Geophysical cartography in Poland — an overview

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A b s t r a c t. Regional analysis and mapping of various geophysical data has been recognized as an important — even crucial — element of geological studies for many years. Due to rapid development of advanced numerical tools it is presently possible to construct, maintain and comprehensively analyse even very large geo-databases, including seismic, gravity, magnetic, geothermal and other geophysical data. In many countries, national geological surveys, commercial companies and research institutions are involved in mapping projects focused on spatial representation of geophysical data that could later be used for various studies.

Recently, new policy of the Polish Ministry of Environment regarding geological cartography in years 2005–2020 has been declared (cf. Ber & Jezierski, 2004). In this document, geological cartography is used as a rather wide term that includes also other geo-disciplines like geoenvironmental studies or surface geochemistry. Among them, mapping of geophysical data is also mentioned. In this paper, short overview of the current state-of-the-art of selected aspects of regional geophysical mapping in Poland is given, with some remarks regarding potential directions of future work.

Key words: *geophysical cartography, seismic data, magnetic field, gravity field, thermal field, petrophysical parameters*

Seismic Data

Seismic data have been used for geological studies for a very long time, and include (a) seismic deep refraction/wide angle reflection studies focused on crustal/lithospheric problems, (b) seismic refraction studies devoted to mapping of the crystalline basement, (c) seismic reflection studies of sedimentary basins (mainly for petroleum exploration), (d) shallow seismic reflection and refraction studies for engineering, hydrogeological, environmental and other purposes. In Poland, very large amount of various seismic data has been acquired during last several decades of geophysical prospecting. Large part of the acquired and processed seismic datasets is available in digital form and could be used for, e.g., regional compilations and mapping projects.

During last years Poland experienced tremendous increase of new generation high-quality deep refraction/wide angle reflection data within the POLONAISE97, CELEBRATION2000 and SUDETES2003 projects co-ordinated by the Institute of Geophysics, Polish Academy of Sciences (cf. Guterch et al., 2004). All the profiles acquired and processed during these experiments provided great wealth of new data on crustal/lithospheric structure of Poland. They could also be used for construction of tomographic (spatial — 3D) models of crustal and lithospheric structure (e.g., Środa et al., 2002), hence — considering their high quality and fairly dense coverage — form important part of regional datasets that could be used for geophysical mapping. Recently competed reprocessing and reinterpretation of selected old deep refraction profiles (Grad et al., 2005) showed that also these data could be integrated with new generation profiles, and could form valuable in-fill datasets as far as regional crustal-scale mapping is concerned.

In the 1950s and 1960s large amount of refraction data targeting top of the crystalline basement has been acquired and interpreted (cf. Młynarski, 2002). They have been integrated in regional scale and formed basis for the country-scale basement map of Skorupa (1974). Presently, it would seem logical to reinterpret this vast dataset using modern processing/modelling software, as due to its dense coverage and overall fairly good quality it could provide important source of independent information on structure of sedimentary basins and regional tectonic zones. Numerical reprocessing and reinterpretation of this seismic data, preferably in conjunction with analysis and modelling of grav-mag data, could certainly form basis for interesting research projects for academia or geological survey.

Similarly to other countries, bulk of seismic data in Poland was acquired during exploration for hydrocarbon. These datasets include analogue (acquired in the 1950s, 1960s and early 1970s.) and digital (acquired in late 1970s and later) recordings. Analogue data have at the moment very limited value, and only in certain areas without other newer data could be used as infill information. All sedimentary basins in Poland have been covered by rather dense coverage of 2D seismic reflection data, and during recent years rapid increase of high-quality 3D seismic data is observed. Interpretation of 2D seismic data was usually focused on particular exploration targets and usually limited by spatial extent of particular 2D surveys. Regional or semi-regional, basin scale seismic (time or depth) maps have been rarely constructed, usually within regional projects completed by the Polish Geological Institute, the PBG Geophysical Enterprise and the Polish Oil & Gas Company. Vast coverage of 2D data available in SEG-Y format combined with potential of modern interactive interpretation software allows presently for very detailed, basin-scale mapping of the sedimentary infill of particular basins. Very good reference point for such regional seismic mapping studies is provided by the mapping project, recently completed by the Danish Geological Survey (GEUS), focused on the Permo-Mesozoic onshore and offshore basin of Denmark (cf. Vejbek et al., 2003). Within this project, basin-scale time, depth and velocity maps have been compiled that provide excellent detailed insight into the structure and stratigraphic architecture of the Danish part of the Peritethys basin. All these maps are available from

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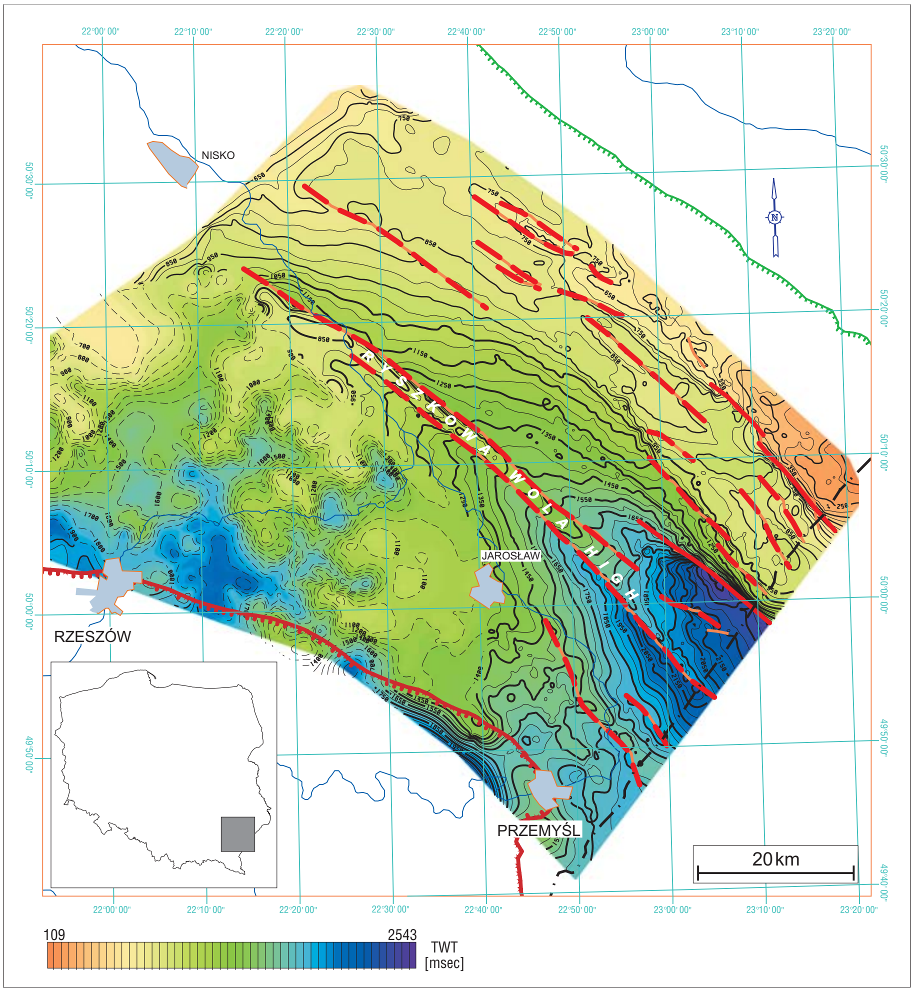

Fig. 1. Semi-regional time seismic structural map of the Badenian evaporitic horizon (approx. top of the pre-Miocene basement) from the eastern part of the Polish Carpathian Foredeep Basin. Red lines — faults (from Krzywiec et al., 2005)

GEUS for commercial and academic users and could be used for both exploration and research purposes. Various regional seismic maps have been also included, e.g., into the *Millennium Atlas: petroleum geology of the central and northern North Sea* (2003). It is expected that recently initiated project on *Southern Permian Basin Atlas*, joint project of the geological surveys of Belgium, Denmark, Germany, the Netherlands, Poland and the United Kingdom, and strongly backed-up by oil industry, will provide platform for construction of regional seismic (and other) maps for the area of the entire Southern Permian Basin. Within particular basins in Poland, some regional structural seismic maps have been constructed that could be used for various regional geodynamic/tectonic studies. An example of such map is given in Fig. 1, showing basement structure of the E Polish Carpathian foredeep basin (cf. Myśliwiec, 2004).

Finally, seismic data could also be used for various shallow applications, including geological mapping, studies of glacitectonic deformations etc. Recently, several projects involving shallow high-resolution seismic reflection surveying completed at the Polish Geological Institute targeted various tasks related to the shallow substratum (cf. Krzywiec et al., 2004a, b). Obtained results, together with vast number of published results of similar studies from other countries, clearly showed that shallow high-resolution seismic data combined together with other geological and geophysical datasets could provide crucial insight regarding shallow subsurface, very important for, e.g., engineering and environmental purposes. Acquisition of dense coverage of shallow high resolution 2D seismic profiles over particular targets would provide means for detailed mapping of their spatial extent and internal structure. Clearly, this area of application of seismic mapping techniques seems to belong to the most promising areas of future studies.

Gravity and Magnetic Data

The whole area of Poland is covered by semi-detailed magnetic survey, and selected regions are covered with detailed (density up to 20 p/km^2) surveys (Fig. 2; cf. Petecki et al., 2003; Wybraniec, 1999). In parts of NE Poland detailed measurements were carried out of total intensity of magnetic field or of its vertical component. Large amount of detailed surveys were collected in the Sudetes, too. Presently, the semi-detailed survey of ground measurements in Carpathian with its foreland and Sudetes is being completed. Its results will replace the existing aerial measurements of much lower quality.

Since there is a large set of magnetic measurements of really high quality available, demand for more detailed comprehensive geophysical-geological studies devoted to particular geological structures or regions still exists. For example, within the Holy Cross Mountains magnetic data point density of recently finished semi-detailed survey does not suffice to trace the expected geometry of diabase intrusions of important commercial value, hence even more detailed localised surveys seem to be necessary. Such detailed surveying should be followed by construction of various maps targeting identification of particular geological structures.

Detailed surveys would be necessary also in near-border areas, where lateral continuation of anomalous bodies is difficult to establish. For example, magnetic anomalies of the Lublin area (SE Poland) have their counterparts within the W Ukraine, and only integrated mapping of the datasets from both countries could provide reliable regional maps of magnetic anomalies. Detailed survey in some regions of the Outer Carpathians would allow to precise geometry of various magmatic bodies known from this area.

Some other tasks of magnetic cartography in Poland should be linked with the micromagnetic measurements. Among them the most important seems to be micromagnetic mapping of heavy minerals concentrations in the beach sediments of the Baltic Sea.

Except for some areas covered by lakes, the whole area of Poland is covered by semi-detailed gravity surveys (Fig. 2; cf. Królikowski & Petecki, 1995) that have been extensively used for various projects ranging from regional crustal/lithospheric studies to detection of shallow targets.

Since the opportunity of fast and precise location of datapoint on the water (using high precision GPS techniques) exists, it is important to fulfill data gaps related to lakes.

Apart from regional semi-detailed survey, numerous detailed surveys (density up to 20 p/km^2) have been acquired in certain parts of Poland. Several such detailed surveys have been acquired above selected salt structures and provided very detailed information regarding their structure. Comparison of detailed and semi-detailed surveys acquired above the Inowroław salt diapir (Fig. 3) proves that only denser survey displays details of internal structure of these salt structures. Considering increased interest in salt structures due to developing plans for construction of underground gas storage and nuclear waste disposal sites it might be necessary to acquire new high-density high-quality gravity surveys above selected salt structures in Poland.

Thermal Field

Thermal measurements have been conducted in Poland for almost a hundred years. Studies completed till the1960s were summarized in heat flow density map by (HFD) Plewa (1994) (Fig. 4A). On this map, some high anomalies could be observed, especially in regions of Toruń and Warszawa and close to the eastern border of Poland, which are evident errors caused by HFD calculation from one borehole logging. The last one was never confirmed by Ukrainian data.

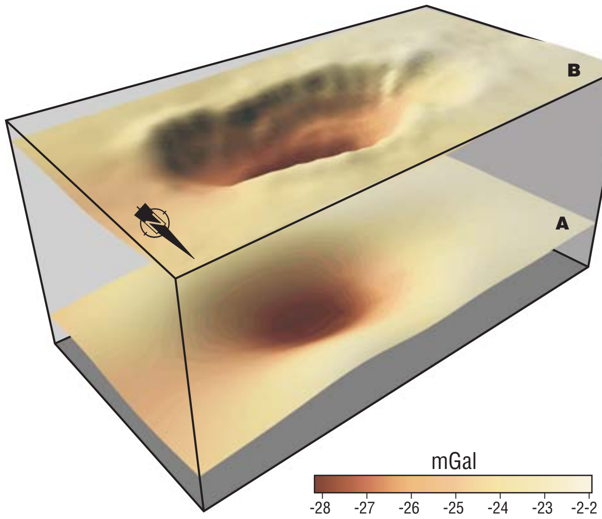

Fig. 3. Bouguer anomaly map of Inowrocław salt diapir — comparison of semi-detailed (A) and detailed (B) surveys

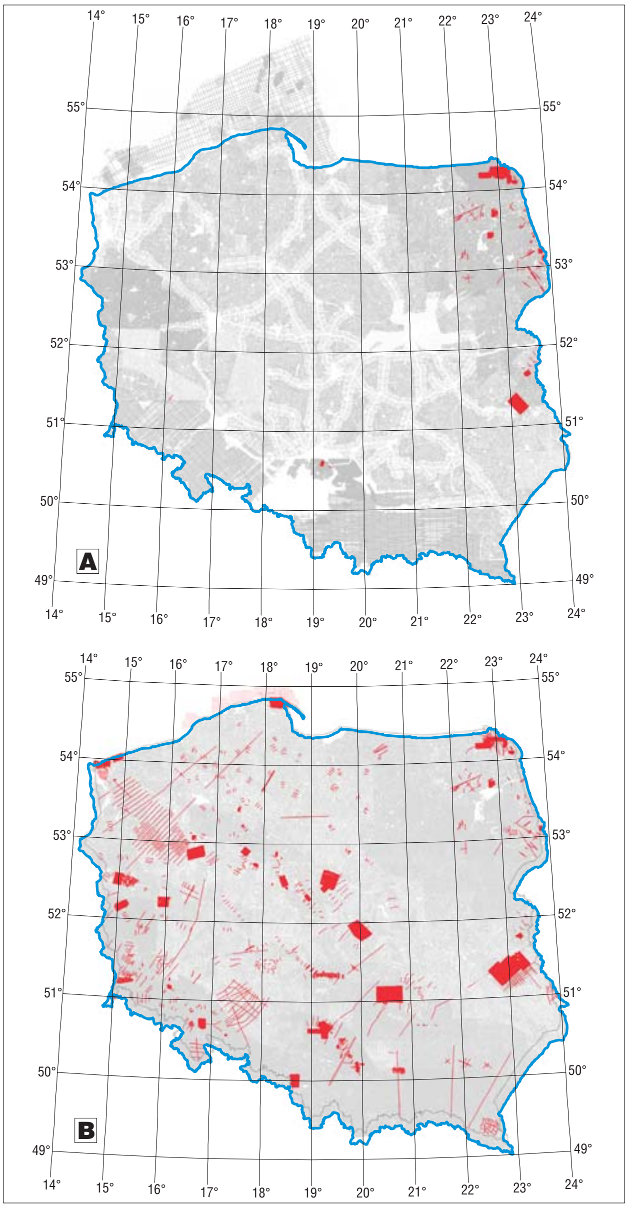

Fig. 2. Distribution of magnetic (A) and gravity (B) data in Poland. Gray dots marks semidetailed survey, red dots marks detailed surveys

The second map of Gordienko and Zavgorodnaya (1996) (Fig. 4B) comprises more data. The interpretation was here based on similarities between Ukrainian stratigraphic units, lithology and their Polish counterparts. Therefore it is still an approximation.

The latest effort made by Karwasiecka and Bruszewska (1997) (Fig. 4C) was based on additional new data and previous results of other authors since 70-ties. Different approaches are not comparative with one another. It causes an error in the vertical pattern of HFD variation.

In their calculations, Karwasiecka and Bruszewska generally applied deep borehole data but in different depth intervals. For the thermal conductivity (TC) pattern, they used detailed information based on core measurements or a mean value for stratigraphic or lithological units in particular cases, depending on the quantity of data.

A major attempt to find a general pattern of temperatures and heat flow for the whole of European territory was taken by the European Commission (Hurter & Haenel, 2002). However, quite similar accusations can be put forward, as it was already discussed above. The data included has been achieved with the use of different approaches. Some data has already been corrected by the paleoclimatic effect and some has not, and the depth of boreholes is unknown. Therefore, the map is full of artefacts concerning one value for a large area. The Polish contribution is the data from the first map presented in Fig. 4A.

The most vital problem in the study of the terrestrial heat flow is to obtain accurate data from observations concerning the thermal structure and heat flow (HF) in holes. That information requires the availability of a deep borehole. Shallow-depth holes can be encumbered with a serious error relating to a variety of effects, including hydrological influence, topography, ground temperature variations and long-term climate changes.

ted for calculations. It is possible that this effect may relate to the whole territory of Poland. A heat flow revision is therefore required.

Polish Carpathians and its foredeep is the region with a small number of data but the paleoclimatic effect is also expected over there. At the moment, the information is insufficient to be involved in thermal lithosphere and rheological modelling. New high quality Deep Sounding Data of CELEBRATION project require better, reliable geothermal data. The already completed Polish Geological Institute project of thermal modelling of North of Poland (POLONAISE'97 seismic experiment area) yielded excellent results concerning deep lithosphere developments, its temperature and heat flow structure, thickness thermal lithosphere and finally a general pattern of 1300 isotherms and "Moho" heat flow (Majorowicz, 2004). Extending investigations to the South of Poland enabled us to prepare such maps for the whole of Poland, which is strongly desirable for geological and geophysical reasons, for example magnetic issues.

In search of various different problem solutions, some new data has been gathered, concerning thermal conductivity or heat production. Values of radiogenic heat production applied to the problems are often assumed as stable for the investigation area with no spatial variation. The preparation of a radiogenic heat production map for separate stratigraphic units, and, in result, the obtainment of the total value for sedimentary cover could be very helpful in miscellaneous problems. Confirming its share in terrestrial heat flow will give an additional argument to answer for mantle heat contribution.

Thermal conductivity (TC) is strongly required parameter for heat flow density determination. Even though a lot of data may have been gathered, it demonstrates a large dispersion in a broad range of values. For local scale modelling, the representative data is not sufficient, therefore it is necessary to control this parameter with laboratory measurements on rock samples. The new approach of HFD estimation features bases on synthetic TC curves which

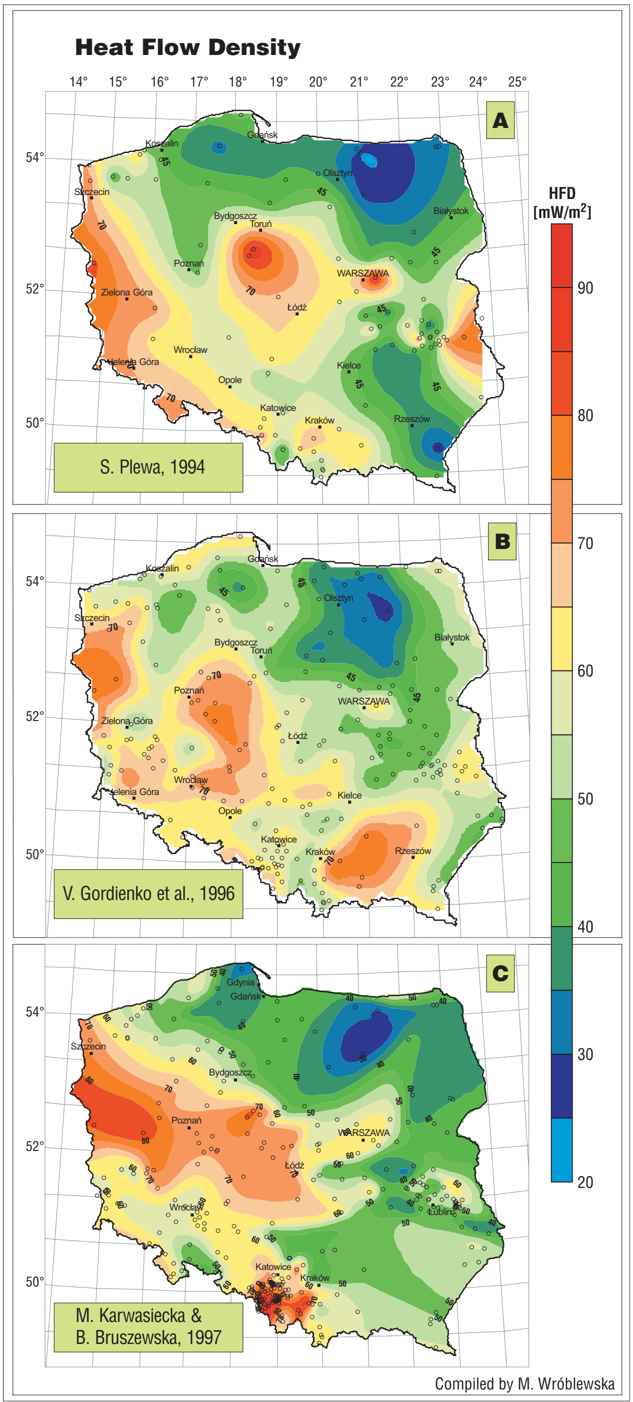

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Fig. 4. Comparison of different heat flow density maps of Poland. See Majorowicz et al. (2002) for more detailed description

Long-term paleoclimatic surface temperature seems to play an important part in the creation of the observed vertical variations in the heat flow (Szewczyk, 2005). The correction applies specifically to the borehole located in front of an ice cover. In the holes below 1000 m depth, the result is probably underestimated even to 60% (Gosnold et al., 2005). It again confirms the importance of depth interval adap-

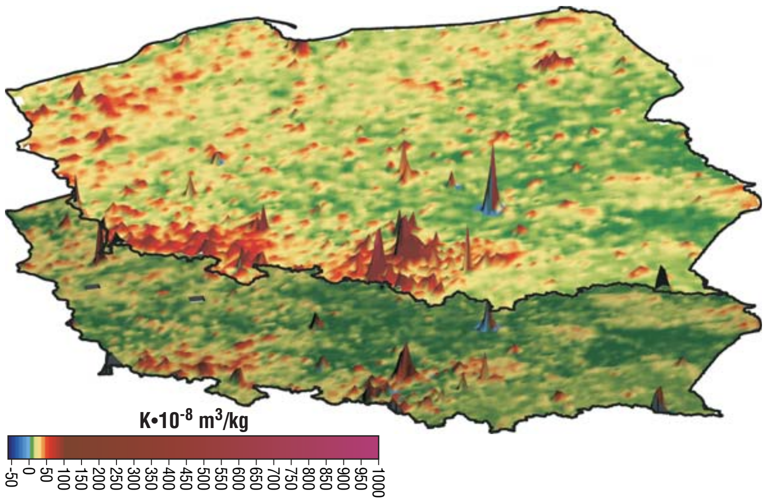

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Fig. 5. Maps of magnetic susceptibility of topsoils (upper panel) and subsoils (lower panel) in Poland. Map of magnetic susceptibility of topsoils was constructed using dataset of Magiera et al. (2002)

enables to calculate a synthetic temperature log extended to the interval that lacks thermal information (Szewczyk, 2001) and further allows for estimation of heat flow within comparative depth levels with continuous information regarding thermal conductivity changes. As the HFD is highly TC-sensitive, it seems that the new method gives better results then the method using an average TC value. This method also gives us an excellent opportunity to create a thermal conductivity map. Application of continuous log information verified with laboratory measurements helps find a pattern for TC parameters variations for every stratigraphical layer.

This method should also be applied in order to obtain temperature and temperature gradients for successive depths 1000 m up to 5000 m. Current maps of temperature (e. g., Karwasiecka, 1994) are saddled with the same error as the heat flow map described above. Additionally, an incorrect mapping system has been used, which may be rather troublesome for the user.

Cartography of petrophysical parameters

Surface mapping of petrophysical properties. The main presently ongoing research at this matter is the mapping of magnetic susceptibility of soils for the area of Poland (Fig. 5). The cornerstone of these magnetic studies is acknowledging the fact that magnetic iron minerals, whose presence in soils can easily be detected by magnetic susceptibility measurements, are components of numerous industrial dusts. If the origin of magnetic particles and a considerable part of heavy metals permeating into soils as a result of industrial emission or imission is the same, the application of magnetic susceptibility measurements for the detection of potential high risk-areas is possible. During the preparation of *Geochemical atlas of Poland* (Lis & Pasieczna, 1995), a set of more than 20,000 soil samples from the whole area of Poland was collected. They were gathered over a 5 km x 5 km grid, from two depth levels: 0–20 cm and 40–60 cm. In 2002, the *Atlas of Magnetic Susceptibility of Soils in Poland* (Magiera et al., 2002) was published. The map of susceptibilities was evaluated on the base of higher-level sample measurements only. In this way, primary anomalies were located, mostly associated with city agglomerations and mining areas, but in some cases natural sources could not be excluded. Similar measurements but for two levels of soils and additionally alluvial sediments from the delta of Vistula river (north Poland) were published by Nawrocki et al. (2000). Magnetic susceptibility mapping is a really quick and cheap method, especially with use portable tools for *in situ* measurements. It can be useful particularly in the case of periodically repetitive measurements (environmental monitoring). When some areas with strongly increased values of susceptibility (for instance huge urban agglomerations and industrial regions) are identified, we should have more detailed maps for them available on demand. Evaluation of repetitive maps for selected areas characterized by dust imission higher risk is justified. Selected areas of Poland with cement factories and iron metallurgy should be taken under consideration. Another problem which can be solved using this method is the degree of heavy metals contamination of dam lakes sediments and flood sediments on river terraces. Longitudinal maps of magnetic susceptibility of soils prepared for agricultural belts situated close to motorways would be very effective for estimation of rangeland contamination along those roads.

Another task for shallow geophysical cartography is connected with landslide hazard areas where three-dimensional electric-sounding imaging is the most promising method.

Maps of petrophysical parameters for the main lithostratigraphic horizons. The main task for this kind of cartography would be estimation of lateral variability of some physical parameters for particular lithostratigraphic horizons. Among them the most important are density, porosity, magnetic susceptibility, thermal conductivity and elasticity. Lateral variability of selected petrophysical parameters in particular horizons with the same initial lithology should reflect different degree of diagenesis, thermal maturity or mineralization. In the area of Poland maps of petrophysical parameters should be completed especially for selected wide-spread carbonate horizons of Ordovician, Devonian, Zechstein, Middle Triassic and Upper Jurassic.

Currently, the database of petrophysical properties contains a large set of laboratory and borehole geophysics measurements. Magnetic properties were measured on cores from more than 500 wells. Samples were taken mainly from crystalline basement of the East European Platform, Palaeozoic volcanic intrusions of the Holy Cross Mountains and Sudetic basalts. Collection of density measurements is much wider thanks to the oil companies activity. They were gathered for complete profiles often and for whole area of Poland (not for selected units). Unfortunately there is a lack of any precise review of those data, presenting petrophysical characteristics for particular lithostratigraphic units. After such a review the new measurements should be done in order to fill the gaps and improve the quality of old estimations.

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References

BER A. & JEZIERSKI J. 2004 — Polityka resortu środowiska w dziedzinie kartografii geologicznej na lata 2005–2020. Prz. Geol., 52: 1037–1041.

GORDIENKO V.V. & ZAVGORODNYAYA O.V. 1996 — Estimation of heat flow in Poland. Acta Geoph. Pol., 44: 173–181.

GOSNOLD W., MAJOROWICZ J., ŠAFANDA J. & SZEWCZYK J. 2005 — Has Northern Hemisphere Heat Flow Been Underestimated?, The Joint Assembly, 2005, Jt. Assem. Suppl., T43D-01.

GUTERCH A., GRAD M., KELLER G.R., POLONAISE'97, CELEBRATION2000, ALP2002, SUDETES2003 WORKING GROUPS, 2004 — Huge contrasts of the lithospheric structure revealed by new generation seismic experiments in Central Europe. Prz. Geol., 52: 753–760.

GRAD M., GUTERCH A. & POLKOWSKA-PURYS A. 2005 — Crustal structure of the Trans-European Suture Zone in central Poland — reinterpretation of LT-2, LT-4 and LT-5 seismic profiles. Geol. Quarter., 49: 243–252.

HURTER S. & HAENEL R. (ed.) 2002 — Atlas of Geothermal Resources in Europe. European Community.

KARWASIECKA M. 1994 — EUROPROBE — opracowanie cieplnego pola Ziemi na obszarze Polski. Oddz. Górnośl. Państw. Inst. Geol., CAG Państw. Inst. Geol.

KARWASIECKA M. & BRUSZEWSKA B. 1997 — Gęstość powierzchniowego strumienia cieplnego ziemi na obszarze Polski. CAG Państw. Inst. Geol.

KRÓLIKOWSKI C. & PETECKI Z. 1995 — Gravimetric Atlas of Poland. Polish Geol. Inst.

KRZYWIEC P. 1999 — Miocene tectonic evolution of the Eastern Carpathian foredeep basin (Przemyśl–Lubaczów) in light of seismic data interpretation. Pr. Państw. Inst. Geol., 168: 249–276.
KRZYWIEC P., ALEKSANDROWSKI P., RYZNER-SIUPIK B., PAPIERNIK B., SIUPIK J., MASTALERZ K., WYSOCKA A., KASIŃSKI J. 2005 — Budowa geologiczna i geneza mioceńskiego zrębu Ryszkowej Woli w rejonie Sieniawa–Rudki (E część zapadliska przedkarpackiego) — wyniki interpretacji danych sejsmiki 3D. Prz. Geol., 53: 656–663.
KRZYWIEC P., MORAWSKI W., ZIENTARA P. & JÓŹWIAK W. 2004a — Badania metodą płytkiej sejsmiki refleksyjnej wysokiej rozdzielczości w rejonie Orłowo (SW Mazury). Pr. Państw. Inst. Geol., 181: 55–72.
KRZYWIEC P., MORAWSKI.W. & TWAROGOWSKI J. 2004b — Aktualny stan wykorzystania metod geofizycznych w badaniach osadów czwartorzędowych i trzeciorzędowych. Pr. Państw. Inst. Geol., 181: 13–36.
LIS J. & PASIECZNA A. 1995 — Geochemical Atlas of Poland. Polish Geol. Inst., Warsaw.
MAJOROWICZ J. 2004 — Thermal lithosphere across the Trans-European Suture Zone in Poland. Geol. Quarter., 48: 1–14.
MAJOROWICZ, J.A., WRÓBLEWSKA M. & KRZYWIEC P. 2002 — Interpretacja i modelowanie ziemskiego strumienia cieplnego w obszarze eksperymentu sejsmicznego POLONAISE'97 — analiza krytyczna. Prz. Geol., 50: 1082–1091.
MAGIERA T., LIS J., NAWROCKI J. & STRZYSZCZ Z. 2002 — Podatność magnetyczna gleb Polski. Inst. Podstaw Inż., PAN.
MYŚLIWIEC M. 2004 —Traps for gas accumulation and the resulting zonation of the gas fields in the Miocene strata of the eastern part of the Carpathian foredeep (SE Poland). Prz. Geol., 52: 657–664.
NAWROCKI J., LIS J., GRABOWSKI J. & PASIECZNA A. 2000 — The magnetic susceptibility of soils and alluvial sediments from Gdańsk region (northern Poland). Geol. Quarter., 44: 341–345.
PLEWA S. 1994 — Rozkład parametrów geotermalnych na obszarze Polski. Wyd. CPPGSMiE PAN, Kraków.
PETECKI Z., POLECHOŃSKA O., CIEŚLA E. & WYBRANIEC S. 2003 — Magnetic Anomaly Map of Poland 1 : 500 000. Ministry of Environment and Polish Geol. Inst., Warsaw
SZEWCZYK J. 2001 — Estymacja gęstości strumienia cieplnego metodą modelowań właściwości termicznych ośrodka, Prz. Geol., 49: 1083–1088.
SZEWCZYK J. 2005 — Wpływ zmian klimatycznych na temperaturę podpowierzchniową. Prz. Geol., 53: 77–86.
ŚRODA P., CZUBA W., GRAD M., GUTERCH A. & GACZYŃSKI E., POLONAISE WORKING GROUP 2002 — Three-dimensional seismic modelling of crustal structure in the TESZ region based on POLONAISE'97 data. Tectonophysics, 360: 169–185.
SKORUPA J. 1974 — Seismic map of Poland 1 : 500,000. Polish Geol. Inst.
MŁYNARSKI S. 2002 — Seismic refraction investigations in Poland (1964–1978) and their use in continuing studies. Geol. Quarter., 46: 247–253.
WYBRANIEC S. 1999 — Transformations and Visualisation of Potential Field Data. Polish Geol. Inst. Spec. Pap., 1: 1–88.