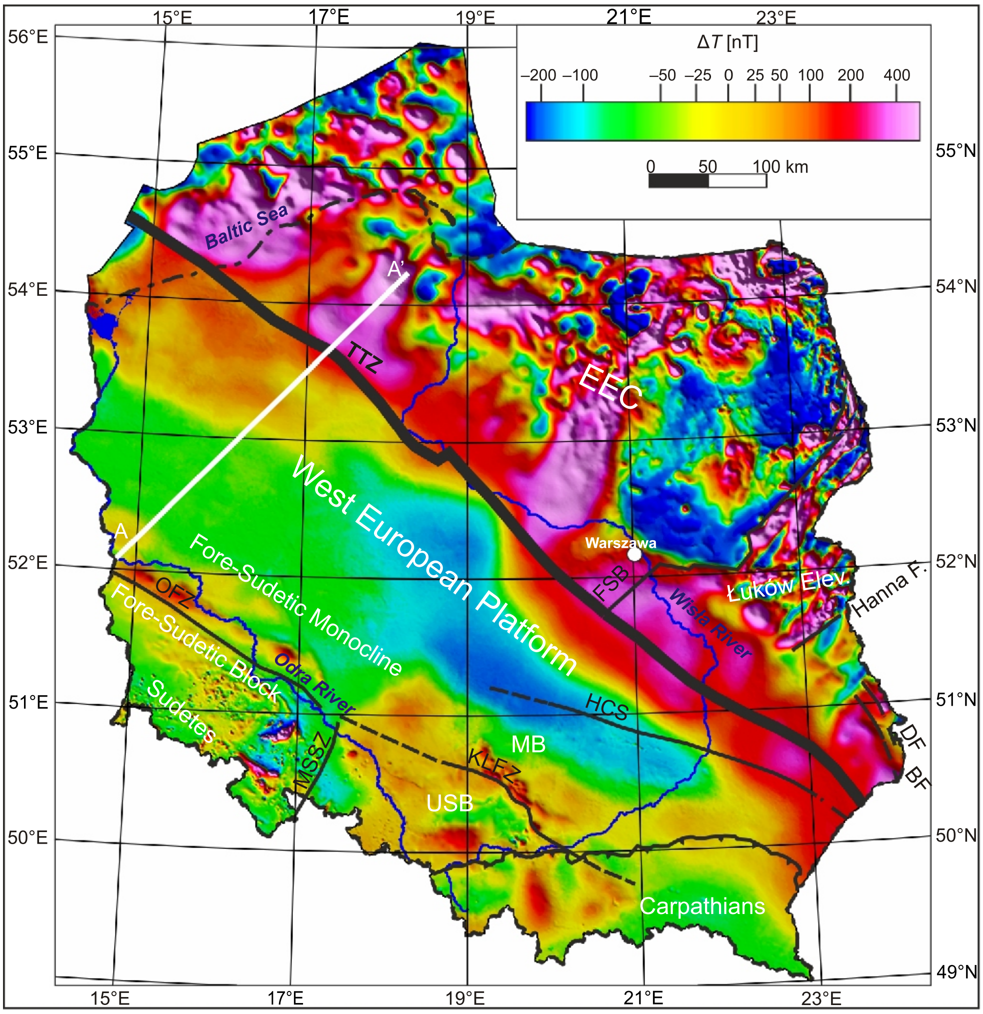

Fig. 3. Total intensity magnetic anomaly map of Poland, and a sketch of main geological discontinuities and blocks

BF – Białopole Fault; DF – Dubienka Fault; EEC – East European Craton; FSB – Fennoscandia–Sarmatia boundary (after Bogdanova et al., 2015); HCS – Holy Cross Suture; KLFZ – Kraków–Lubliniec Fault Zone; MB – Małopolska Block; MSSZ – Moravo-Silesian Suture Zone; OFZ – Odra Fault Zone; TTZ – Teisseyre-Tornquist Zone (after Narkiewicz et al., 2015); USB – Upper Silesian Block; white line – profile A–A' (see Fig. 6)

REDUCTION TO THE POLE

A shape of a magnetic anomaly results from the body's magnetization direction as well as inclination and declination of the local Earth's magnetic field. Reduction to the pole (RTP) is a mathematical approach proposed by Baranov (1957) and Baranov and Naudy (1964), which simplifies the anomaly shape. It recalculates the observed anomaly into the anomaly that would be observed at the magnetic pole, i.e. assuming verticality of the magnetization and ambient field. Thus, magnetic interpretation becomes simpler, since the reduction to the pole centres the anomalies over their causative structures.

PSEUDOGRAVITY TRANSFORMATION

Magnetic anomalies can be transformed to the equivalent gravity anomalies, on condition that the distribution of source's magnetization is proportional to the density distribution (Baranov, 1957). The transformation based on the Poisson's relationship between the gravitational and magnetic potentials caused by a source of uniform density and uniform magnetization contrasts. This operation is called pseudogravity transformation that produces pseudogravity anomalies.

The pseudogravity transformation, computed assuming a ratio of magnetization to density of 0.5, consists of reduction to the pole and vertical integration. The latter transform enhances long wavelength anomalies, leading to enhancing anomalies caused by deep magnetic sources (Blakely, 1995).

The pseudogravity procedure simplifies anomaly patterns and emphasizes principal magnetized domains within the basement (Blakely and Simpson, 1986).

The aforementioned procedures were performed on the data in the wavenumber domain using the *MAGMAP™* software from Geosoft. Both filtering methods require knowledge of the magnetization direction and were executed under the assumption that the magnetization is parallel to the ambient magnetic field. The resulting reduced-to-the-pole and pseudogravity maps are shown in Figure 4.

Reduction to the pole results in a slight northward migration of anomaly maxima, and changes their amplitudes. In western Poland, there has been a significant change in the course of the isolines that now run more regularly along the NW–SE direction. By suppressing strong but shallow magnetic disturbances, the magnetic pseudogravity map provides a clearer outline of regional magnetic provinces.

MAGNETIC ANOMALY PATTERN

Potential field techniques, especially magnetic surveys, are used commonly to map the basement structure beneath the sedimentary cover. With the exception of local anomalies caused by intra-sedimentary sources (Dąbrowski and Karaczun, 1971; Karaczun and Królikowski, 1982; Nawrocki et al., 2007, 2008) the dominant contribution to the magnetic anomaly field of Poland is from the crystalline basement. Therefore, the currently compiled database and the new magnetic anomaly maps (Figs. 3–5) offer insights into lithology, structural architecture and tectonic character of the crystalline basement on both regional and local scales.

A distinct division into several magnetic regions, showing quite different magnetic characteristics, is apparent. These re-

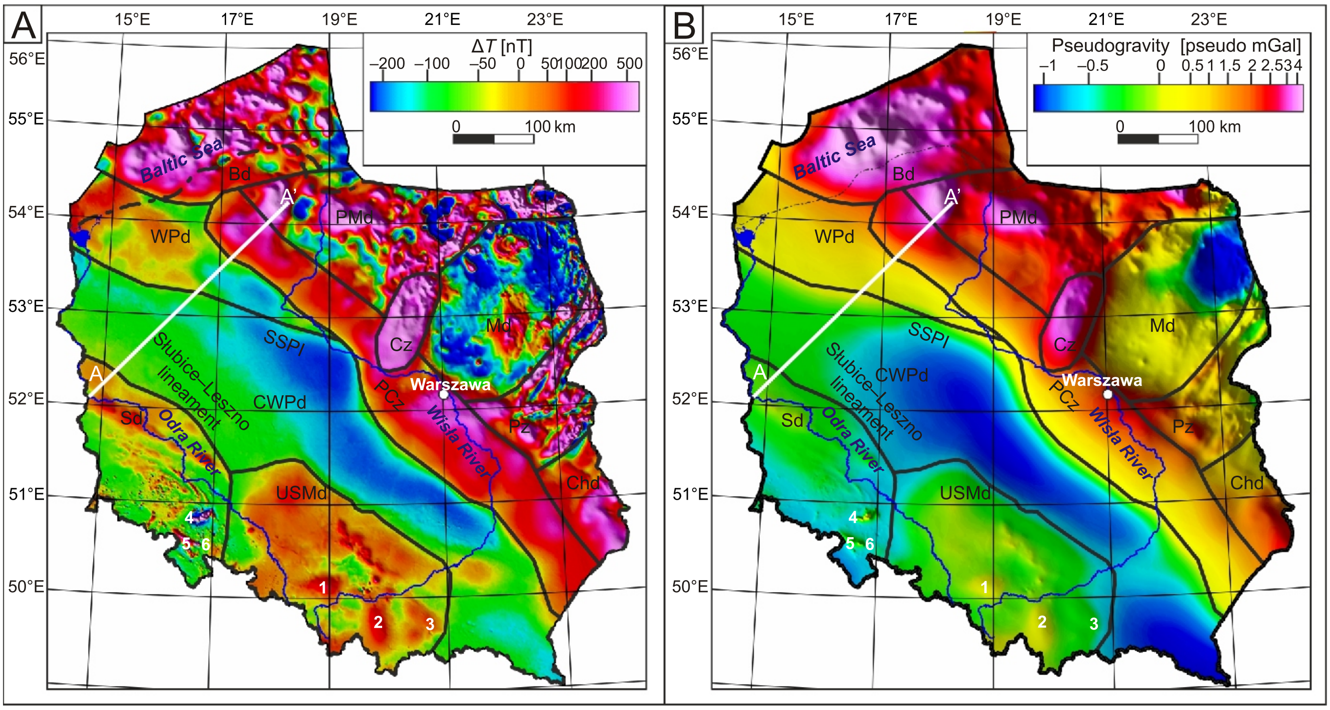

Fig. 4. Reduced-to-the-pole (RTP) total intensity magnetic anomaly map (A) and pseudogravity anomaly map (B)

Black lines – borders of magnetic domains; Bd – Baltic domain, Chd – Chełm domain, CWPd – central and western Poland domain, Cz – Ciechanów zone, Md – Mazowsze domain, PCz – Platform Contact zone, PMd – Pomerania–Mazury domain, Pz – Podlasie zone, Sd – Sudetic domain, SSPl – Szczecin–Stargard Szczeciński–Piła–Inowrocław lineament, USMd – Upper Silesia–Małopolska domain, WPd – Western Pomerania domain; anomalies: 1 – Tychy, 2 – Jordanów, 3 – Nowy Sącz, 4 – Gogołów–Jordanów, 5 – Nowa Ruda, 6 – Braszowice; other explanations as in Figure 3

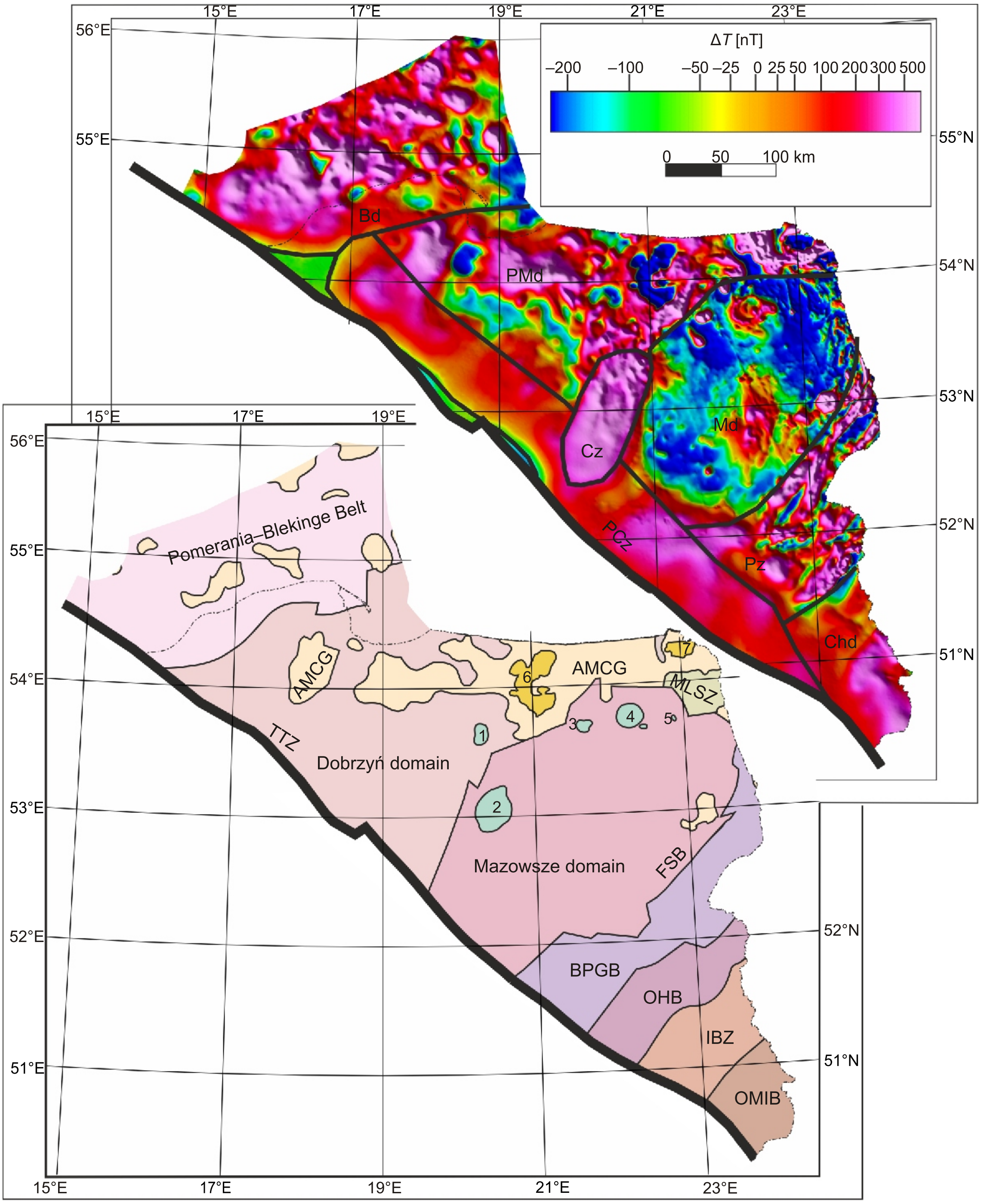

Fig. 5. RTP map of the EEC, and a sketch of main geological discontinuities and blocks

TTZ – Teisseyre-Tornquist Zone (after Narkiewicz et al., 2015), FSB – Fennoscandia–Sarmatia boundary (after Bogdanova et al., 2015); Fennoscandia: MLSZ – Mid-Lithuanian Suture Zone, AMCG – Anorthosite-Mangerite-Charnockite-Granite association, Paleozoic massifs: 1 – Olsztynek, 2 – Mława, 3 – Pisz, 4 – Ełk, 5 – Tajno; Sarmatia: BPGB – Belarus–Podlasie Granulite Belt, OHB – Okolovo–Holeszów Belt, IBZ – Ivano–Borisov Zone, OMIB – Osnitsk–Mikashevichi Igneous Belt (after Krzemińska et al., in press); Mesoproterozoic massifs of Fennoscandia: 6 – Kętrzyn, 7 – Suwałki (after Kubicki and Ryka, 1982); other explanations as in Figure 4

gional magnetic domains are characterized by their anomaly wavelengths and amplitudes, heterogeneity, internal magnetic patterns and trend directions, and, in many cases, are separated by outstanding gradient zones. Magnetic anomalies are mainly caused by lithological and structural changes in the buried basement related to successive stages of magmatism and metamorphism and associated P-T pathways. However, the influence of variable source depths on anomaly shapes and amplitudes may also be significant.

The area of Poland is divided into two major magnetic provinces by the NW–SE trending line. The northeastern province, corresponding to the EEC, is characterized by the presence of intense magnetic anomalies. The southwestern province is part of the younger Phanerozoic West European Platform, where the overall intensity of existing magnetic anomalies is definitely lower, except for a few particular regions. The boundary between the two provinces is marked by a strong gradient zone, roughly corresponding to the Teisseyre-Tornquist Zone (TTZ), in the shape suggested by Narkiewicz et al. (2015; Fig. 3). Mazur et al. (2015) modified the TTZ-shape in its northern part by moving it further to the north-east and east. Thus, the TTZ runs through the elongate positive anomaly of the PCz unit described later in this article.

Inhomogeneity of both provinces as well as their division into smaller domains can be observed. As a first step, a simple regional identification of their geometrical shapes based on distinct internal structural patterns has been performed. In most cases, the geographical extent of these domains can be determined based on magnetic anomaly patterns or, more objectively and accurately, by tracing the maximum horizontal gradient magnitudes of pseudogravity (Cordell and Grauch, 1985; Blakely and Simpson, 1986). The boundaries of distinguished domains are marked by black lines in Figures 4 and 5.

The detailed description of magnetic domains is beyond the scope of this paper, as the main goal is to present a new compilation of magnetic data of Poland. Nevertheless, a brief description of main magnetic domains is given below, along with some information on their geological context. Although the geological importance of some of magnetic domains and anomalies has been studied (Cieśla and Wybraniec, 1998; Petecki, 2001, 2008; Grabowska and Bojdys, 2001; Dziewińska and Petecki, 2004; Królikowski, 2006; Grabowska et al., 2007, 2011; Lemberger et al., 2008; Wiszniewska and Petecki, 2016), many features still remain to be investigated to find a closer relationship between the magnetic field and crystalline basement geology.

EAST EUROPEAN CRATONIC PROVINCE

Several units within the EEC province have been distinguished based on geophysical and geological data by Kubicki and Ryka (1982) and Ryka (1998). Subsequent investigations of fundamental importance for the knowledge about the Precambrian crystalline basement have been performed in the next years (e.g., Dörr et al., 2002; Wiszniewska et al., 2002; Bagiński et al., 2007; Williams et al., 2009; Krzemińska et al., 2009a; Demaiffe et al., 2013). These results, supplemented with the newest geochemical, isotope and U-Pb dating studies of borehole samples, with the magnetic and gravity data used to set geological boundaries, enabled compilation of a novel geologic map of the crystalline basement in the Polish part of the East European Platform (Krzemiński et al., 2014; Krzemińska et al., in press). The previous lithostratigraphic division, with a large number of metamorphic formations and local groups established by Kubicki and Ryka (1982) and Ryka (1998), has been replaced by a more up-to-date chronostratigraphic classification. The areal extent and geological importance of these domains together with their subdivision are further developed below.

Within the EEC magnetic province, the following domains are distinguished: Platform Contact zone (PCz), Chełm domain (Chd), Podlasie zone (Pz), Mazowsze domain (Md), Ciechanów zone (Cz), Pomerania–Mazury domain (PMd), and Baltic domain (Bd; Fig. 4).

PLATFORM CONTACT ZONE

The Platform Contact zone (PCz) is contoured in magnetic images (Fig. 4) as a separate elongate unit, because the layout and direction of its magnetic anomalies is different from those in the neighbouring units. It is characterized by broad positive anomalies of moderate amplitudes and spreads across hundreds of kilometres. A series of positive magnetic anomalies occurring in this zone is bordered to the SW by a well-expressed magnetic gradient zone. Southwestward of this line, there is a prominent magnetic low. The character of the magnetic field indicates a major lithological and/or tectonic boundary in the basement.

The blurred shape of anomalies and their gradients indicate a deep location of magnetic sources related to a deepening of the crystalline basement rocks. Their direction is in general compatible with the direction of the gradient zone, especially in its southern part where these anomalies are strongly separated from the NE–SW-trending anomalies of Chd. North of Warsaw, the anomalies of the western border of PMd and Cz terminate within PCz.

CHEŁM DOMAIN

In the Chełm domain (Chd), located in SW Poland, the anomalies trend mainly SW–NE and, subordinately, NW–SE (Fig. 4). Geologically, the domain belongs to Sarmatia (Bogdanova et al., 2006), which is approximately equivalent to the Ukrainian part of EEC including the Ukrainian Shield. The northwestern border of Sarmatia is defined along the Hanna Fault (Żelichowski, 1972; Bojdys et al., 2003; Krzemińska et al., in press), bounding the Łuków Elevation from the south.

The SW-trending anomalies of Chd appear to terminate against the regional anomalies of PCz. The anomaly pattern indicates that the lithology and architecture of the crystalline basement is strongly diversified (Grabowska and Bojdys, 2001). Several faults appear across the area. They are both perpendicular and parallel to PCz (Fig. 4). Two of them are the Dubienka and Białopole faults traced in the POLCRUST-01 seismic data (Malinowski et al., 2015).

The new geologic map of the crystalline basement in the Polish part of EEC suggests the existence of two Paleoproterozoic domains: Osnitsk–Mikashevichi Igneous Belt and Ivanovo–Borisov Zone in Chd (Fig. 5; Krzemińska et al., in press).

PODLASIE ZONE

To the north of Chd, an obvious NE–SW-trending magnetic field fabric is observed (Fig. 4). This area, labelled herein as the Podlasie zone (Pz), is characterized by a set of several belt-shaped anomalies extending from Poland to western Belarus. Their boundaries can be clearly marked using the magnetic data patterns. These strong linear magnetic highs and lows delineate the Belarus–Podlasie Granulite (BPGB) and Okolovo–Holeszów (OHB) belts (Fig. 5; Krzemińska et al., in press). These belts are regarded as a southern fragment of the Fennoscandian part of EEC, bordering Sarmatia from the NW (Bogdanova et al., 2006; Krzemińska et al., in press). However, according to the new tectonic subdivision of the South Baltic region (Bogdanova et al., 2015), the BPGB and OHB belong to Sarmatia.

MAZOWSZE DOMAIN

The broad magnetic Mazowsze domain (Md), bounding Pz from the north, is characterized by a negative low amplitude anomaly of RTP data (Fig. 4). According to the new geological data, this magnetic domain corresponds mainly to granitoids and paragneisses (Williams et al., 2009; Krzemińska et al., in press). On top of the subdued regional field level, there are prominent local magnetic anomalies. These correspond to various rock types characterized by distinct magnetic properties, mainly syenites and amphibolites, whereas granites and gneisses with low magnetic susceptibility dominate elsewhere in the domain. For example, negative local magnetic anomalies are related to the Paleozoic syenite massif of Ełk (Wybraniec and Cordell, 1994), while positive anomalies to the Paleozoic gabbro-syenite massif of Pisz and the composite, small carbonatite-syenite massif of Tajno (Fig. 5, e.g., Krzemińska et al., 2006).

Characteristic features of Md are narrow, linear anomalies, usually striking NW–SE, and thus parallel to the TTZ. They may be related to magmatic dykes. The geographic extent of Md mostly overlaps the Late Svecofennian Mazowsze orogenic domain (Fig. 5; Krzemińska et al., in press).

CIECHANÓW ZONE

The NNE-trending Ciechanów zone (Cz) is a prominent positive magnetic belt of moderate to high amplitudes, bounding Md in the north-west (Fig. 4). This regional feature terminates to the SW within PCz. The Paleozoic syenite intrusion of Mława occurs within the belt (Fig. 5). This is expressed as a local anomaly with a reduced amplitude value. Note that Cz is now supposed to belong to the geological Mazowsze Domain according to the recent geological studies (Krzemińska et al., in press).

POMERANIA–MAZURY DOMAIN

In the north and north-west, Md and Cz border the E–W trending Pomerania–Mazury domain (PMd) that has a complicated structure and a very diversified magnetic pattern (Fig. 4). This is a belt-shaped Mesoproterozoic domain earlier termed as the Mazury Complex that is composed of rocks associated with AMCG magmatic rocks emplaced along an E–W trending lineament in northern Poland and southern Lithuania (Wiszniewska et al., 2002). Characteristic features of this zone are distinct magnetic anomalies related to the different groups of intrusive rocks (Wiszniewska, 2002; Skridlaite et al., 2003; Bagiński et al., 2007; Krzemińska et al., 2009b, in press). The strong negative magnetic local anomalies are related to the Mesoproterozoic anorthosite massifs of Kętrzyn and Suwałki (Fig. 5; Cieśla and Wybraniec, 1998; Cieśla et al., 1998; Wiszniewska et al., 2002). The latter consists also of gabbro-norite, gabbro and diorite, hosting Fe-Ti-V ore deposits (Wiszniewska and Petecki, 2014). The positive anomalies coincide with gabbro, norite, monzodiorite and granodiorite intrusions, as confirmed by numerous drillings (Wiszniewska, 1995). The Paleozoic syenite massif of Olsztynek is also distinguished in this domain.

BALTIC DOMAIN

The Baltic domain (Bd) is characterized by a regional magnetic high with a superimposed mosaic pattern of strong positive magnetic anomalies (Fig. 4) associated with early Mesoproterozoic AMCG magmatism. It is separated from PMd by a narrow latitudinal zone of magnetic low. This magnetic domain is now defined as the Late Svecofennian Pomerania-Blekinge Belt (Fig. 5; Krzemińska et al., in press).

WEST EUROPEAN PLATFORM PROVINCE

The West European Platform province strongly differs from the East European Cratonic province mainly by its weakly differentiated magnetic field. The following main domains can be distinguished: Upper Silesia–Małopolska domain (USMd), Sudetic domain (Sd), Central and Western Poland domain (CWPd), and Western Pomerania domain (WPd; Fig. 4).

UPPER SILESIA–MAŁOPOLSKA DOMAIN

The Upper Silesia–Małopolska domain (USMd) of moderate magnetic intensity and several magnetic highs of regional importance (Fig. 4) generally consists of the Upper Silesian Block (USB) and the SW part of the Małopolska Block (MB) (Fig. 3; Dadlez et al., 1994). The NE boundary between the USB and MB corresponds to the Kraków–Lubliniec Fault Zone (KLFZ) which is marked by the belt of local anomalies connected with bimodal intrusive rocks (Buła et al., 1997; Żaba, 1999). The southern part of the domain is dominated by the positive Tychy, Jordanów and Nowy Sącz anomalies (Fig. 4). The latter two are associated with the southward-dipping Precambrian basement of the Outer Carpathians (Grabowska et al., 2007, 2011).

SUDETIC DOMAIN

The Sudetic domain (Sd) comprises the Sudetic Mts., the Fore-Sudetic Block and the SW part of the Fore-Sudetic Monocline as far as the Dolsk Fault Zone. The domain has low magnetic field amplitudes with the exception of several intensive residual anomalies associated with the serpentinized ultramafic, diabase or amphibolite rocks, e.g. Gogołów–Jordanów, Nowa Ruda and Braszowice (Fig. 4; Petecki and Rosowiecka, 2016; Wiszniewska and Petecki, 2016). Numerous intense local magnetic anomalies of small areal extent occurring in the area are related to Cenozoic (pre-Quaternary) volcanites.

One of the most prominent magnetic feature in the N part of Sd is a zone of positive magnetic anomalies trending NW–SE. These anomalies are related to the sub-Permian Wolsztyn–Leszno High imaged as a deep crustal structure by the wide-angle reflection and refraction (WARR) P4 seismic profile (Grad et al., 2003). The western extension of the zone passes into the Mid-German Crystalline High (Wonik et al., 2001; Gabriel et al., 2011). The northern boundary of this magnetic region is expressed by the SE-trending magnetic gradient zone defined as the Słubice–Leszno magnetic lineament (Fig. 4; Petecki, 2008) and adopted here to trace the NE boundary of Sd. It approximately corresponds to the Dolsk Fault, a distinct crustal boundary marked on the WARR P4 profile, which shows a fundamental change in crustal structure (Guterch and Grad, 2006).

The eastern boundary of Sd is less clear. However, a magnetic low between Sd and USMd is apparent. The source of this low coincides with the Staré Město Belt and its northern continuation in the Fore-Sudetic Block, marking the boundary between the Moravo-Silesian (E) and Moldanubian/Saxothuringian (W) parts of the Sudetes (Mazur et al., 2006), labelled MSSZ (Moravo-Silesian Suture Zone) in Figure 3. Therefore, it is here assumed as the eastern limit of Sd.

CENTRAL AND WESTERN POLAND DOMAIN

In the area north and north-east of the Słubice–Leszno lineament, including central Poland, there is a vast magnetic low (Fig. 4) defined here as the central and western Poland domain (CWPd). This magnetic low is bounded to the north by the Szczecin–Stargard Szczeciński–Piła–Inowrocław (SSPI) gradient zone (Petecki, 2008). The magnetic field of CWPd has no strong local anomalies of regional importance.

The absence of magnetic anomalies in this domain suggests either consistently lower magnetization of the basement rocks in comparison to the neighbouring magnetic domains, or a smooth top of the basement at a great depth. It should be noted that the western extension of CWPd in eastern Germany is also associated with predominantly negative magnetic anomalies (Wonik et al., 2001; Gabriel et al., 2011). CWPd is characterized by the presence of a thick low-velocity upper crustal layer (Guterch and Grad, 2006) that could be partly responsible for the generally low magnetic anomaly values.

WESTERN POMERANIA DOMAIN

The Western Pomerania domain (WPd) is located north-east of the SSPI gradient zone between CWPd in the south-west, Bd in the north and PCz in the north-east. The magnetic field in this area is characterized by NW–SE-trending low-amplitude anomalies (Fig. 4). This magnetic domain is terminated to the north-east by a steep magnetic gradient zone that borders on the regional magnetic highs of PCz. According to Petecki (2001) the subdued anomaly pattern in this area reflects a considerable depth of ~18.5 km to the top of the magnetic basement, estimated based on the spectral method of Spector and Grant (1970). This, in turn, suggests a considerable displacement of magnetic basement along a gradient zone bounding PCz to the SW, which is in accordance with the WARR seismic data (Guterch and Grad, 2006). The results of magnetic modelling (Fig. 6; Petecki, 2008) indicate that the edge of the elevated crystalline basement of EEC is situated near this gradient zone. Prominent positive magnetic anomalies located NE of this gradient zone have been modelled as the sources showing a considerable vertical extent and steeply dipping edges, and related to the structure of the EEC crust in the PCz and PMd magnetic domains (Petecki, 2008).

The southern boundary of the domain, defined by the SSPI gradient zone, is best represented as a magnetic contact at depths of 18–23 km, using the Euler deconvolution method (Petecki, 2008). The presence of a magnetic low over CWPd indicates consistently lower magnetization of the crust constituting the domain as compared to WPd and Sd. In addition, the results of magnetic modelling suggest that the SSPI gradient zone represents a NE-dipping contact in the middle and lower crust (Fig. 6), which is in accordance with the lower crustal and sub-Moho reflectors dipping north-eastwards, revealed on the GB-2B-96 and 25-III-82 profiles crossing the SSPI zone (Petecki, 2003). These results may indicate that SSPI represents a crustal-scale south-vergent thrust. Extension of this zone into northern Germany correlates well with the Stralsund–Anklam faults system (Hoffmann and Franke, 1997).

The northern boundary of Sd expressed by the Słubice-Leszno magnetic lineament (SL in Fig. 6) has been modelled as a contact zone of bivergent nature. While the magnetic contact in the upper part of the crust shows a NE'ward dip, the contact in the middle and lower crust dips to the opposite direction (Petecki, 2008).

CONCLUSIONS

Ten magnetic surveys made over different portions of Poland during the past several decades have been used to compile the magnetic data set and to produce the most up-to-date total intensity magnetic anomaly map for the whole country. The

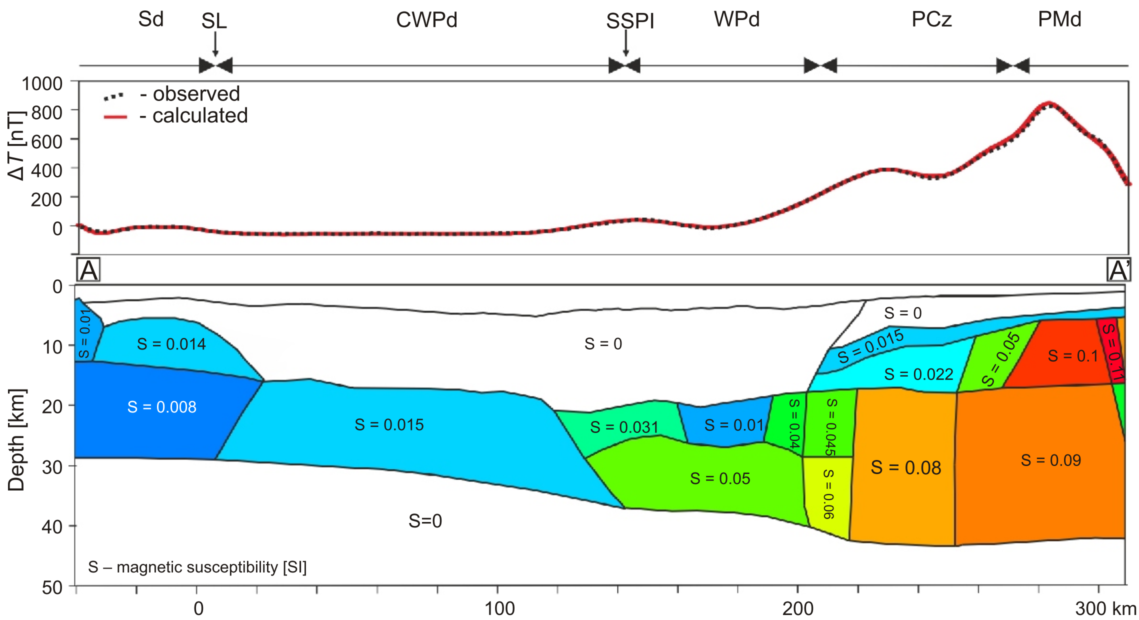

Fig. 6. Magnetic modelling along A-A' profile (Petecki, 2008)

SL – Słubica–Leszno magnetic lineament; for profile location and explanations see Figure 4 global reference field, DGRF 1982.5, was used to eliminate the effect of the Earth's core magnetic field from the data. The map represents a substantial upgrade from the previous compilations of magnetic anomaly data for Poland (Karaczun et al., 1978; Petecki et al., 2003). This new compilation has provided a view of the various magnetic signatures related to the major geological and tectonic units of the country. The RTP and pseudogravity anomalies were computed to improve positioning of anomalies and highlight magnetic features with distinct boundaries and characteristic anomaly patterns. These transformations clearly show the different anomaly signatures of the East European Craton and West European Platform of central and western Poland and indicate the magnetic basement division into smaller domains.

The new magnetic maps described in the present paper allow integration with other geophysical and geological data for better definition of the magnetic basement. They can be utilized for a wide range of purposes, starting from regional to even trans-European studies. On a regional, country scale, the magnetic data have recently been used for constructing the geological map of crystalline basement in the Polish part of the East European Platform (Krzemińska et al., in press), analyzing the basement structure of the Paleozoic Platform in Poland (Narkiewicz and Petecki, 2017) and the Sudetes and surrounding areas in SW Poland (Petecki and Rosowiecka, 2016). The new magnetic anomaly map of Poland provides an opportunity for future advances in the understanding of the Polish lithosphere by integration of the magnetic data with other existing geophysical and geological data.

Geology knows no borders, so to improve interpretation of the magnetic anomaly pattern it would be suitable to merge this map with magnetic maps of surrounding countries. This integration of magnetic anomaly data will be a powerful tool for further evaluation of the structure and tectonic evolution of the areas that span across national boundaries. In this context, the cross-border tracing of such geological units as the Mid-German Crystalline Rise and crustal domains of EEC would be important for understanding the regional tectonic setting of Central Europe.

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