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THE EVALUATION OF SALT DOME VERTICAL MOVEMENTS IN INOWROCŁAW DETECTED BY CLASSICAL PRECISE LEVELLING AND GPS SURVEYING TECHNIQUES

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ABSTRACT
The paper discusses a problem of salt structures recent vertical movements that are observed by geodetic surveys on the example of salt dome in Inowroclaw. Presented survey results were carried by several years with use of precise levelling and GPS survey techniques. The new surveys were involved in 2002 that are carried on established network points and benchmarks of former existed country levelling network. Comparative analysis of obtained displacement results derived by different methods is discussed as well. The effects of the analysis are conclusions providing the usefulness of GPS techniques in the presented research. Other conclusions derived from carried observation deal with features of determined vertical displacements.

KEYWORDS: levelling, GPS surveys, salt dome geodynamic, mining deformations

INTRODUCTION

The presented paper deals with several problems related to geodynamics study. Most of all it presents an example of combined surveys carried out with use of GPS and levelling observations. The discussed conclusions were evaluated by three surveying campaigns carried out on the area of Inowroclaw. This is a particular area in mining and geological aspects. Although the area is concerned as post mining (salt mining), there are still terrain surface displacements observed. The salt dome deposit is a specific geological structure with a terrain surface being affected by diapirism (uplift) and hydrogeological processes (subsidence). The affecting processes and former mining influence make a specific combination case forming the topography of this quite small area (a few square kilometres). So, the observed displace-ments by levelling observations by years were completed with support of GPS surveys. The efficiency of benchmark height changes by GPS was tested on a presented example. So, the obtained displacement results were compared with these derived by levelling surveys.

BACKGROUND INFORMATION

The deformation of the terrain surface on the area of Inowroclaw should be considered in view of several environment backgrounds:

- geology (geological processes as salt dome uplift, underground erosion, karst phenomena),
- hydrogeology (seasonal ground dewatering),
- mining influence.

The geology of the dome in Inowroclaw was discussed in numerous papers (Budryk, 1933; Poborski, 1957; Bujakowski, 1986). The main conclusions (and important for geodetic surveys) resulted from studies can be listed as follows:

- the dome structure is more than 5 km deep (Fig. 1),
- it is covered by cap rock strata,
- the layer of cap rocks is partitioned horizontally in two parts: eastern with gypsum-clay cap rock and western part gypsum cap rocks,
- the effect of this partition differs in hydrogeological conditions. The permeable hydraulically rocks are located in the western part of the study area. Deep water migration and dissolution ability of the gypsum cap rocks is the main reason for erosion process and karst phenomena resulting from this sinkholes occurring on the terrain surface,
- a small hill 12 m elevated (where the city is located) is a topographic effect of the diapir process that started in the end of ice age (that makes an average value of the process rate about 1 mm/yr).

Water migration is a main mechanism forming the top surface of the dome. The role of ground water

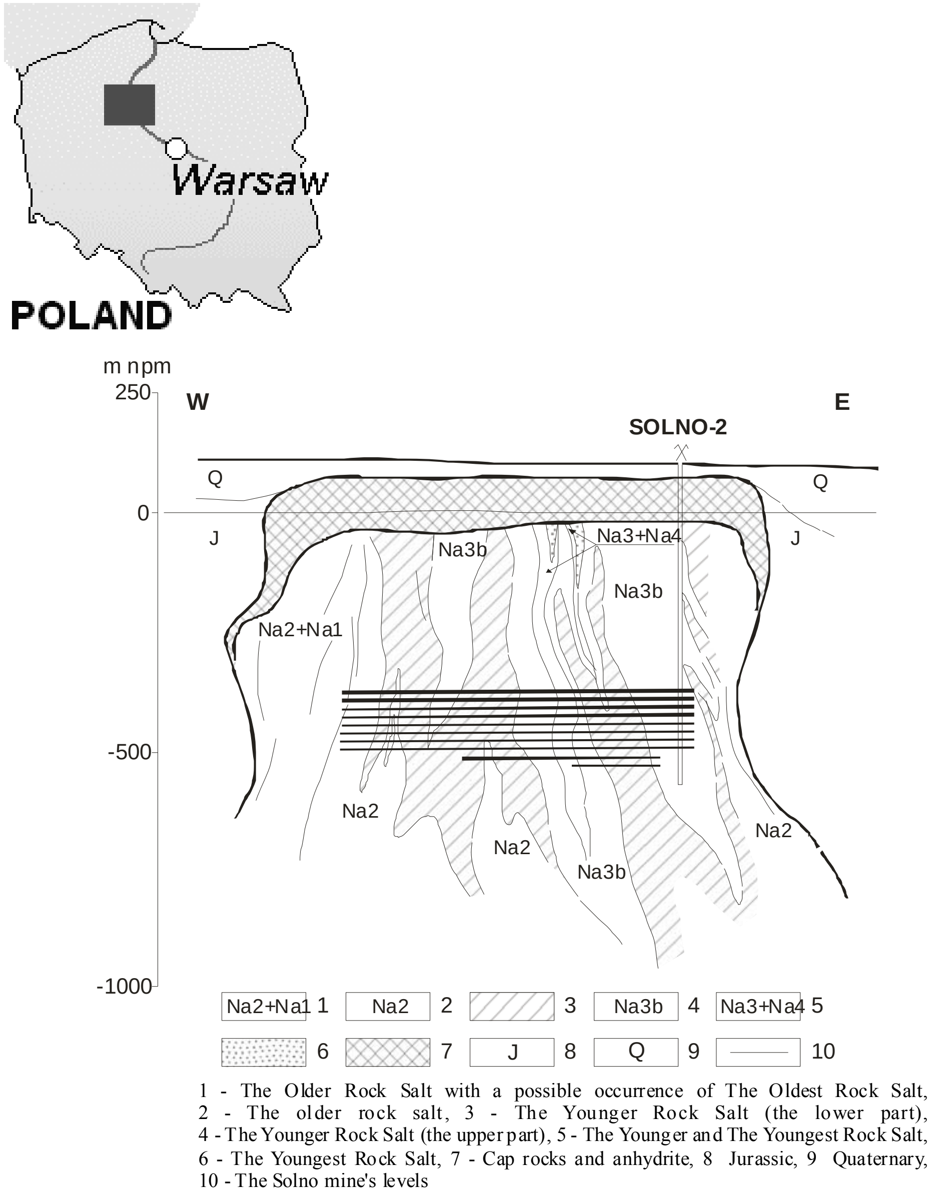

Fig. 1 The localisation of the studied area and salt dome geology in Inowroclaw (after Poborski J., 1957; Bujakowski W., 1986).

influence to the terrain surface displacements was discussed in the paper (Budryk, 1933).

The fundamental geological features of the dome are deep tectonic fractures (faults) determining both diapiric uplift movement of salt and hydrogeological conditions of the upper strata (Fig. 2). The fault zones suggested by Budryk (Budryk, 1933) are considered as areas of deep-water circulation along fracture lines (drainage areas). The main effect of that is subsurface erosion process (subrosion). This process consequently causes in distinctive features as underground caves and sinkholes on the terrain surface. The geological condition (especially ground water circulations) is the right research base to understand any displacement processes observed on the terrain surface by geodetic methods.

Upon the 1991 when the Solno Mine was closed down, the levelling surveys proved only a subsidence of terrain surface on the area of Inowrocław. This process resulting from mining was changed after the end of filling abandoned excavations process (with saline and post saturation wastes). The total volume of all mining chambers (1500) amounted to 16 mln m^3. The subsidence process induced by the Solno mine's excavation works formed bowl-shaped depressions (Fig. 3) with the maximum depth 35 cm.

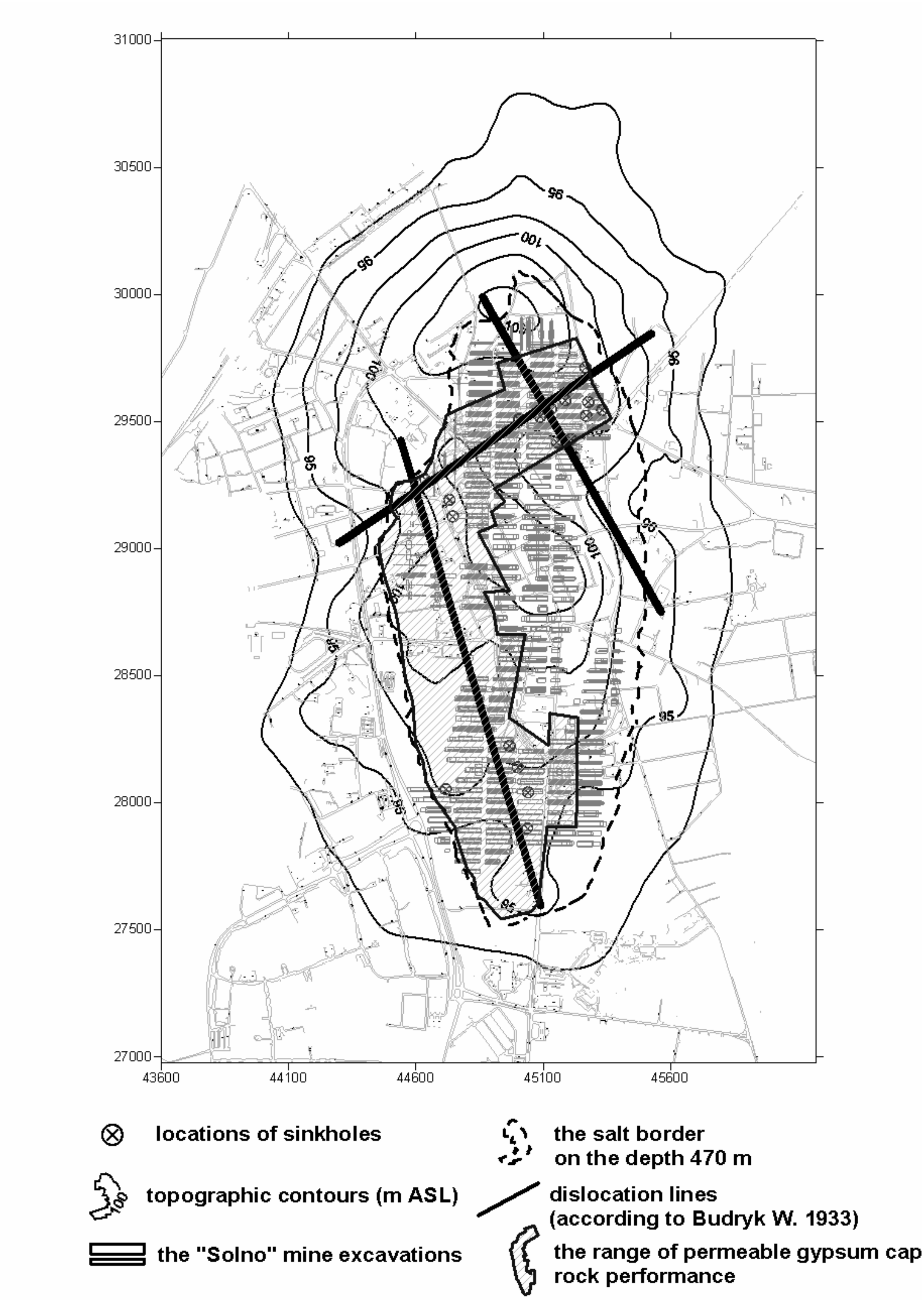

Fig. 2 A map of the most significant mining and geological features of the area of Inowroclaw salt dome.

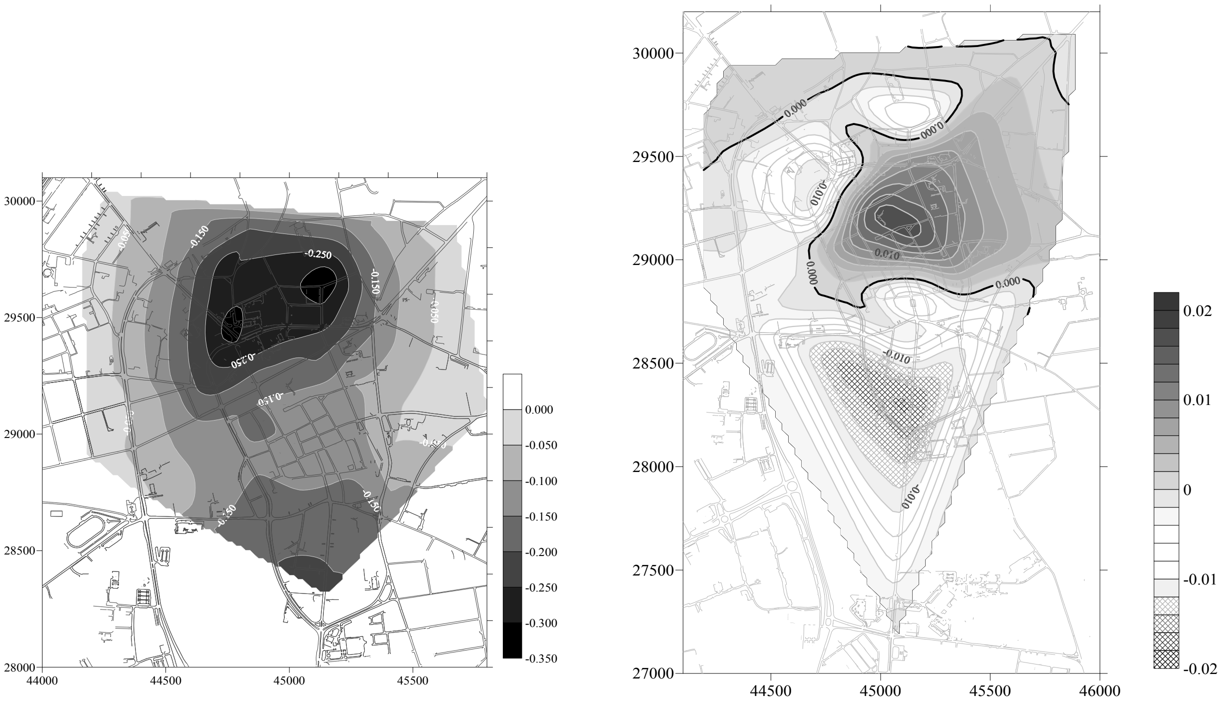

Fig. 3 Vertical displacements (in meters) determined by leveling on the area Inowrocław between 1943-1991 (left) and 1991-2005 (right).

Results of surveys in the aspect of mining were discussed in (Pielok and Szczerbowski, 2003; Szczerbowski, 2004; Szczerbowski, 2005).

FIELD SURVEYS

There were tacheometric, precise levelling and GPS surveys carried for the detection of benchmark displacements (concerned farther as terrain surface displacements) in the frame of research project on the area of Inowrocław. It could evaluate the stability of the Solno mine flooded excavations. Actually, the ground benchmarks established in 2002 and former existing wall benchmarks (only for levelling observations) make a research network with over 100 points. So, the research network involves GPS and levelling benchmarks (for vertical and horizontal displacements) and of 3rd order national levelling network benchmarks (for vertical displacements). The GPS points are located around the salt deposit at its boundaries. Every two-three points make a base for determinations of displacements: one point is located on the internal side of the deposit, the second behind its boundary. Due to technical condition resulting from built-up area limitations (insufficient horizon for GPS observations), some horizontal coordinates were determined by techeometric surveys for certain points. The levelling benchmarks were quite regularly located on the all area of the deposit.

The levelling observations carried in the years 2002, 2004, 2005, 2006 proved high accuracy (standard error of measurements amounted to 1 mm/km). GPS observation (carried in the same years as levelling measurements) provided horizontal and vertical coordinates determined with standard errors 3-5 mm. The next campaign results enabled to elaborate coordinate changes proving point's 3D displacements. The levelling and GPS observation were time-correlated (carried in the same days). GPS observations were referred to POLREF network 3403 point (established due to ETRF'89 Reference System in Poland). The levelling observations were referred to the 126 reference point (located on the area free of mining and geological processes influences, behind the salt deposit boundaries). Although GPS observations were initiated in 2002, the uniform survey condition (long 3-4 hours sessions, the same antennas, adjustment and a reference point) started in 2004. Figure 4 shows locations of network points involved in observations in mentioned above years and displacement evaluated by levelling observations of all existing benchmarks.

SURVEY DATA ANALYSIS

However, there are several areas that are considered for analysis of the measurements (still continued). The main analysis relates to interpretation of detected deformation data. The next, quite important a case study area is an analysis that examines just obtained results of GPS and levelling observations. Such an analysis is presented in the

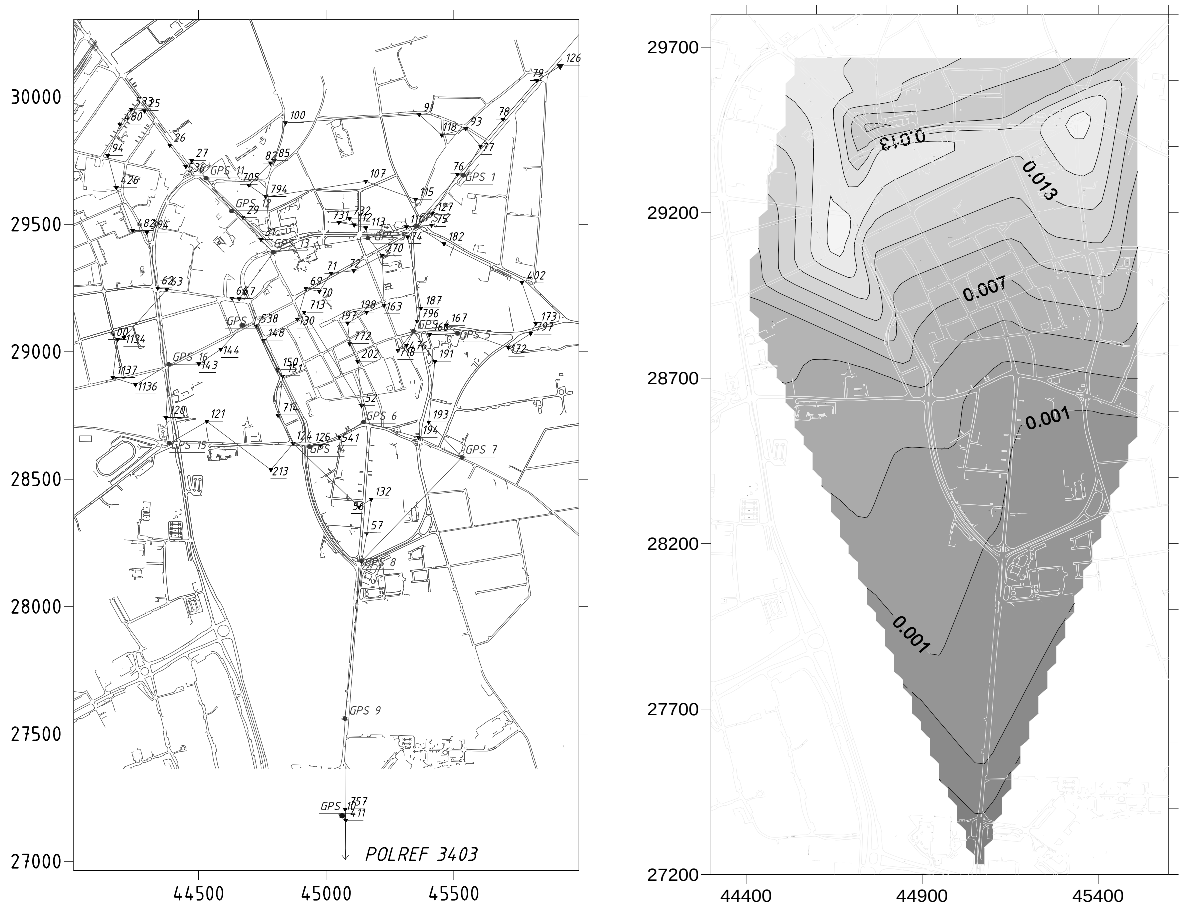

Fig. 4 Localisation of levelling national network benchmarks and project benchmarks (GPS1…) on the area of Inowrocław involved in surveys in years 2002-2006 (left) and vertical displacements on the area Inowroclaw between 2002 and 2006 (right).

paper and it deals with results of periodic height changes (by means of both GPS and levelling observations). Differences between vertical displacements obtained by GPS and levelling were studied to analyze an accuracy of GPS observations in ground displacements monitoring. Having levelling and GPS data observations it was possible to study height changes in two time periods. They survey results are characterised by graphically presented below results (Fig. 5 and Fig. 6). Due to calculated accuracy of levelling observation after adjustment the following height or height changes values are treated as “true” in opposite to GPS observations (where measured heights are evaluated with higher values of errors and in a different coordinate system).

As it was mentioned the following analysis concerns two basic time periods of the measurement results: 1) 2004-2005; 2) 2005-2006. The benchmark height changes obtained in surveys in 2004-2006 in benchmarks grounded in 2002 demonstrate a certain relationship with the vertical displacement process other benchmarks involved in levelling surveys have been carried out by decades of years (Fig. 4 and Fig. 5). The presented displacements registered after the Solno mine closing down demonstrate both uplift and subsidence. The planar distribution of height changes in years 1991-2005 demonstrates areas being subsidence and uplift basins (Fig. 3). Their location strongly corresponds to geological features (Fig. 2). Subsidence basins are placed over tectonic faults (called as well tectonic lines) and uplift basin over a central part of the deposit (centers of horizontal projections of the basin and the deposit overlain on each other). The rate of uplift process has accelerated after 2004 and in last two years only positive height changes in fact are observed on the area of Inowroclaw (Fig. 4). The next map presents the vertical displacements in Inowroclaw between 2004 and 2006, evaluated from levelling surveys involving all existing benchmarks (over 100). The center of the uplift basin was removed toward to the north and its oval geometry demonstrates longer axis that is NW-SE orientated and parallel to a tectonic line (as it is in the case of the formerly existed uplift basin). The next figures (Fig. 5) illustrate comparison between ground benchmark height changes obtained by levelling and GPS surveys in the period 2004-2006. Another presentation of survey data are maps of vertical

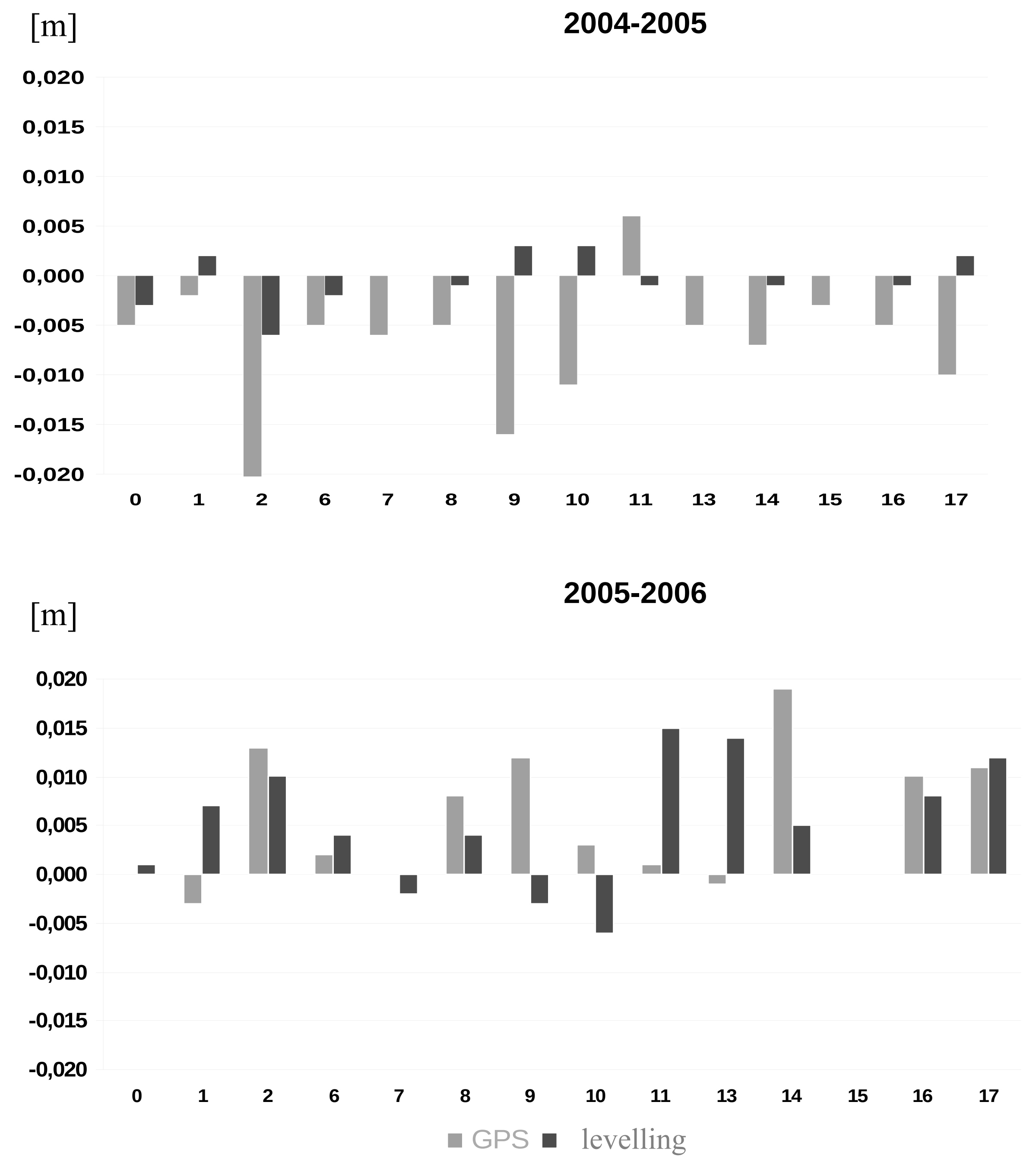

Fig. 5 Vertical displacements of GPS benchmarks on the area Inowroclaw between 2004-2005 and 2005-2006 evaluated by levelling and GPS surveys.

displacements of the benchmarks (separately for levelling and GPS surveys – Fig. 6). Displacements, showed on the Fig. 6, demonstrate slight but obvious differences in general view between interpolated levelling data for all and ground only benchmarks (Fig. 4). The displacements evaluated from GPS surveys provided clear disagreement in comparison with levelling data. This disagreement is graphically presented on charts and as a map of the displacement distribution differences between GPS and levelling data (Fig. 7 and Fig. 8). The map of displacements between 2004 and 2006 demonstrate a certain regularity of the differences being in fact errors of GPS surveys (in determination of points' height). This regularity relies in dependency of points' positions: in northern part of the survey field displacements by GPS surveys are bigger than those determined by levelling, in the southern part they are adequately lower. This note is true for the changes (between concerned displacements) for the time period 2005-2006. The first period (2004-2005) demonstrates generally higher values of displacements evaluated by GPS surveys then evaluated by levelling observations. What's more the distribution of differences in

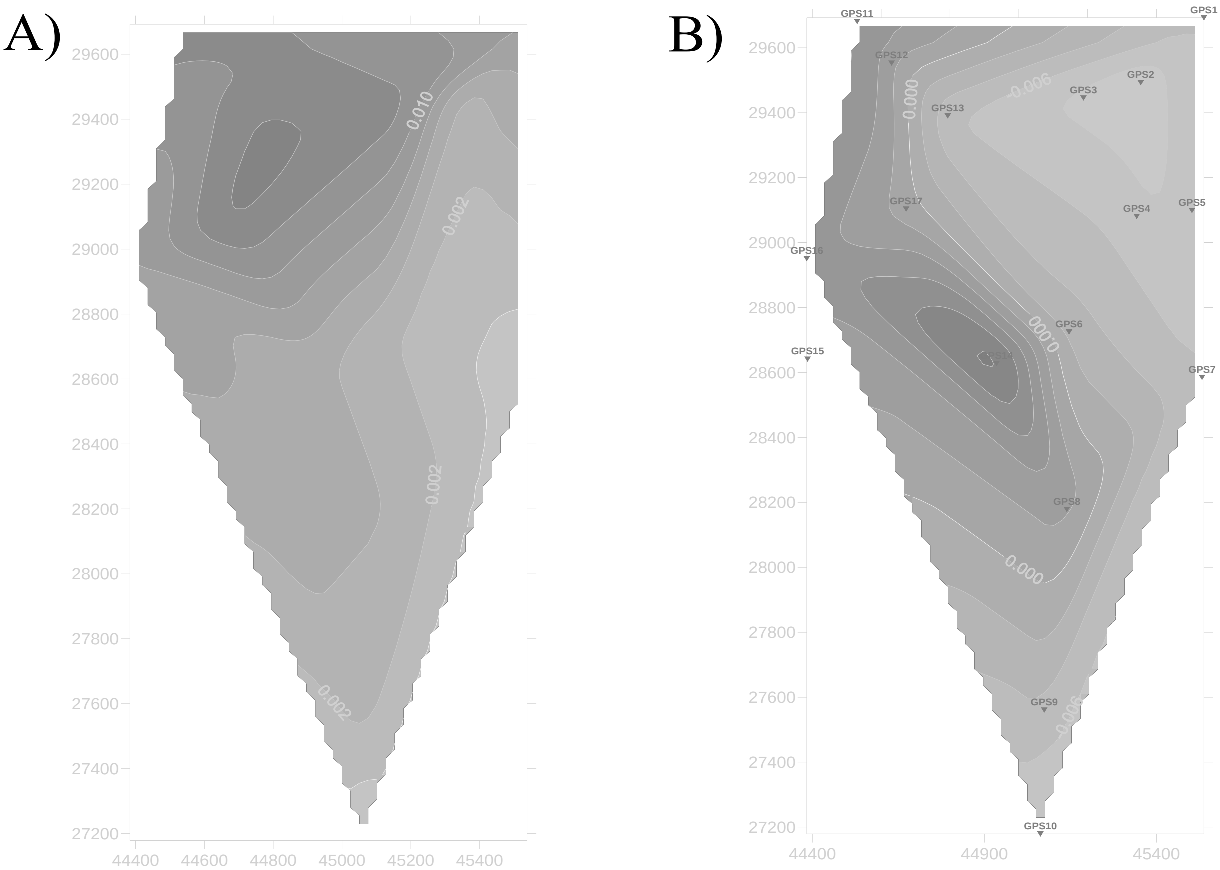

Fig. 6 Vertical displacements of ground benchmarks on the area of Inowroclaw between 2004 and 2006 by levelling (A) and GPS (B) surveys.

mentioned height changes (Fig. 7 and Fig. 8) prove that the observations carried in 2005 and 2006 demonstrate better results – much better and comparable to those obtained by levelling (the height changes data shows the normal distribution). The average value (absolute) of height changes differences in 2004-2006 was 8 mm (the normal, not absolute average value of the differences for 2005-2006 period was 0 mm).

CONCLUSIONS

Due to quite short time of the combined levelling and GPS surveys for displacement analysis, the conclusions have been obtained from this research are yet initial. They are as follows:

1. The survey results prove displacements of the terrain surface on the area of Inowroclaw. Recently, the uplift process is observed (it is not clearly a linear process, points' height changes oscillation demonstrate a certain trend).
2. The displacement results features (its rate, a distribution of displacements etc.) demonstrate different causes of deformation process that is evaluated by geodetic methods.
3. The areas where positive height changes were detected demonstrate a relationship with tectonic lines (faults).
4. The height changes results obtained by GPS observation in many cases correspond to levelling data.
5. Due to values of observed changes, GPS measurements are auxiliary to levelling surveys. The GPS observations enable to evaluate 3D model of terrain surface displacements.

Repeated levelling measurements carried in one year period can detect height changes as the surface movement on the area on Inowroclaw. Geological processes and phenomena that are significant in understanding the environment cause the observed movement. High accuracy GPS data provide information about the displacements enabling elaboration a 3D-deformation model for the studied area (in preparation).

The study of ongoing results is like discovering and reading the nature by geodetic survey. However, the carried surveys are important in some practical aspects. Assessment of some city buildings safety is based on deformation parameters that are derived

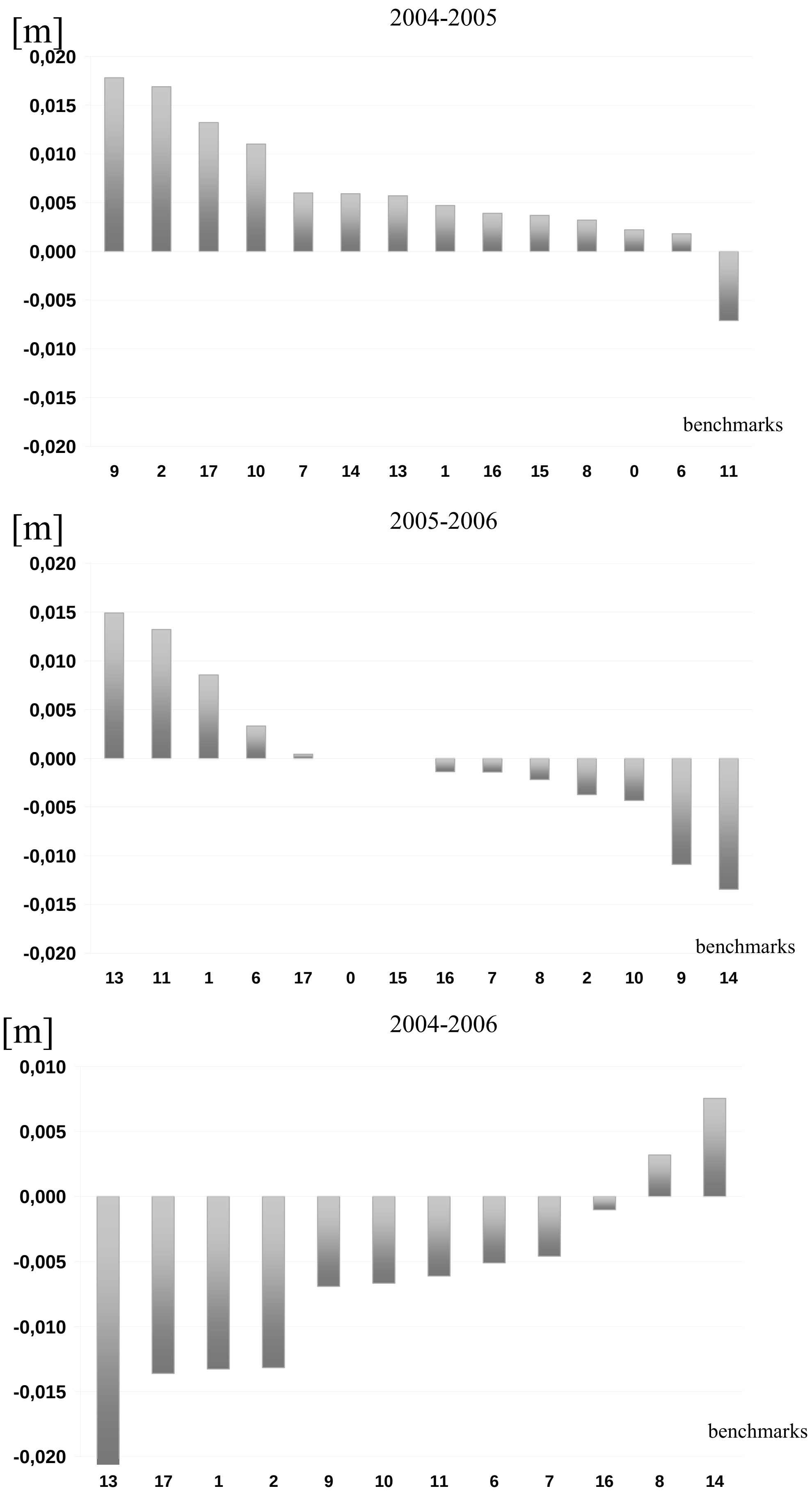

Fig. 7 The differences between height changes evaluated by levelling and GPS for benchmarks of GPS series in 2004-2005, 2005-2006 and 2004-2006.

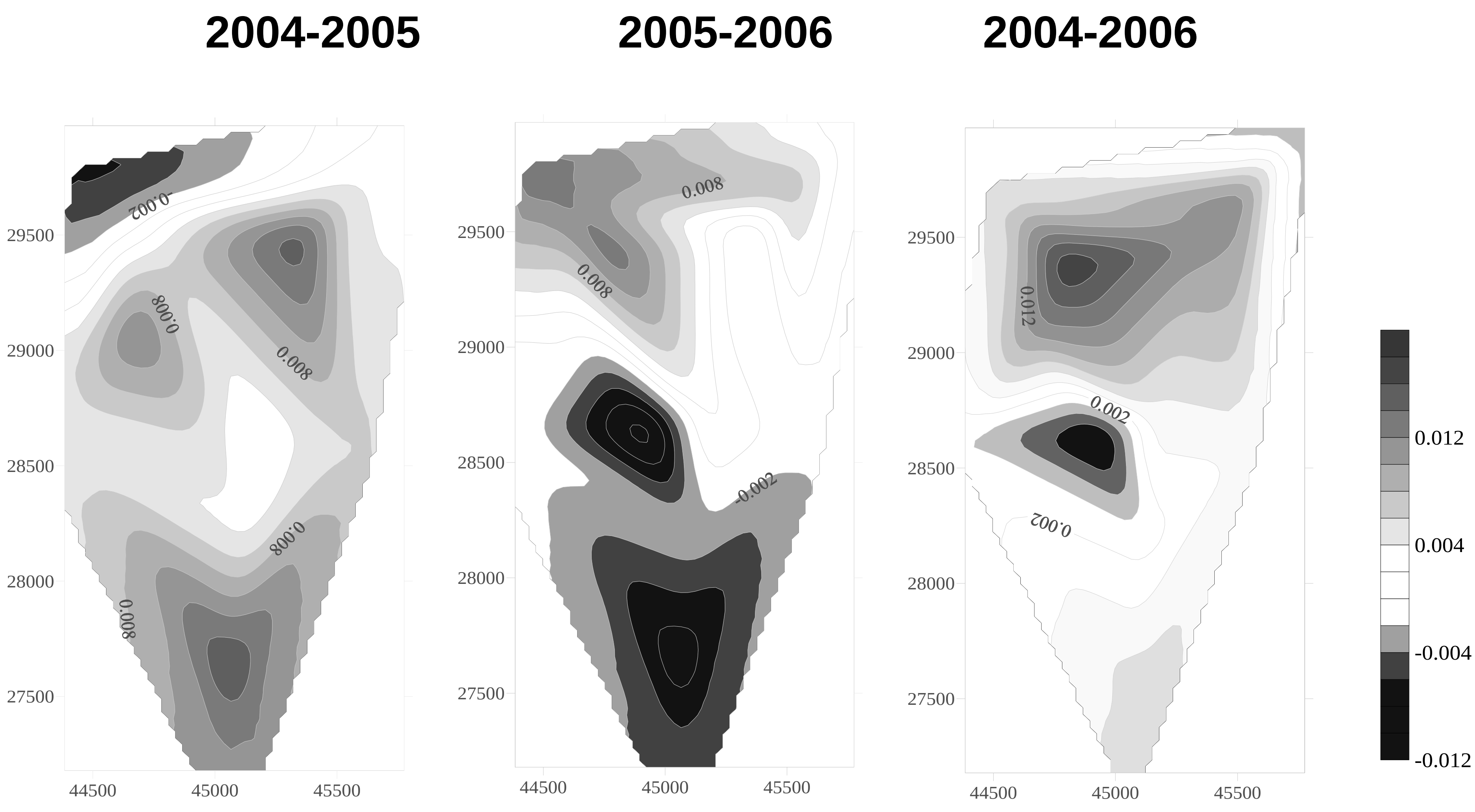

Fig. 8 The planar distribution of height changes differences evaluated by GPS and levelling surveys (in meters). Local coordinate system "Gniezno" (planar units in meters).

form geodetic surveys. The involved GPS surveys provide an argument for their value in the surveys displacement analysis in Inowroclaw located on – according to results of carried surveys –living geological structure that is a moving salt dome (due to halotectonic mechanism).

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REFERENCES

Budryk, W.: 1933, Sinkholes on the area of Inowroclaw, Mining and Metallurgy Review, No. 8. Sosnowiec, 1-14, (in Polish).

Bujakowski, W.: 1986, Cartographic elaboration of the northern part of salt deposit in Inowrocław. Quaterly Geology, Scientific Bulletins of the University of Mining and Metallurgy Kraków, Vol. 10, Issue 4, 121-130, (in Polish, English summary).

Pielok, J. and Szczerbowski, Z.: 2003, Bergmännische, bergbaurelevante und vom Bergbau unabhängige Ursachen von Deformationen der Tagesoberfläche am Beispiel der Geschichte des 130-jährigen Abbaus von Salz in Inowrocław. 3. ALTBERGBAU-Kolloquium, TU Bergakademie Freiberg, 06-08.11.2003, 409-415.

Poborski, J: 1957, The gypsum cap rock outline and development of karst phenomena in salt deposit in Inowroclaw. Archives of Mining Sciences, Katowice, Vol. II, Issue 4, 225-248, (in Polish).

Szczerbowski, Z.: 2002, Geodetic and gravimetric investigations of effects resulting from geodynamic processes occurring in affected by mining activity salt rock mass. Work Safety and Environmental Protection in Mining, Katowice, No. 5 2002, 27-28, (in Polish. English summary).

Szczerbowski, Z.: 2004: Preliminary results of geodetic measurements in the Inowrocław salt dome area, central Poland. Annales Societatis Geologorum Poloniae. Krakow, 319-324.

Szczerbowski, Z.: 2005, Initial interpretation of post-mining movements of the surface in the area of Inowrocław. Archives of Mining Sciences, Vol. 50, Issue 2, 235–249.