Geophysical mapping for structural geology, prospecting and environment protection purposes

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Abstract. Applications of geophysical mapping to structural geology, prospecting and environment protection purposes are presented. Both classic and more advanced geophysical methods can be employed to enhance either regional, semi-detailed or detailed mapping of geological structures. In the case of regional and semi-detailed studies, gravity and magnetotelluric methods are supplementary to seismic, especially where significant screening and attenuating of seismic waves occur. Detailed investigations of environmental protection issues might include a wide range of geophysical methods, but in the case of investigation of groundwater pollution usually resistivity methods are applied. Examples of geophysical works performed by the PBG Geophysical Exploration Company illustrate these applications.

Key words: *geophysical mapping, structural recognition, geophysical prospecting, soil and groundwater pollution detecting and monitoring*

The use of geophysical methods to solve tasks of structural geology dates back almost to the beginning of the geology as science. Usually it is assumed (e.g., Telford et al., 1990) that the beginning of geophysics is marked by Newton and Gilbert works at the dawn of the modern era and therefore the gravity and magnetic methods are the eldest — the "classic" ones. Seismic methods, which are usually acknowledged as the best tool for mapping and imaging of geological method, were developed during the twentieth century, as were the geoelectric and radioactivity methods, etc.

It is difficult to characterise the whole scope of geophysical investigations because dozens of measurement techniques are applied to surface and borehole studies (Telford et al., 1990) and there are also airborne and land geophysical methods. This applies as well to structural and prospecting issues as to environmental protection studies (Vogelsang, 1995).

In general, working principles of geophysical techniques are based on measurements of physical parameters of geological medium (or actually changes in these parameters). These studies provide us with information regarding nature and extent of geological structures and tectonics. Well logging techniques provide us with valuable information in boreholes, decreasing the need of expensive drill core sampling (usually only 10% of the well total depth is sampled now). Integrated surface geophysical investigations (e.g., seismic and gravity and/or magnetotellurics, together with well logging) allow us to obtain a structural-parametric model of the geological medium, verified by borehole information. So, geophysical investigations and their results belong to principal tools utilised by geologists.

Though the term "geophysical mapping" is not so widely applied, there is no doubt that geophysical investigations were used in geophysical mapping for many decades worldwide, in Europe and in Poland.

Let us consider applied research priorities of the Framework Programmes of European Commission (CORDIS website — www.cordis.lu). There are no traces of "geophysical mapping" term in the relevant work programmes but geophysics is present in the projects supported by EC, for example, among issues on structural recognition of geothermal systems, characterization of geological storages and, last but not the least, characterization and monitoring of geo-hazards to sediment-groundwater-soil systems.

In Poland, a long-term policy of the Ministry of Environment on geological mapping (Ber & Jezierski 2004) includes a priority on establishing of (a digital & GIS) Integrated System of Geological Mapping (ISGM — referring to all geological structures, structural surfaces and related geoscience information). This includes a component of geophysical mapping as one of the subsystems.

We can conclude that most of geophysical studies conducted in Poland by the PBG during the previous decades have actually resulted in geophysical mapping, so we can propose a great deal of information to be included into the Integrated System of Geological Mapping.

Geophysical data resources

The territory of Poland is covered by basic regional, semi-detailed (mostly) and detailed ground geophysical surveys, like seismic, gravity and magnetics. Both gravity and magnetic surveys include over a million of stations. Hundreds of thousands of geoelectric (resistivity) measurements were carried out. Well logging measurements have been conducted in hundreds of wells as well as laboratory analyses on millions of drill core samples. A great deal of these geophysical surveys and studies was completed by the PBG Geophysical Exploration Company. Hundreds of projects involving each of the above methods were completed, for various purposes. Databases in a digital form include most of that information, easily accessible for producing geophysical maps. Surface data collected in the 1970s and earlier require converting from the "Borowa Góra" co-ordinate system to any other, currently used co-ordinate system (and this is either time-consuming or inaccurate).

A range of geophysical data applications

The following application examples of geophysical surveys conducted by the PBG for various purposes can be mentioned:

❑ detecting heavy metal traces in soil air,

❑ detecting voids and caverns in post-industrial areas of the Upper Silesia,

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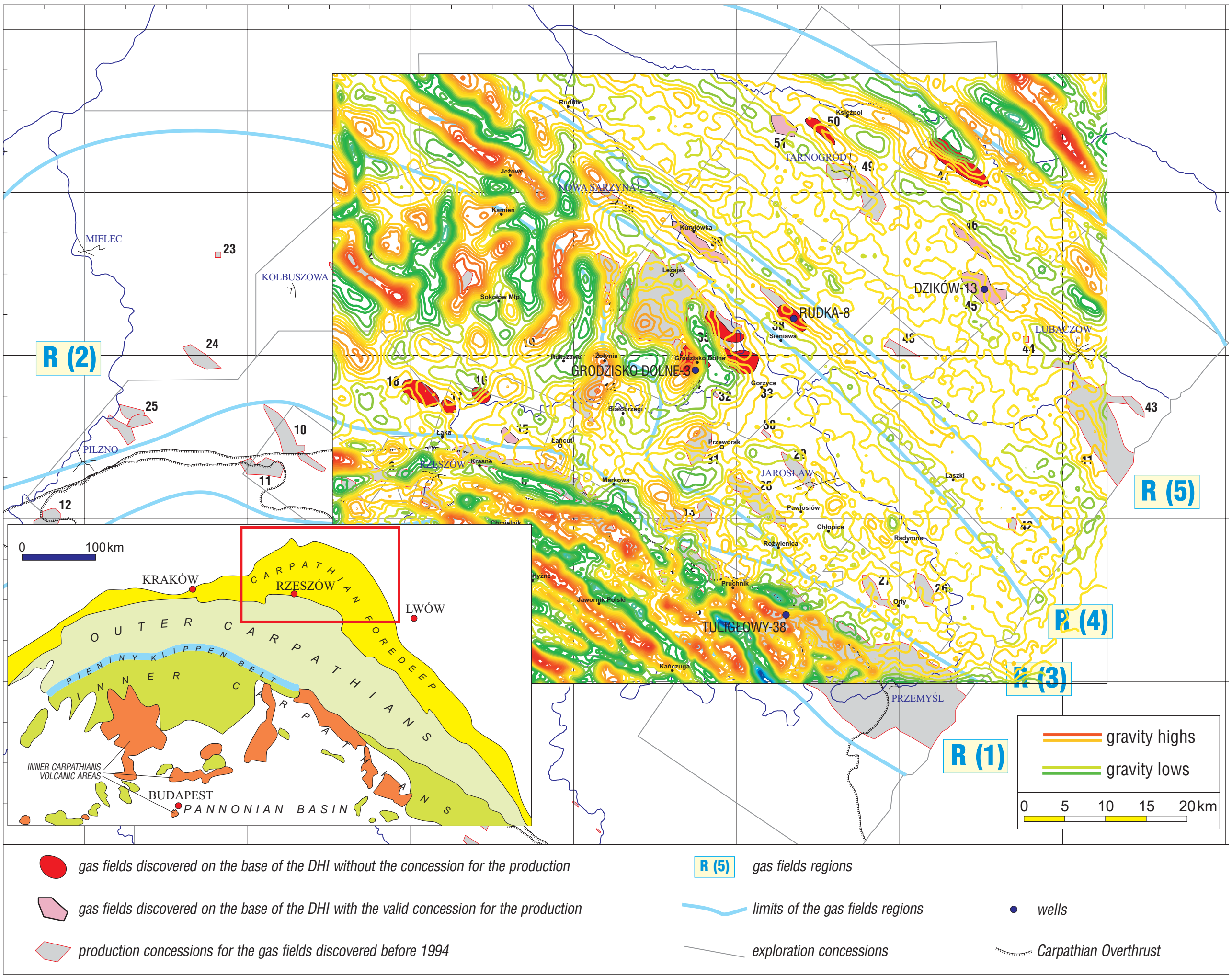

Fig. 1. Map of gravity residual anomalies superimposed on the map of hydrocarbon deposits and in the eastern part of the Polish Carpathian Foredeep (after Myśliwiec, 2004)

❏ evaluation of technical state of flood banks,

❏ prospecting for drinking water,

❏ monitoring of contamination around flotation reservoirs,

❏ lignite prospecting,

❏ geophysical surveys for pre-design studies on localization of nuclear power stations (8 projects in the 1980s),

❏ salt dome structural recognition,

❏ geophysical surveys and studies regarding hydrocarbon prospecting in Poland,

❏ recognition of deep basement of the Carpathians with magnetotelluric method,

❏ aeromagnetic surveys in the Carpathians and the Sudetes, etc.

It is clear that utilization of archive and new, more detailed geophysical data significantly supports solving various tasks of geological cartography. For example, a wide range of recently developed geophysical methods (DC resistivity, electromagnetic, microgravity and micromagnetic methods, etc.) can be applied in environmental cartography (Vogelsang, 1995).

Examples of application of geophysical mapping

Gravity surveys provided basic information for recognition of regional geological structures of Poland. A good example of application of gravimetry to geological mapping is recognition of the Miocene basement features, which differ significantly in physical parameters (velocity or density), especially if at the top of the basement early Paleozoic to Precambrian formations appear or evaporates are present (Karnkowski, 1993) below Miocene clastic formations. Generally, gravity residual anomalies (transforms) attributed to a depth range of (sub)-Miocene basement and overlying Miocene formations are an excellent mapping tool to trace anticlinal and synclinal structures within the top of basement (Fig. 1), supporting seismic mapping where coverage of seismic surveys is incomplete or seismic data are of insufficient quality (e.g., Szczypa & Oniszk, 2001).

Residual anomalies reflect the depth range of the roof of Miocene basement (0.5–2.5 km). Residual anomaly highs (yellow, orange and red) reflect elevated structures within the roof of Miocene basement (Wójcicki, 2003) and synclinal structures are reflected by residual anomaly lows (green).

Another example is also related to structural features but in a more detailed scale, on mapping of features within the top of Meso-Paleozoic basement of Carpathians (Fig. 2). Seismic structural map was extrapolated, where no seismic profiles exist or seismic survey results are of poor quality, with the use of magnetotelluric data, acquired for the whole area. On the basis of geological-geophysical interpretation (magnetotelluric, seismic, gravity, well-logging and geological data and concepts) a number of known hydrocarbon structures was analyzed and then localization of perspective structures has been proposed.

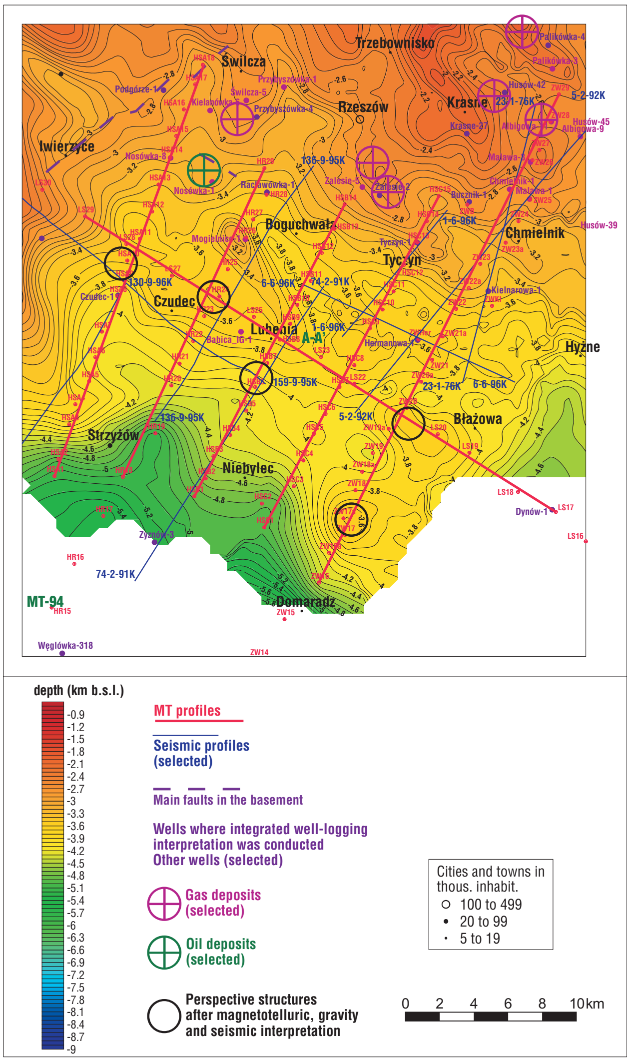

Fig. 2. The roof of the basement of the Carpathians according to seismic (northern and central part) and magnetotelluric (southern part) works, with indicated known hydrocarbon and perspective structures (after Wójcicki & Stefaniuk, 2002)

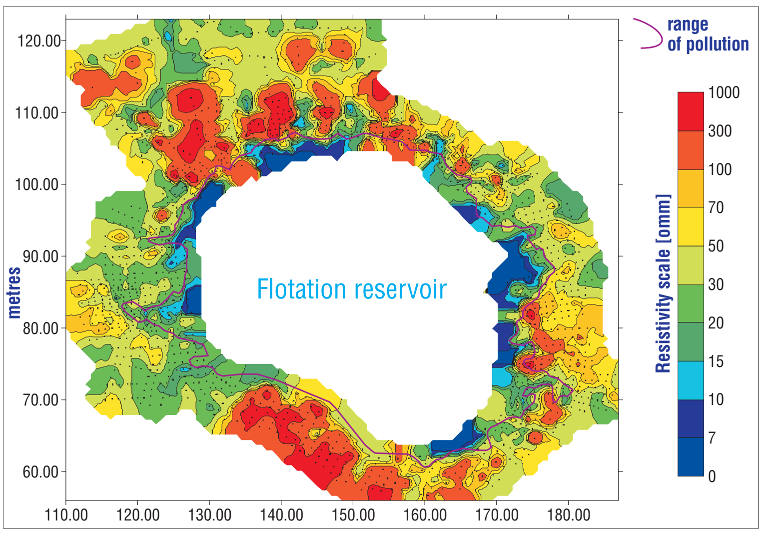

Fig. 3. Resistivity Map reflecting a range of ground water pollution around the flotation reservoir in the copper field a mining area (resistivity soundings)

The third example refers to environmental geology mapping. Resistivity survey was employed to perform groundwater pollution monitoring around the flotation reservoir of a copper mine. The pollutant agents in this case are heavy metals. Polluted areas are marked out as low resistivity zones around the reservoir (Fig. 3). So, changes of the extent of low-resistivity zones around the reservoir are attributed to changes of the extent of contamination.

Low resistivity (dark and light blue) zones are highly polluted and high resistivity (red/orange) are unpolluted. Whether the zones of intermediate resistivity are polluted or unpolluted it is resolved on the base of repeated measurements (monitoring of pollution changes). The works have been performed by the PBG (Farbisz, 1986, 1997) in co-operation with the AGH University of Science and Technology, Kraków for the Lubin Copper Mine.

Conclusions — geophysics within the Integrated System of Geological Mapping (ISGM)

Integration of old and new data, including data conversions, with other geoscience data, will be possible within the frames of the long-term priority task of the Polish Ministry of Environment — the ISGM. Surely, the system will be based on database components developed in the Polish Geological Institute (PGI website — pgi.gov.pl/pgi en). The project will start from elaborating a metadata component (information on all relevant geophysical data available). A geoelectric (actually DC resistivity) metadatabase, elaborated by the PBG and maintained by the PGI as a component of a geological database is an example of such information. It is proposed to enable metadata presentation both in text (catalog) and in graphic form for selected areas, defined by co-ordinates (rectangles), geological units, map sheets, survey areas, etc. Metadata attributes (GIS tables) should include relevant survey information (method, equipment, survey parameters, contractor, etc.). Then geophysical data necessary for mapping applications should be collected, merged (this include unification of co-ordinate and geodetic systems, data standards and formats where necessary) and stored in previously designed geophysical database components. Data can be either in digital form (enabling various ways of their presentations as plots, maps, sections) or raster format (selected categories of archive data, which can be eventually digized or transformed into raster formats like seismic SEG-Y/SEG-B data). It is important to include all public geoscience information into the ISGM. This applies also to a great deal of archive information produced by all Polish exploration companies using public funds.

Finally, a subsystem of geophysical mapping is proposed enabling spatial analysis of geophysical data (grids, sections, cubes, etc.) and their transforms in required scales (depending on the problem). The end users of the whole system should be research institutions, prospecting companies, local authorities and citizens.

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