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METHODOLOGY OF PERIODIC GRAVIMETRIC INVESTIGATIONS IN MONITORING GEODYNAMIC PROCESSES - SELECTED EXAMPLES

Monika ŁÓJ*, Janusz MADEJ and Sławomir PORZUCEK

AGH University of Science and Technology, Faculty of Geology, Geophysics and Environmental Protection, Department of Geophysics al. Mickiewicza 30, 30-059 Cracow, Poland
**Corresponding author's e-mail*: mloj@geol.agh.edu.pl

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ABSTRACT
This paper presents preliminary results from two geodynamic research areas; one located in the Polish segment of the Western Outer Carpathians (multidisciplinary geophysical - gravimetric and geoelectric, geodetic, geologic and morphostructural investigations) and the other being the research area of the "Dębina" salt dome in Bełchatów.
Inner and Western Outer Carpathian shows contrast tendencies characteristic of young tectonic movements. Gravity network cuts through this fragments of Polish Outer Carpathian Mountains that was most uplifted in Quaternary.
"Dębina" salt dome separates Bełchatów deposit from Szczerców deposit. Currently, the exploitation on the Bełchatów field approaches the slat dome limits and at the same time the construction of the new Szczerców strip mine has been started, which influences the dynamics of the phenomena occurring in the salt dome.
The idea behind this research project is to attempt to quantitatively interpret the results received from the gravimetric investigations i.e. to link temporal gravity changes with geodynamic processes in the earth's crust and dynamic processes on "Dębina" salt dome

KEYWORDS: gravity measurement, geodynamic processes, temporal gravity changes

The paper presents preliminary results from two geodynamic research areas; one located in the Polish segment of the Western Outer Carpathians and designed for the research project KBN 5 T12E 031 25; and the other being the research area of the "Dębina" salt dome in Bełchatów.

The goal of the research project is an attempt to quantitatively interpret the results received from gravimetric investigations i.e. to link periodic gravity changes with geodynamic processes in the Earth's crust.

Polish experience in the field of gravimetric investigations for geodesy and geodynamics purposes has been presented in papers by Zanimoskiy et al. (2000) and Ząbek and Pachuta (2000).

The monitoring of the Earth's gravitational field changes in Poland has been conducted since late 1970s by the Institute of Geodesy and Geodetic Astronomy of the Warsaw University of Technology. The registered variations of this field in the contact area of the Podhale Flysch and the Magura Nappe reach the value of 100 μGal. In the Sudetes, in the Śnieżnik Massif, a correlation was established between the vertical movements of rock complex and gravitational variations. Therefore, there is solid ground to presume that there exists a direct link between the observed gravitational changes and the course of present geodynamic processes occurring in the Earth's crust. It is important to emphasize, however, that the accuracy of present gravimetric measurements exceeds the anticipated values of gravitational changes in active geodynamic areas.

In addition to geodetic measurements, which have been performed since 1967 at the Polish first geodynamic research area near Czorsztyn, K. Czarnecka applied also geophysical investigations there that included seismic and geoelectric resisitivity methods (Czarnecka, 1975, 1986).

Gravimetric investigations on this research area, however, were not performed until 1978 (Ząbek et al., 1993). Geodetic and geophysical investigations have been performed at other Polish geodynamic research areas; they, however, concentrate on investigating tectonic movements in the areas of mining exploitation. The results from these investigations allowed a hypothetical model of the dynamics of the area of Poland to be defined (Czarnecka, 1988). It is also noteworthy to quote the experimental gravimetric investigations on the Olkusz-Wadowice geodynamic research area undertaken in the years 1976-1980 by researchers of the then Institute of Geophysics of the AGH University of Science and Technology. At present, periodic gravimetric investigations on two geodynamic research areas have been performed: in the Sudetes (Cacoń, 2000) and in the area of Wodzisław Śląski (Barlik, 1993). Displacements and

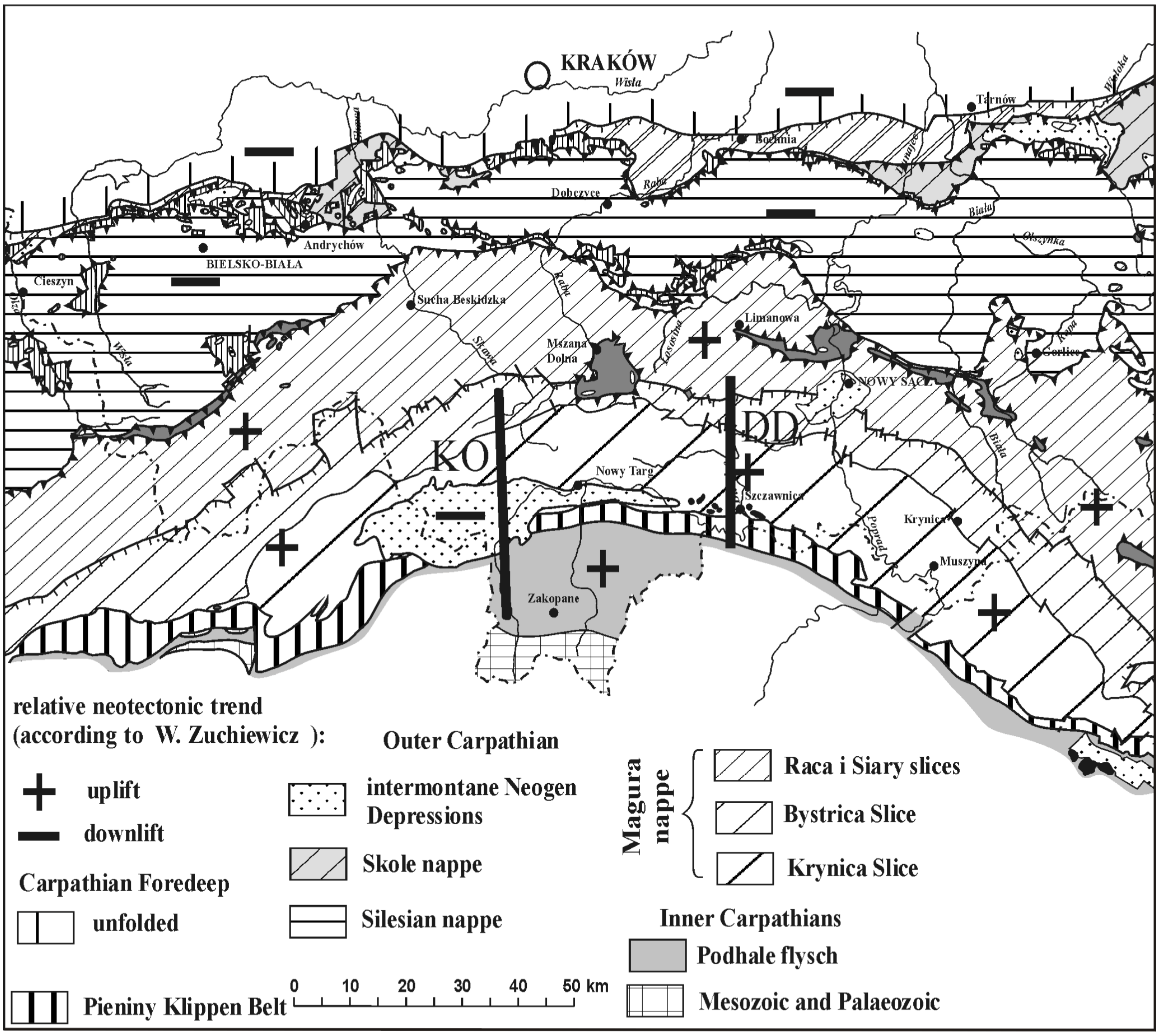

Fig. 1 Carpathian tectonic unit and geodynamic profiles location

changes in gravitational field resulting from mining exploitation were investigated on the latter one.

Attempt at combining integrated gravimetric, geologic and geomorphologic investigations have been undertaken relatively recently at a geodynamic research area in the Sudetes (Barlik and Cacoń, 1999; Cacoń and Dyjor, 1999; Cacoń, 2000). The assumptions and preliminary results unequivocally encourage to undertake such investigations in the Carpathians.

Neotectonic tendencies of the Carpathians and the Carpathian foreland have long been known in a broad outline (e.g. Żytko et al., 1989; Zuchiewicz, 1995, 1998). The long advanced hypothesis on vertical movements in the area of the Carpathians and tectonic foreland have recently been supplemented by a hypothesis on the prevailing role of horizontal movements on the shaping of neotectonic pattern, which was documented both in geodetic investigations (Hefty, 1998), and measurements of present stress in boreholes (Jarosiński, 1998).

The Carpathians are a part of the folded-nappe range of the Alpine orogen. As a young mountain range, they are the area of present tectonic movements, which result in the continuous uplift of the Carpathians. In the territory of Poland, there lies the northernmost part of the Western Carpathians including a little fragment of the Inner Carpathians and a significant fragment of the Outer Carpathians named Flysch (Fig. 1). The separating zone is the range of the Pieniny Klippen Belt, whose western segment immerses under Quaternary sediments of the Orawa Valley. The Inner Carpathians include the area of the Podhale Flysch and the Paleozoic-Mesozoic formations.

The structure of the Outer Carpathians has a typical nappe character. The following major nappes can be distinguished there: the Magura Nappe, the Silesia Nappe, the Dukla Nappe, and the Skolska Nappe, built of the formations of the Carpathian Flysch and subunits differing them (Fig 1).

The geological investigations, which were carried out in this area, enable one to determine relative tendencies of young tectonic movements, which the individual geologic elements undergo. These are presented by "+" and "–" symbols in Figure 1 (Zuchiewicz, 1984, 1995).

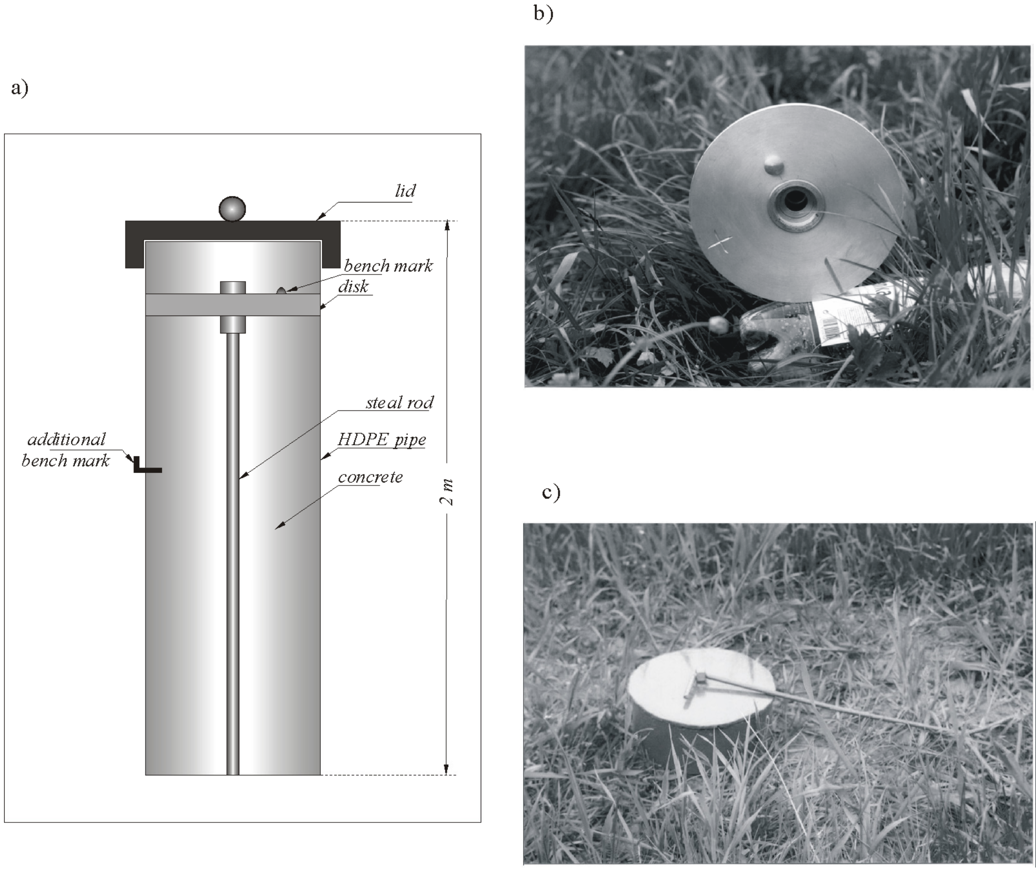

Fig. 2 Construction of geodynamic station, a) station cross – section, b) disc appearance, c) lid

Therefore, under the above-presented circumstances, the Department of Geophysics, AGH University of Science and Technology in Cracow has launched a research project, the purpose of which is to carry out a comparative analysis of the results from the area of the Polish segment of the Western Outer Carpathians which show diverse tendencies of young tectonic movements. These are going to be integrated and multidisciplinary geophysical (gravimetric and geoelectric), geodetic, geologic and morphostructural investigations.

The investigations are performed in two meridian-oriented profiles:

1. KO (The Orawa Valley: Koniówka - Czarny Dunajec – Wróblówka – Spytkowice – Wysoka)
2. DD (The Dunajec Gorge Valley between Krościenko and Zabrzeże – Łącko – Młyńczyska)

These profiles cross the geological structures of diverse age and style of tectonic deformation. They also show dissimilar neotectonic tendencies (Żytko et al., 1989; Zuchiewicz, 1995, 1998).

Profile 1 (KO) crosses the contact of the Inner Carpathians with the Outer Carpathians and shows contrastive tendencies in young (Pliocene-Quaternary) tectonic movements. The Wróblówka Depression (the southern segment of profile KO) shows late Pleistocene, and even Holocene subsidence, while the southern segment of the Magura Nappe (in northern segment of this profile) shows little ascending tendencies (Baumgart-Kotarba, 1991-92, 2000, 2001). Recently, shallow seismic profiling has been made in the area of Czarny Dunajec and Wróblówka.

Profile 2 (DD) crosses the most uplifted in the Quaternary part of the Polish Outer Carpathians.

The antecedent gorge through the Lubań-Radziejowa Mountain Range (in the north part of the designed profile DD) belongs to one of longitudinal neotectonic elevations, which manifests itself in the Quaternary tectonic uplift of the order of 150 m (Starkel, 1972; Zuchiewicz, 1984, 1991, 1998).

Observation stations were fixed every 5 km on the profiles. The location of the stations was chosen in such a way that possible influence of subsurface factors on the stability of the station eliminate was eliminated. It means that the choice fell on the areas where:

1. The ground close to the surface is very stabile (which enabled the station to contact with the ground)
2. There is no flow of the subsurface formations that could cause the dislocation of the stations.

The pattern of the observation station distribution is shown in Fig. 2. Each station was fixed 20 cm under the ground surface and attached to the stabile rock base at a depth of 2 m.

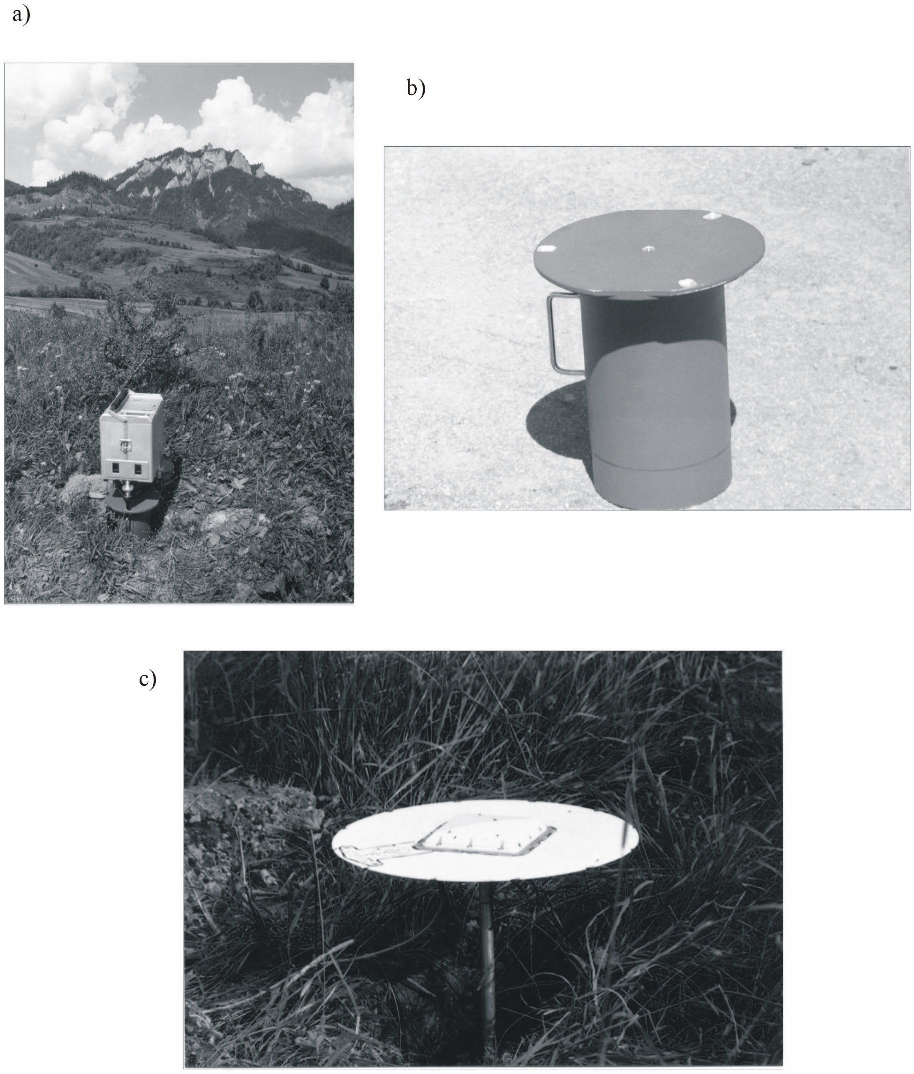

Fig. 3 Gravity and GPS measurement and using devices a) gravity meter on stand, b) stand, c) GPS aerial

The basis of the station is HDPE pipe with a diameter of 20 cm. This pipe is filled with concrete in which a steel rod, ended with flat disc with the same diameter as the diameter of the pipe, was fixed. This disc is the main part of the station (Fig. 2b). Elements used for attaching necessary measurement devices, an bench mark and the sign of north direction were placed on the disc. To protect the disc surface form impurities, the station was covered with a steel lid (Fig. 2c).

Additionally, the second bench mark was placed ca. 70 cm under the ground and screwed in the circumference of the pipe and sheltered by a plastic pipe with a lid. It can serve as a height reference in case when the bench mark on the disc was destructed.

The exact levelling of the fixed disk was of greatest importance during the stabilization of the stations, because each deviation from the vertical line can render difficulties during observation.

To make a geodetic measurement at the stabilized station using the GPS, it is necessary to mount there a suitable grip on which an antenna is placed (Fig. 3c). In case of the gravity surveys, the station is the base for a special tripod on which surface measurement devices – i.e. gravimeters – are leveled. (Fig. 3a, b).

To determine horizontal and vertical changes of location of the stations at the profiles during successive measurement series, a GPS static measurement will be taken during two twenty-four hours surveys. Moreover, the tying of profiles to the net of the permanent stations: KRAK – AGH, ASG-PL in the Silesian Province and selected stations of the POLREF net and to Polish Geodynamic Net is expected. Results of the measurements will be processed by means of the BERNESE programme, which is the world standard in the field GPS measurements applied to geodynamic purposes.

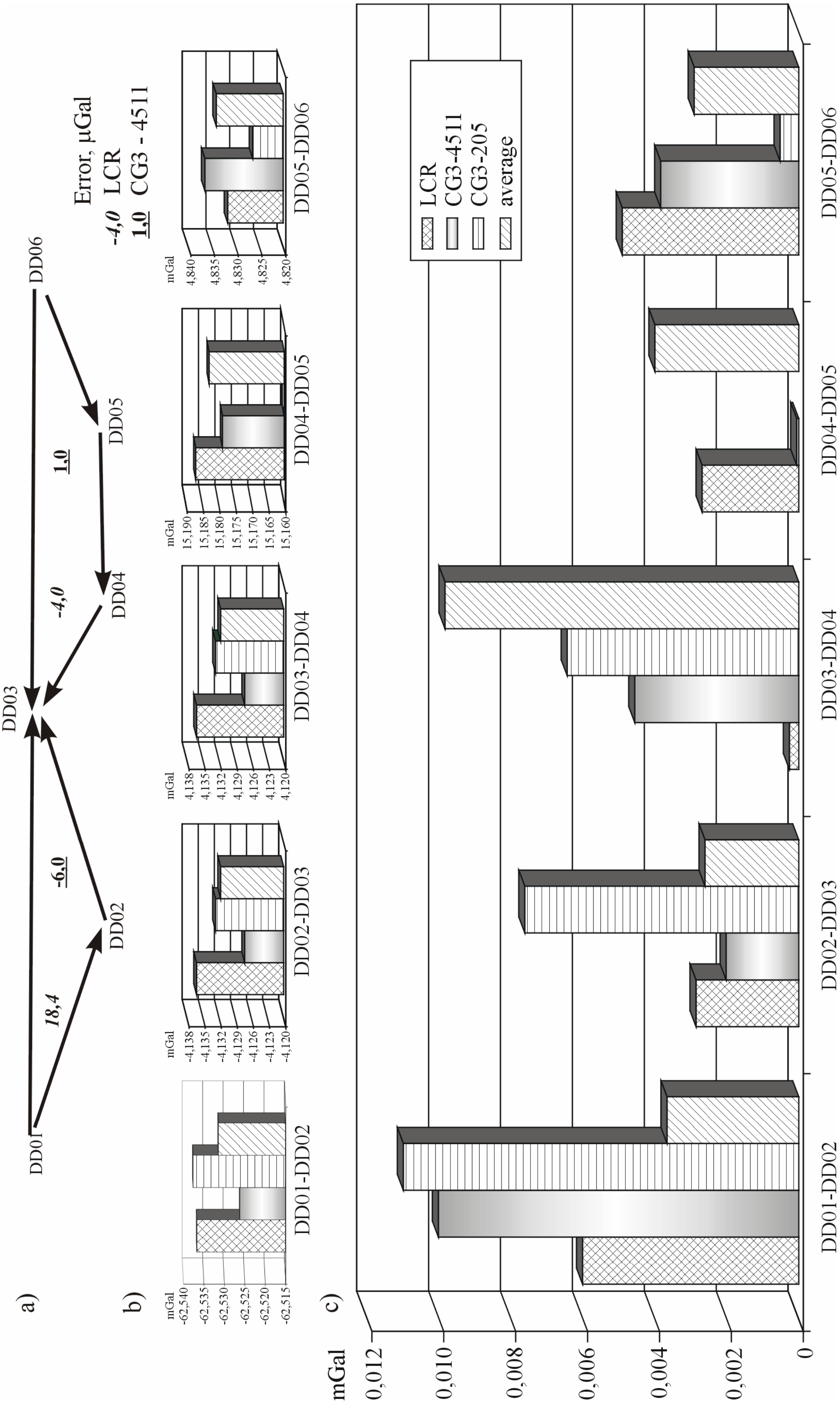

Fig. 4 First gravity measurement series on Dunajec Valley profile, a) measurement diagram, b) values of gravity, c) errors

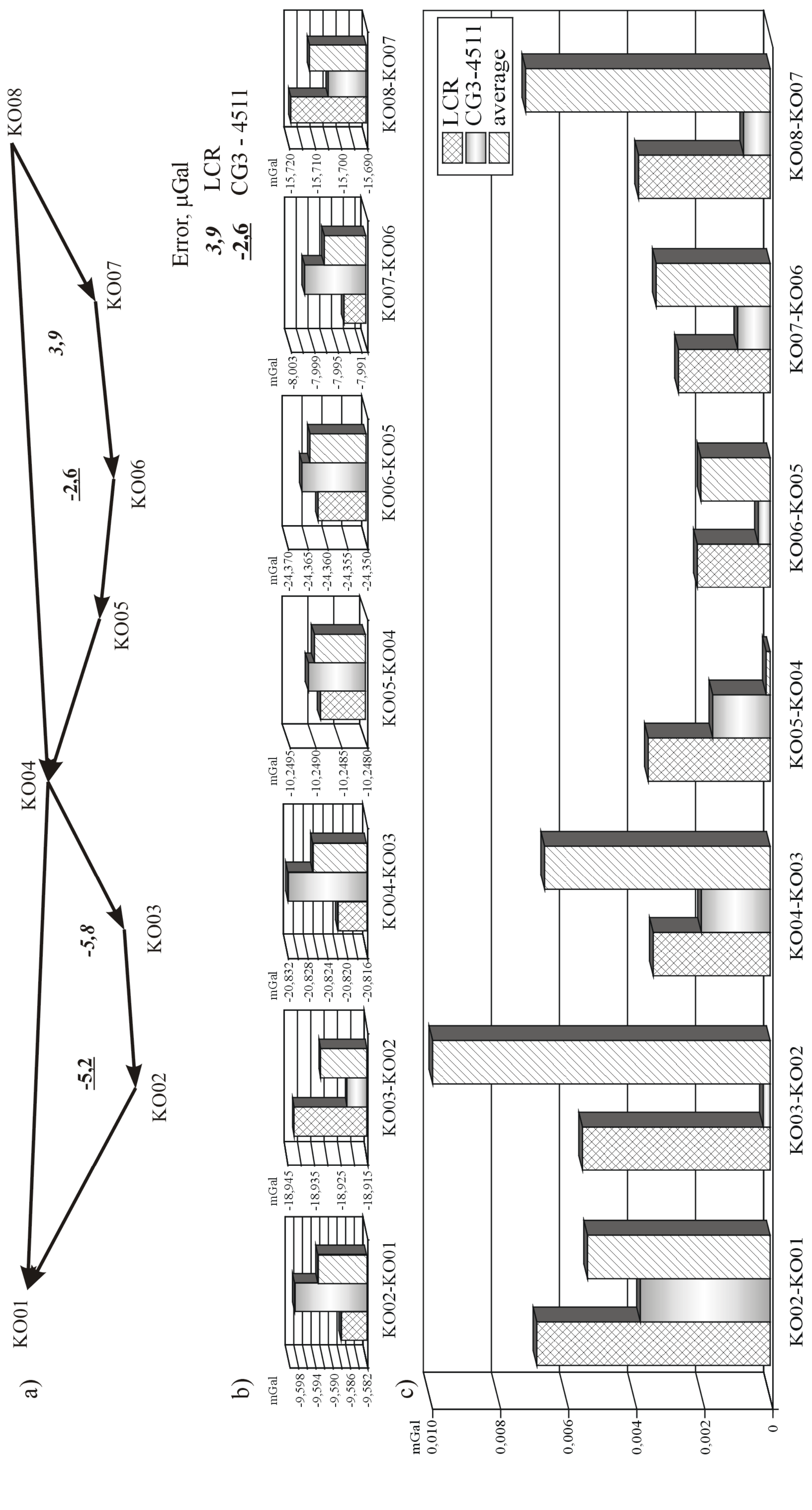

Fig. 5 First gravity measurement series on Orawska Valley profile, a) measurement diagram, b) values of gravity, c) errors

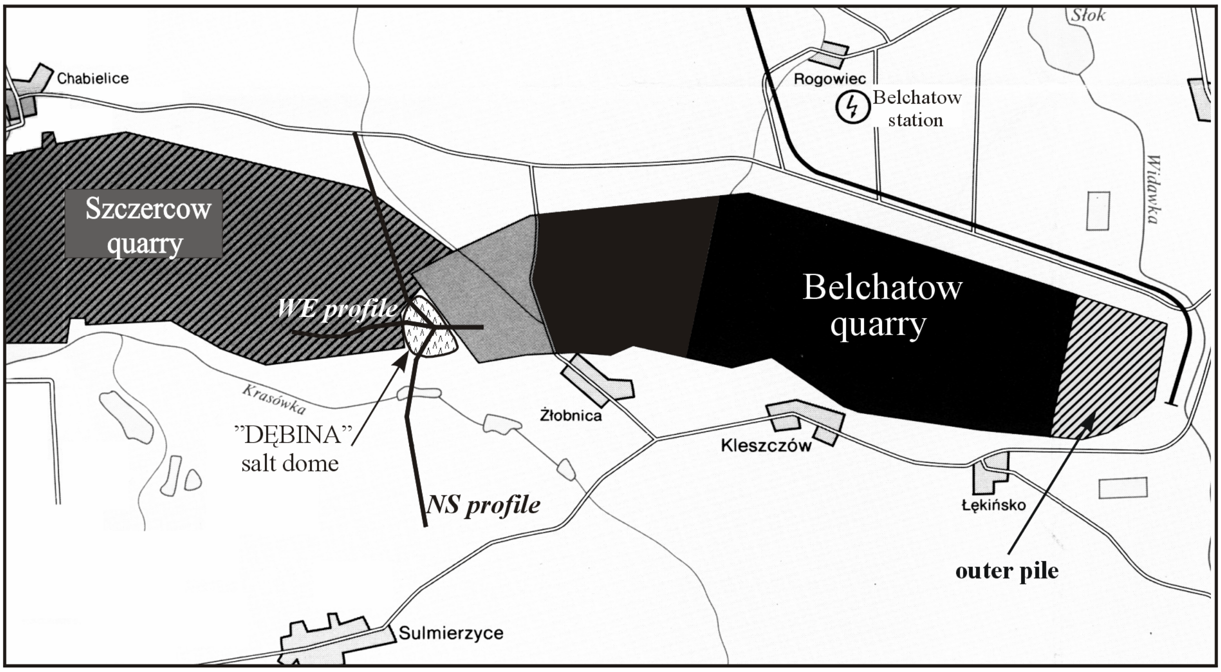

Fig. 6 Location of survey profiles on "Dębina" salt dome

The assumed accuracy will not be smaller than 3-5 mm for geodetic coordinates B and L, and 5-7 mm for height coordinate H.

Gravity surveys at each profile will be carried out at yearly intervals. The choice of such methodology results from the fact that we want to study gravity field changes in terms of the statistics, with regard to expected small values of temporal gravity field and anomalies and first of all, to their trend in time. It allows proper time intervals, adjusted to specific geodynamic conditions at the profiles, to be planned in the future.

Gravity measurements will be taken with the use of astatic quartz gravimeters with automatic data recording and seismic filter, and a metal gravimeter.

To secure great accuracy of gravity observations, the measurements are taken by the double chain method with the use of a few gravimeters. In this method the observation is made twice at each outer point of the chain and three times at the inner point. This approach enables the calculation of gravity field changes between stations on a triple increment-measurement basis, which considerably raises the precision of their calculation. It is the optimal method of the gravimeter drift elimination. Using this method it is possible to obtain gravity field differences between observation stations determined with great accuracy. Moreover, the error of the determined values is then definitely smaller as compared with results form the stations standard method. Gravity survey at each area will be tied to stations of the national gravity network. The selected station is station POGK 97 of the Polish Primary Gravity Network at Nowy Targ.

In July 2004, the first series of gravity measurements with the use of three gravimeters (two CG-3 SCINTREX gravimeters, and one LaCosteandRomberg gravimeter) was made at fixed measurement stations of profiles DD and KO.

First, the calibration of the measurement devices was made on the route Myślenice – Nowy Targ – Zakopane. The calibration was performed in such a way that the obtained results could be compared during the analysis of the gravity data form profiles DD and KO.

To check the correctness of measurements, two separate measurement meshes were closed at each profile (Fig. 4a and Fig. 5a). It was found that the error obtained using this approach did not exceed the precision of measurement devices.

Based on the gravity field values, gravity changes between the stations were calculated for each gravity meter (Fig 4b, Fig 5b), moreover, an average gravity value was calculated.

A calculation error was determined for each gravity value between the stations. The values of the errors are shown in Fig. 4c (profile DD) and Fig. 5c (profile KO). It can be seen that the error of value determination is smaller than the accuracy of the apparatus used. It may be concluded that the gravity surveys were performed with high precision and very stable measurement conditions maintained. The data can be a basis for the comparative analysis with future measurement series.

The second research area includes profiles over the "Dębina" salt dome, which separates exploitation fields of the "Bełchatów" brown coal mine – field Bełchatów and field Szczerców in the Kleszczów Trough (Fig. 6).

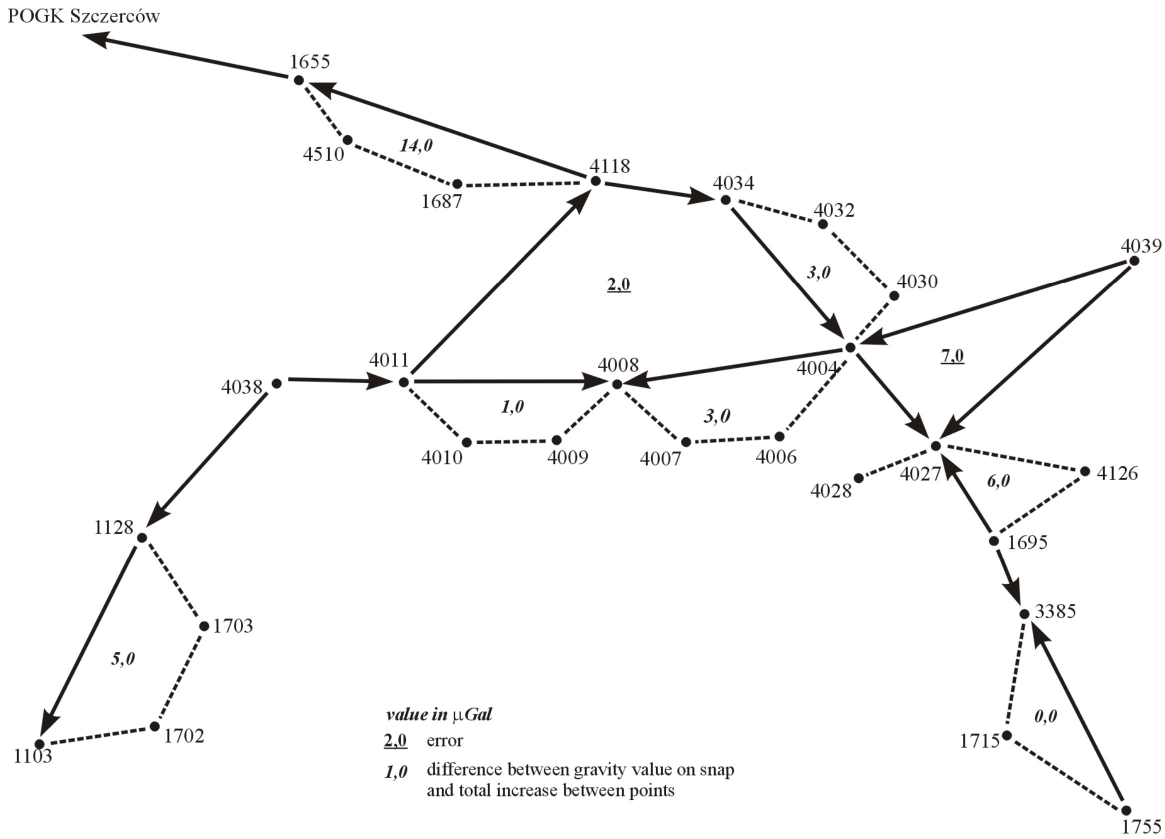

Fig. 7 Gravity measurement diagram on "Dębina" salt dome

The Kleszczów Trough is the deepest neotectonic foredeep at the Polish Lowland. The central part of the Kleszczów Trough in west is closed by the "Dębina" salt dome, which separates the Bełchatów field from the Szczerców field.

The geological structure of the region of the Bełchatów basin is formed of the Zechstein, Jurassic, Cretaceous, Tertiary and Quaternary succession.

Miocene terrigenic sediments represent the main formation of the brown coal formation in Poland. It is a significant deposit, which reaches a considerable thickness. The overburden of the deposit consists of the Tertiary and Quaternary sediments. The Mesozoic base of the deposit is built of the Jurassic and Cretaceous sediments. The Permian sediments from the deposit neighbourhood are Zechstein native salts from the "Dębina" salt dome. The dome is a local elevation of the Permian salt deposit, which was found at a depth of 2700 m.

In the horizontal plane, the salt dome resembles an irregular ellipse with the major axis of NS direction and dimensions of 500×650 m, with the eccentrically shifted culmination of the salt horizon, drilled at 170 m depth. In the vertical plane, the salt dome has the shape of a trunk rising from N, E and W at an angle of 70-85°. An anhydrite-gypsum cap of a 20-70 m thickness covers the salt body. The exterior part of the salt dome is breccia, which was deposited from crushed and mixed Jurassic and Cretaceous and Tertiary rocks of the maximum thickness of 60 m.

At present, the exploitation of the Bełchatów field is approaching to the salt dome boundaries. Simultaneously the construction of the new Szczerców opencast mine began. The target depth of the Bełchatów opencast mine will amount to 280 m, so its base will be located 120 m below the salt horizon whose depth was estimated at 170 m. A considerable unloading of the rockmass as a result of deep pits excavated in the close neighbourhood of the salt dome may affect the primary balance and deformations connected with the plasticity of salt. As a result of rockmass unloading, new cracks can open and cause new directions of water migration and lixiviation of the dome (Cała et al., 2004). Tension changes and dehydration may also give rise to dislocations over the salt and around it that are mainly connected with quite spacious breccia zone surrounding the salt dome.

It is planned to conduct several series of gravity surveys connected with the advance of the exploitation front. Measurement will be oriented NS and WE (Fig. 6). The gravity observations consist in a relative measurement of the Earth's acceleration changes at a observation station. To compare values from each measurement series, measurements will be taken at permanent stations, under similar technical conditions during measurement. Second and third class geodetic stations, available at the study area, as well as bench marks of the KWB "Bełchatów" geodetic network were used as observation stations.

In August 2004, the first base gravity measurement series was made with the use of CG-3 SCINTREX gravimeter. To improve the survey, a measurement approach shown in Fig. 7 was applied. The approach consisted in taking a single measurement at each station in such a way that there was one gravity difference between the stations and for checking the accuracy of measurements using the chain method for selected observation stations.

The analysis of the differences of gravity measured between the stations and the sum of its increments between other stations and mesh closing in the chain method shows that the values of mis-closure are similar and much smaller than the accuracy of the measurement device.

The presented gravity observations from the basic measurement series at two profiles of the Carpathian research area and in the neighborhood of the "Dębina" salt dome prove that the accuracy of measurements was very high. It provides a good forecast for further surveys. Both the geodynamic station construction and the applied survey methodology are significant elements that give good repetition of observations with the chain method as well as a small value of the Δg error.

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