ANALYSIS OF POST-MINING GROUND DEFORMATIONS CAUSED BY UNDERGROUND COAL EXTRACTION IN COMPLICATED GEOLOGICAL CONDITIONS

Jan BLACHOWSKI [1)]*, Stefan CACOŃ [1, 2)] and Wojciech MILCZAREK [1)]

[1)] *Wrocław University of Technology, Institute of Mining Engineering, Teatralny 2, 50-051 Wroclaw, Poland, phone +48 71 320 68 73*
[2)] *Wroclaw University of Environmental and Life Sciences, Institute of Geodesy and Geoinformatics, Grunwaldzka 53, 53-357 Wroclaw, Poland, phone +48 71 320 56 17*
**Corresponding author's e-mail:* jan.blachowski@pwr.wroc.pl

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ABSTRACT
The study concentrates on analysis of heterogeneous rock mass deformations in the final years of underground coal extraction and during the revitalisation period after the end of mining. The research has been carried out in the Walbrzych Coal Basin where underground mining ceased at the end of the 20th Century. In the paper results of initial stages of ground deformation studies on a fragment of the Walbrzych mining grounds concerning analysis of benchmark height changes in a selected levelling line has been described. The results indicate ground subsidence in the period immediately after end of coal extraction and change to a steady uplift of the ground a few years later (2000-2008). Abnormal changes of heights in tectonic fault zones have also been observed. These could be related to heterogeneous rock mass reaction during the revitalisation period.

KEYWORDS: mining ground deformation, underground coal mines, levelling measurements

1. INTRODUCTION

Underground mining causes various types of ground deformations. When the rock mass is homogeneous, the greatest subsidence of mining grounds occurs over the exploited deposits. In such cases subsidence forecasts, e.g. using the Budryk-Knothe theory correspond relatively well to the actual ground changes observed e.g. through repeated levelling measurements of control networks (Piwowarski et al., 1995; Kwiatek, 2007). Greater problems of ground deformation arise when rock mass, subjected to mining, is characterised by complicated geology and tectonics.

In the paper, the authors focus on the problem of deformation of heterogeneous, in terms of geology and tectonics, rock mass during its revitalisation. The research object is the former Walbrzych Coal Basin where underground mining ceased at the end of the 20th Century. The problem has significant social dimension connected with redevelopment of former mining grounds. Insufficient knowledge concerning rock mass reaction to changing groundwater levels and other conditions, obstructs decision-making regarding location of new engineering and building developments. The studies undertaken have important scientific meaning as literature of the subject lacks descriptions of research experiences in this field. The significance of this problem arises also from the fact of damages to new buildings located on post-mining grounds where rock mass changes have not yet finished, especially in tectonic zones.

This paper describes the results of initial stages of research in a selected fragment of the Walbrzych Coal Basin concerning analysis of benchmark height changes in a levelling line. Repeated (obligatory) levelling measurements of this line have been realised in the final period of coal extraction (1980-2000) and in 2008. Results of analyses have shown abnormal height changes of observed points located in a tectonic fault zone. The studies use spatial analyses (GIS) based on geographical datasets developed in the course of preliminary work (Blachowski, 2008).

2. COAL MINING IN WALBRZYCH (SW POLAND)

The Walbrzych Coal Basin is located within the administrative borders of the Walbrzych District (*Poviat*) in the Dolnoslaskie Voivodeship (SW Poland). Extraction of hard coal in this area dates back to the early 16th Century. The output from mines increased gradually over the years as new methods of coal mining were introduced. After the World War II production reached its maximum during the 1950'ties (approx. 3 250 thousand tonnes) and steadily decreased since then to approx. 1 160 thousand tonnes in 1990. Between 1993 and 1998 all the mines have been closed (Piatek and Piatek, 2002). In the concluding stages of coal extraction four mining grounds existed there: "*Bialy Kamien*" for the

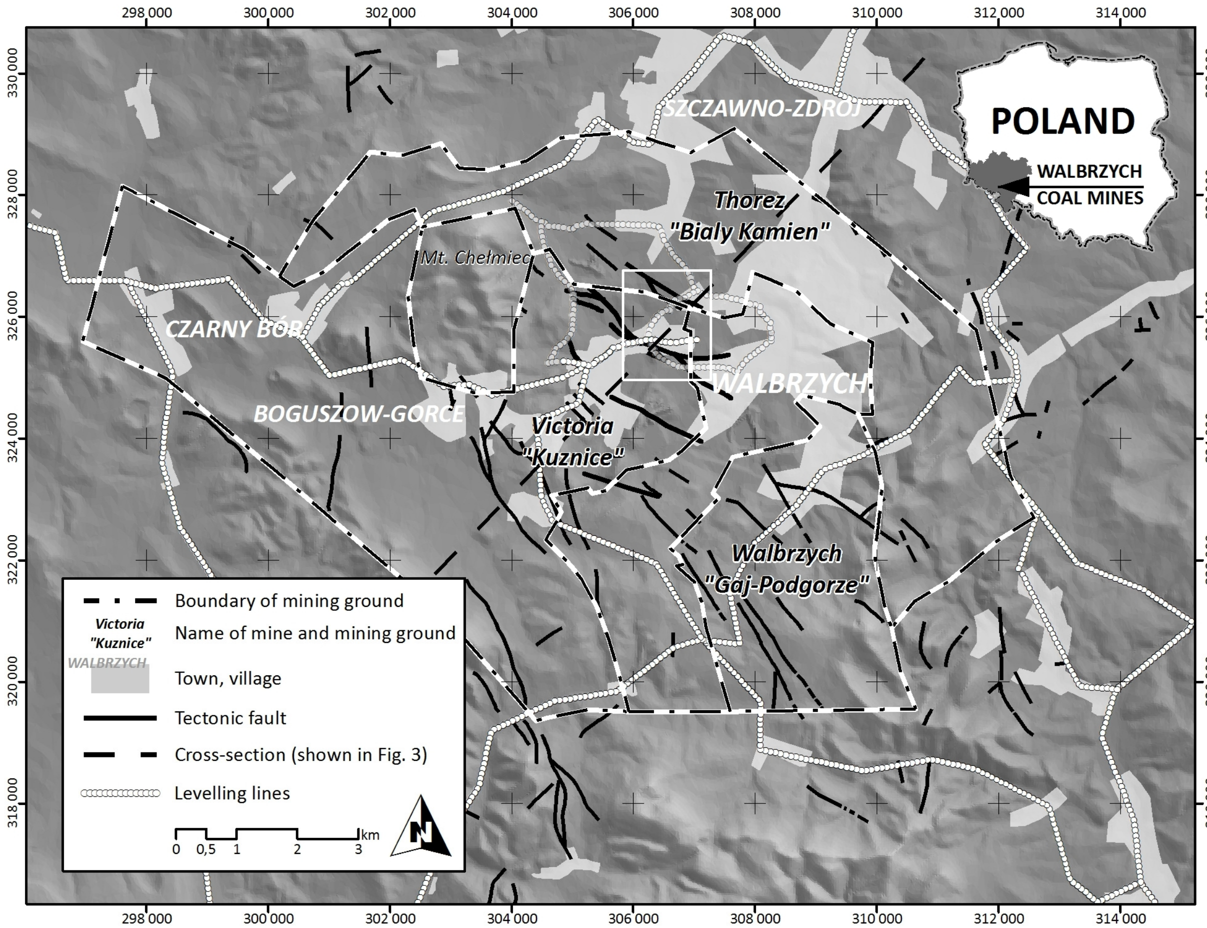

Fig. 1 Location of the former coal mines in Walbrzych (SW Poland) – the white rectangle shows study area described in this paper (Fig. 2).

"*Thorez*" mine, "*Kuznice*" for the "*Victoria*" mine and "*Gaj* and *Podgorze*" for the "*Walbrzych*" one. Location of the mining grounds has been shown in Figure 1. The decision to end coal mining has been caused by very difficult geological and mining conditions, which made the operation hazardous and unprofitable.

2.1. LOCATION OF THE RESEARCH AREA

The authors have decided to begin studies of ground deformations in the central part of the basin. It covers parts of the "*Thorez*" and "*Victoria*" coal mines (Fig. 2). The area has been selected for several reasons, i.e.: available, for analysis, results of past geodetic measurements, ground deformation forecasts made for the 1945-1990 period that indicated the greatest subsidence there (Jedrzejec et al., 2000) and the fact that coal extraction took place there during final years of mining operations (1990'ties).

2.2. GEOLOGY AND TECTONICS

Coal deposits of the Walbrzych Coal Basin are associated with the Upper Carboniferous deposits. Four coal-bearing geological complexes have been identified: *Walbrzych*, *Bialy Kamien*, *Zacler* and *Glinik* formations. Altogether 80 coal seams have been documented, among these 30 in the *Walbrzych* layers and 48 in the *Zacler* ones (Kominowski, 2000). There are two main coal basins, the larger *Sobiecin* and the smaller *Gorce* synclines separated by the *Chelmiec* magma intrusion (laccolite) (Fig. 1). The whole area is divided by numerous tectonic faults extending generally from NW towards SE but many further transformed by intrusions. Cross-section through the Walbrzych basin showing dip of coal deposits is presented in Figure 3. Dip of coal seams ranges from 30 to 60 degrees in the southern part of the *Sobiecin* syncline and 30 to even 90 degrees in the *Gorce* syncline (Kominowski, 2000).

2.3. UNDERGROUND MINING METHODS

Between World War I and World War II and after 1945 Walbrzych mines used longwall mining system with wooden roof support. Exploited voids (gobs) were fully filled. Several coal layers (panels) were mined at the same time.

During the 1970'ties Walbrzych mines used longwall and caving mining system with steel roof

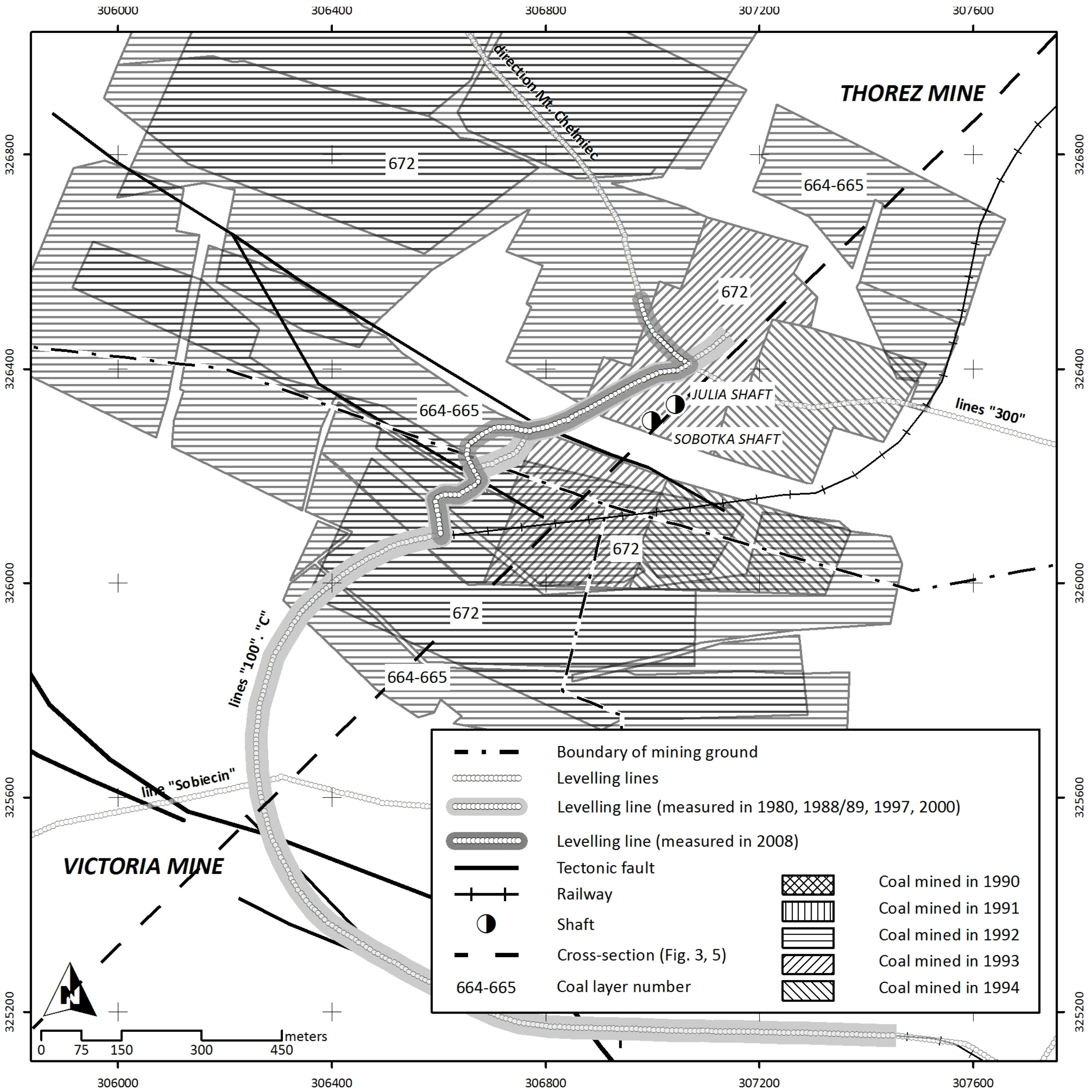

Fig. 2 The analysed part of former mining grounds in Walbrzych.

support (chocks). Inside protective pillars (e.g. for shafts) full pneumatic fill was used for gently inclined coal layers, whereas steeply inclined ones were mined with longwall system, full dry fill and wooden roof support.

After 1990, in the analysed area of the "*Thorez*" and "*Victoria*" mines, coal layers 664-665 and 672 were exploited. The following mining systems were used: longwall and caving and longwall and fill. In 1998 with the end of mining, physical liquidation of underground cavities and technical infrastructure on the surface has begun.

2.4. GEOGRAPHICAL INFORMATION SYSTEM DATABASE

For the purpose of the described and planned analyses, geographical datasets have been created containing information on the spatial location, 3D geometry of particular coal seams and tectonic faults, as well as underground excavations (e.g.: drifts, cross-cuts, adits and shafts). Additional attributive information has been associated with graphical database of coal seams including, type of mining method used and year of coal exploitation (Blachowski, 2008). Geographical information system (GIS) has been used for combined spatial and temporal analyses of levelling measurement results.

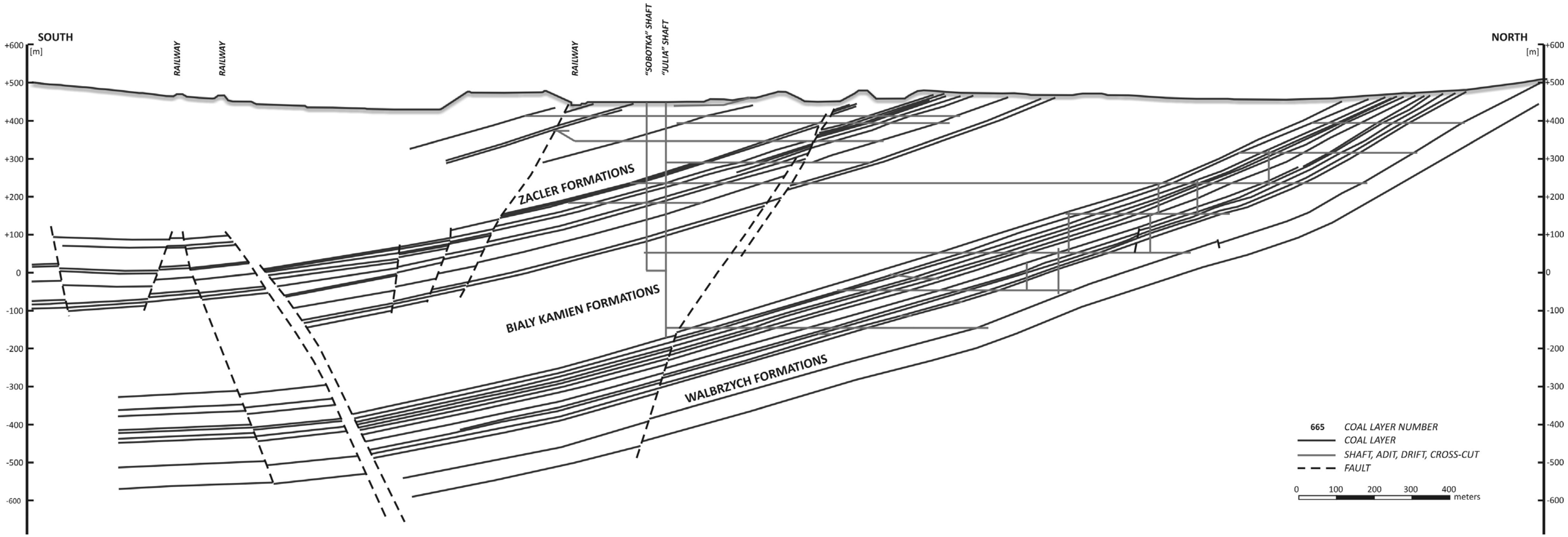

Fig. 3 Cross-section through the Walbrzych Coal Basin coal formations, faults and main underground excavations.

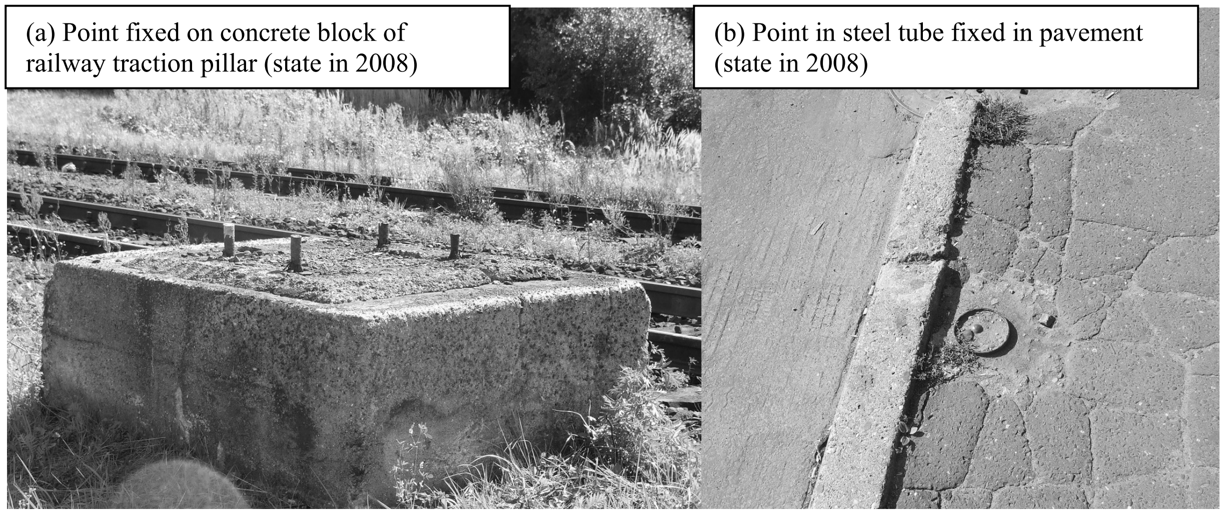

Fig. 4 Condition of the levelling line measured in 2008 (photo Milczarek, 2008)

Table 1 Benchmark heights (a.s.l.) and height differences (2000-2008).

Benchmark number	Previous height (2000) [m]	Present height (2008) [m]	Height difference [mm]
1	*2*	*3*	*4*
302	444.110	444.233	+ 123
611	444.234	444.386	+ 152
303	442.752	442.903	+ 151
104	442.020	442.168	+ 148
105	441.827	441.970	+ 143
106	441.945	442.091	+ 146
108	442.618	442.749	+ 131
109	443.171	443.310	+ 139
111	444.288	444.426	+ 138
112	445.080	445.218	+ 138
113	445.344	445.752	+ 408

3. GEODETIC MONITORING OF MINING GROUNDS

In the years after World War II coal mining grounds have been continuously surveyed. The effects of underground coal extraction on the ground have been realised with repeated levelling measurements of points (benchmarks) making up local control network. The network constituted of the following levelling lines: „*Sobiecin*", no. „*100*", no. „*300*" and „*C*", shown in Figure 2. National levelling network (2nd and 3rd class) and a network of additional benchmarks dispersed in build-up and developed parts of the city have been also used (Fig. 1).

In the analysed part, including protective pillar of the "*Julia*" shaft, geodetic surveys used 2nd class precise levelling and 3rd class geometric levelling techniques. Reference points (benchmarks) have been located in two areas, NW slope of Mt. Chełmiec and near the Czarny Bor village.

Location and marking of control benchmarks has been conditioned by the course of particular control levelling lines. The points have been fixed below ground level by means of steel tubes filled with concrete in street pavements (Fig. 4b) or with reinforced concrete blocks beyond build-up areas (Fig. 4a).

Typical accuracy of determining position of points amounted to ± 1.2 mm/km, whereas average error of height determination was ± 3.3 cm.

In late 1990'ties when surveying services of the coal mines have been disbanded control measurements of the lines were discontinued. From that moment on, practically no quantitative data on ground deformation has been collected.

3.1. ANALYSIS AND INTERPRETATION OF THE 1980-1997 LEVELLING MEASUREMENTS

The last geodetic control measurements of selected levelling lines were made in 1997 and 2000. Results have been used together with results of levelling measurements from 1980 and 1988-1989 in analyses of benchmark height changes along levelling line no. "100" (Fig. 2). The analysis covered the last 15 years of mining and time immediately after it had stopped. Results of vertical movement have been presented in (Blachowski et al., 2007; Cacon et al., 2007). The calculated subsidence amounted to –947 mm for the 1980-1989 period and –1007 mm for the 1898-1997 one. Ground deformation matched the extracted coal levels no 664-665 and 672. However for the second examined period benchmark height changes have been found to be uncharacteristic for coal extraction methods used. These changes occurred in a tectonic fault zone.

3.2. NEW LEVELLING MEASUREMENTS

In the summer of 2008 the authors carried out new levelling measurement of the line no. "100". (Fig. 2). Because of bad technical condition and destruction of large number of benchmarks in the result of modernisation of electric traction along railway only a fragment of the line could have been surveyed. Reference point (benchmark no 102) was located at the foot of Mt. *Chelmiec*. The section of the line has been measured twice with Leica DNA 03 digital level and measuring rod. Precision of these measurements corresponded to geometrical levelling of increased accuracy. Results of the newest measurement and comparison with previous elevations (2000) have been given in Table 1.

3.3. ANALYSIS AND INTERPRETATION OF 1997-2008 LEVELLING MEASUREMENTS

The results of latest measurements (2008) have been compared with the results of the 1997 and 2000 surveys. This period practically covers the time since the end of mining operations. Eleven surviving benchmarks have been analysed. The calculated benchmark heigh t changes range from +128 to +152 mm. The subsidence trend has been reversed

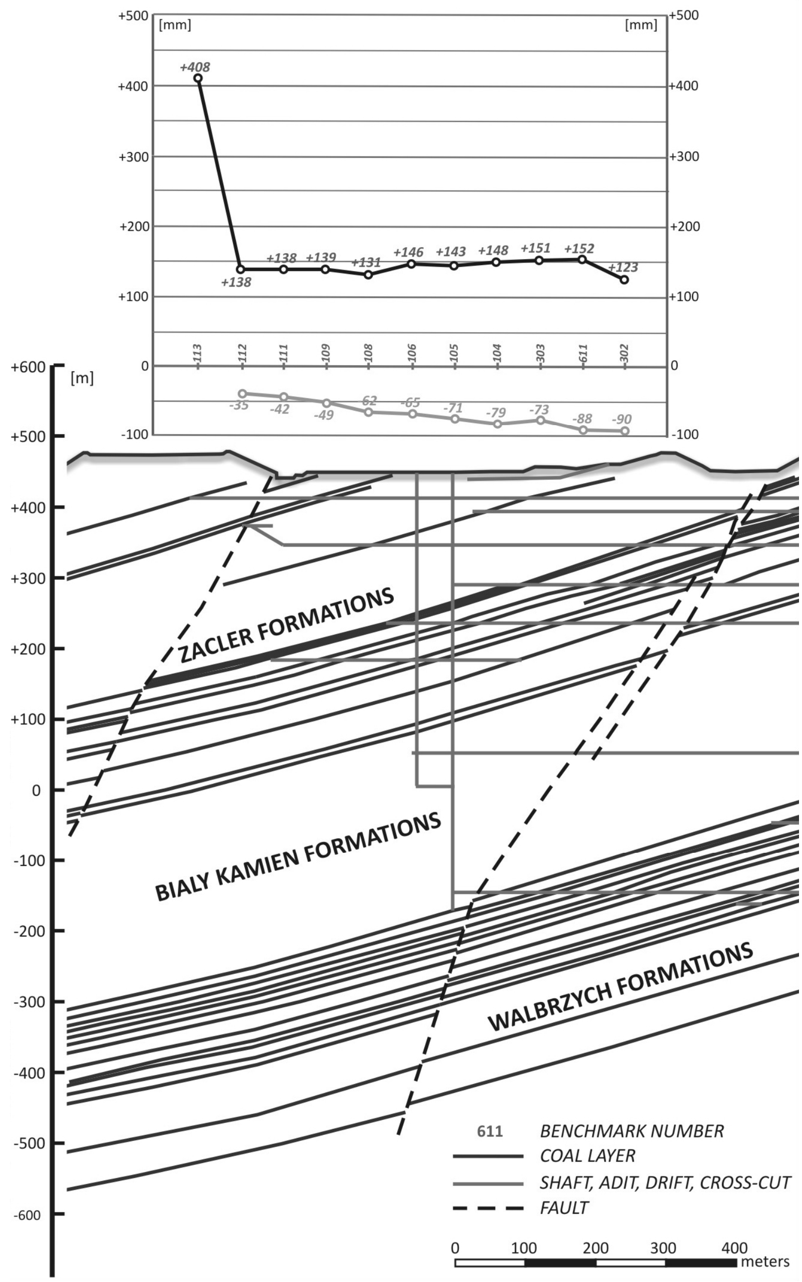

Fig. 5 Benchmark height changes measured between 1997-2000 (gray line) and 2000-2008 (black line) and underground mining situation.

a few years after the mines were closed. The observed uplift of the ground can be connected to rock mass reaction after end of underground coal extraction and rebuilding of ground water level. Gradual, self-acting, return to the state of balance of ground water level in Carboniferous formations amounts to approx. 340 m between 2000 and 2003 (Fiszer et al., 2002). Anomalous uplift of benchmark (approx. +40 cm) as compared to other examined points has been observed. It is probably linked to one of the fault zones in the analysed part of former mining grounds. The changes of benchmark heights between 1997-2000 and 2000-2008 have been shown in Figure 5.

4. CONCLUSIONS

In the paper attention has been drawn to the unique character of the former Walbrzych Coal Basin connected with its specific geological conditions and coal mining history. Results of analysis of benchmark height changes in a levelling line ("100") made for the

1980-2000 (final years of coal extraction) and 2000-2008 (post-mining) periods have been given.

Analysis of height changes between 1997 and 2000 (including period immediately after end of mining) has revealed ground subsidence of up to -9 cm. Analysis of the same section between 2000-2008 has shown relatively even uplift of the ground (approx. +15 cm). Anomalous uplift (+40 cm) has been observed in a tectonic fault zone.

Ground deformations in the studied part of former mining grounds have atypical character. This could be connected with, complicated, heterogeneous rock mass structure, probable effect of tectonic faults and its reaction to groundwater level restoration.

Information presented in this paper calls for of a detailed analysis of this phenomenon in tectonic fault zones. Planned integrated analysis based, among other things, on geodetic observations and numerical modelling of 3D structures should allow reliable interpretation and assessment of the processes happening in this area.

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