Acta Geodyn. Geomater., Vol. 6, No. 3 (155), 339–349, 2009

RECENT VERTICAL MOVEMENTS IN THE WROCLAW SECTION OF THE MIDDLE ODRA FAULT ZONE

Piotr GRZEMPOWSKI [1)]*, Janusz BADURA [2)], Stefan CACOŃ [1)] and Bogusław PRZYBYLSKI [2)]

[1)] *Institute of Geodesy And Geoinformatics, Wrocław University of Environmental and Life Sciences, Grunwaldzka 53, 50-357 Wrocław, Poland*
[2)] *Polish Geological Institute, Lower Silesian Branch, al. Jaworowa 19, 50-122 Wrocław, Poland*
**Corresponding author's e-mail:* grzempowski@kgf.ar.wroc.pl

(*Received* June 2009*, accepted* August 2009)

ABSTRACT
Analysis of benchmark height changes along national 1st order precise levelling lines crossing the Middle Odra Fault Zone in the Wroclaw area has been presented in this paper. The zone separates Fore-Sudetic Block from the Fore-Sudetic Monocline and is one of the main geological structures in Lower Silesia. Five national precise levelling lines cross the research area: Ząbkowice Śląskie – Wrocław, Syców – Wrocław, Karczów – Wrocław, Kawice – Wrocław oraz Krotoszyn – Wrocław. These levelling lines were measured in 1956-58, 1975-80 and 1999. Changes of benchmark heights have been presented in comparison with geological cross-sections made along the levelling lines. In the result, areas of the greatest relative vertical displacements correlated with geology and tectonics have been found.

KEYWORDS: Neotectonics, Middle Odra Fault Zone, recent tectonic activity, Lower Silesia, precise levelling

1. INTRODUCTION

Geodetic studies of present-day geodynamics in Lower Silesia concentrated, to date, on the Sudety Mts. and Fore-Sudetic Block areas. These studies have shown horizontal and vertical movements of the earth's crust (Kontny, 2003) that are, in general, in accordance with sub-regions marked out basing on geological structure. The Middle Odra Fault Zone (**MOFZ**) is parallel to the Sudetic Marginal Fault (**SMF**) for which long-term observations of GPS network points have shown compression (Kontny, 2003). Because these structures have developed in the same geological period there is probability for their present-day joint evolution. The research area is one of the most active parts of Poland with vertical velocities of earth's crust movements reaching up to 3.5 mm/year (Kowalczyk, 2006). The analysed area is located in the Central-European Subsidence Zone extending from the North Sea, through Hamburg, Berlin, Wroclaw and Kędzierzyn where it joins the Moravian Gate tectonic depression.

2. DESCRIPTION OF THE RESEARCH AREA

The analysed area is located in the Sudetic Foreland, Silesian Lowland and Poludniowowielkopolska Lowland. Several smaller physiographical units can be distinguished in this area: Trzebnickie Hills, Milicz-Głogów Depression, Wrocław – Bremen Outwash Valley (Pradolina) and an area of inselbergs in the Sudetic Foreland. Geologically the area is located in the Fore-Sudetic Block and the Fore-Sudetic Monocline. The Fore-Sudetic Monocline lies on the footwall of the Fore-Sudetic Block. Both units border along the **MOFZ** system of NW-SE dislocations. The Cretaceous Opole Depression, located partly on the Fore-Sudetic Block and the Fore-Sudetic Monocline, is a unit of a lower rank. The main national precise levelling lines are located along the Legnica – Wroclaw – Opole line and perpendicular to it Krotoszyn – Ząbkowice line.

Cainozoic subsidence zone in the Wroclaw area is connected to the **MOFZ,** which has NW-SE direction. Precise location of faults in this zone is very difficult to establish because of 50 to 200 m thick Neogene deposits. Middle Odra Fault Zone originated in Lower Palaeozoic and was reactivated in Permian-Mesozoic, Oligocene and Neogene. Subsidence movements in the area can be observed until present times as shown in the drainage basin form, changes of the Cainozoic deposits distribution and present-day movements registered with geodetic techniques (Badura et al., 2004; Grzempowski and Cacoń, 2005). The area is a part of the Central European Subsidence Zone (**CESZ**) (Kockel, 1988; Aizberg, 2001; Reicherter et al., 2008). In contrast in the area of the inselbergs varied rising movements occur in relation to the **CESZ** (Badura, 1999). In the area east of Wroclaw strong lowering movements took place in Miocene, in Pleistocene the movement's component was reversed.

Changes of vertical movements in the area of Wroclaw from 5 precise levelling lines that concentrically meet in the city centre have been analysed. The Ząbkowice Śląskie – Wrocław line crosses longitudinally the Fore-Sudetic Block. The line runs in a narrow Ślęza tectonic graben from Ząbkowice to Łagiewniki (Badura, 1999). Within the graben lower rank tectonic units can be found. Between Łagiewniki and Domasław underneath the Cainozoic deposits several tectonic steps can be distinguished throwing down the Fore-Sudetic blocks by approx. 50 – 100 m. The Fore-Sudetic Monocline starts near the Bielany Wrocławskie. In this area the metamorphic foundation of the Fore-Sudetic Block has been downthrown approx. 1000m. The down-throw in the Middle Odra Fault Zone is not manifested in the relief of the sub-Cainozoic stratum in all of the profiles. In the Wroclaw area a rhomboidal depression can be clearly seen on the map of sub-Cainozoic stratum (Badura et al., 2004). Its southern border replicates the form of the Middle Odra Fault Zone.

The Wrocław – Syców and Wrocław – Krotoszyn levelling lines run within the limits of the Fore-Sudetic Monocline. Small number of deep boreholes and geophysical probing in the Wroclaw area makes it difficult to determine the roof of the Triassic deposits in the Wrocław Monocline. In the Wroclaw area it sinks deeper than in the NE of Oleśnica. In the Oleśnica – Syców area horst can be identified in the sub-Cainozoic stratum with orientation reflecting direction of the cuestas in the Krakow – Częstochowa Upland. These cuestas have generally NW – SE to WNW –ESE orientation.

In the sub-Cainozoic stratum between Wrocław and Krotoszyn a depression of the Triassic formations can be noticed under the Trzebnickie Hills. It is presumed, in papers related to glaciotectonic studies, that the Triassic formations form a horst under these hills, which indirectly caused deep-rooted glaciotectonic changes (Krzyszkowski, 1993). This problem can be solved only after more data on the depth of Mesozoic stratum is made available. North of the Trzebnickie Hills in the Fore-Sudetic Monocline foundations secondary grabens and horsts can be identified. Basing on the differences in thicknesses of brown coals in these grabens it has been accepted that these were active in the Middle Miocene (Piwocki, 1992).

The Kawice – Wrocław levelling line runs almost entirely within the limits of the Fore-Sudetic Block and crosses the **MOFZ** in the Wróblowice area only. In this part of the city the Modele Odra fault is displaced by approx. 2.5 km northwards on a perpendicular fault. On the Fore-Sudetic Block buried inselbergs, probably of tectonic origin, can be found.

The Wrocław – Opole levelling line runs parallel to the Odra River valley. To the east of the Wroclaw – Opole depression tectonic unit can be found. It is a tectonic depression filled with Upper Cretaceous deposits. It has been formed on the Wrocław Monocline and the Fore-Sudetic Block. In the Brzeg area tectonic horst composed of Triassic formations can be identified. The sub-Cainozoic stratum rises between Wrocław and Łosiów by approx. 160 m. The surface of sub-Cainozoic stratum in the Opole Depression is the least known. This is due to the uncertainty of lithological descriptions and mapping of stratigraphic boundaries associated with profiles of the drilled cores. Macroscopically the Upper Cretaceous deposits cannot be distinguished from the Neogene formations. It is possible that already in the Oława area the roof of Upper Cretaceous deposits is actually 50 m higher.

The Cretaceous Opole Depression is an area of changing component of tectonic movements. In the Upper Cretaceous it was subsiding, then rose. It is probable that it constituted the western part of the Meta-Carpathian ridge until the late Middle Miocene. At this time the ridge constituted the main European watershed between the Paratethys and the North Sea drainage basins. In the Upper Miocene the western part of the depression subsided. Development of a tectonic graben perpendicular to the ridge allowed a new river network to be created, draining the Eastern Sudetes and the Western Carpathians to the North Sea. In Pleistocene this area was rising in blocks again. Between the rising blocks orthogonal depressions, such as the Niemodlin Depression, have developed (Badura and Przybylski, 1999).

3. ANALYSIS OF RELATIVE BENCHMARK HEIGHT CHANGES IN THE RESEARCH AREA

3.1. DESCRIPTION OF THE LEVELLING DATA

To determine relative benchmark height changes in the area of the Middle Odra Fault Zone 1st order national precise levelling lines running perpendicular to the zone and along its axis have been analysed in the vicinity of Wroclaw and in the adjacent areas (Fig. 1).

The lines were measured in Lower Silesia in 1956, 1975-80 and 1999. Chronological details of measurement campaigns for particular levelling lines are given in Table 1.

Initial data for analyses consisted of the Catalogue of heights obtained from the Centre for Geodetic and Cartographic Documentation in Warsaw. The Syców – Wrocław, Ząbkowice – Wrocław and Karczów – Wrocław lines have been measured three times, while the Kawice – Wrocław and Krotoszyn – Wrocław lines twice. Analysis of changes of height differences between nodal benchmarks revealed negative changes on all the lines in the direction towards the nodal benchmark located in the Wroclaw area (central part of the Wrocław basin). The greatest changes occurred between the nodal benchmarks Karczów – Wrocław –54 mm and

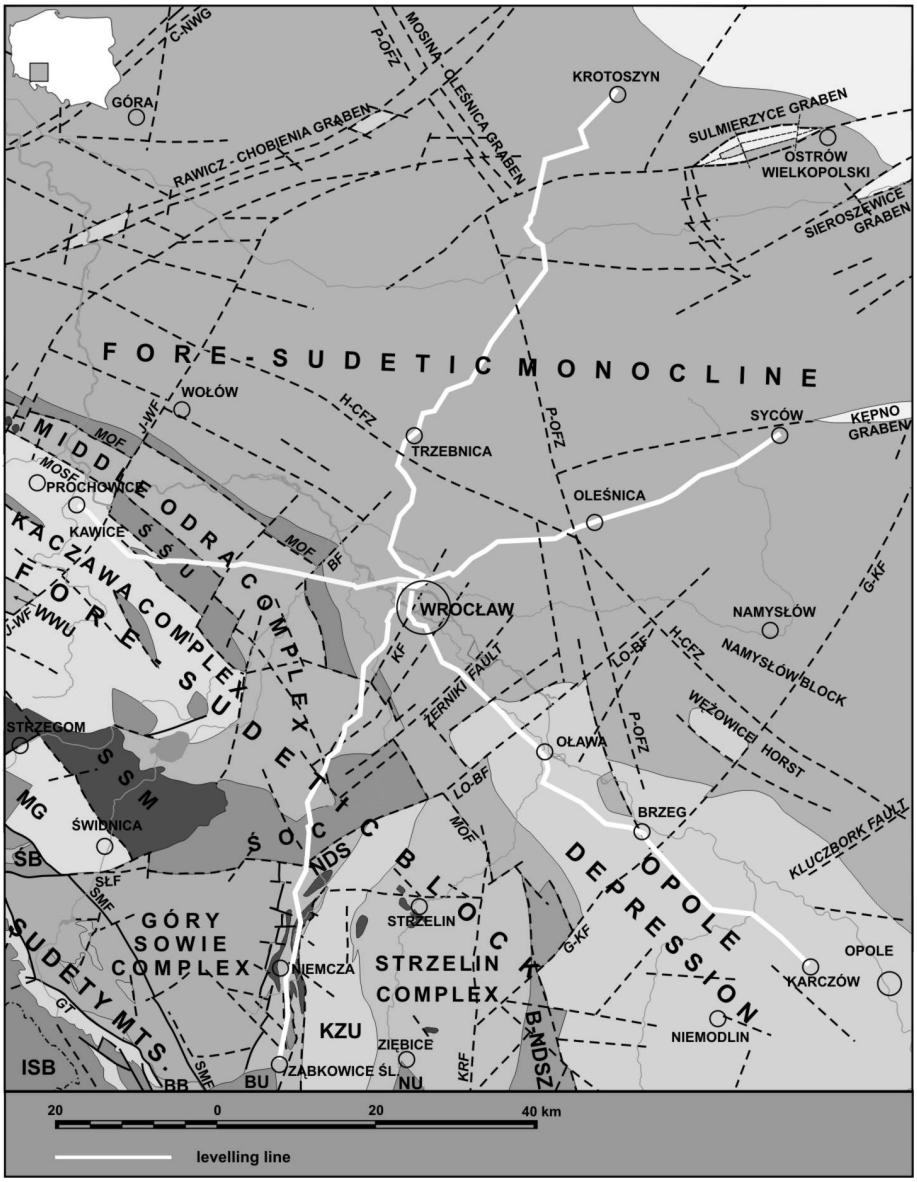

Fig. 1 Location of the analysed 1st order national precise levelling lines.

Table 1 Measurement campaign years of the 1st order national precise levelling lines.

LEVELLING LINES	YEARS OF THE MEASURMENTS
SYCÓW - WROCŁAW	1956, 1975, 1999
ZĄBKOWICE- WROCŁAW	1956, 1975, 1999
KARCZÓW - WROCŁAW	1958, 1980, 1999
KAWICE - WROCŁAW	1975, 1999
KROTOSZYN - WROCŁAW	1980, 1999

Syców – Wrocław –53 mm. These concern 41 and 43 years respectively (Table 2).

Between 1956 and 1999 all the analysed changes of height differences between nodal benchmarks exceeded the double mean error value of their determinations (significant changes of benchmark heights are marked in bold – Table 2). Between 1956 – 1975(80) significant change of height difference occurred between the Karczów – Wrocław nodal benchmarks only, whereas in the

Table 2 Changes of height differences between nodal benchmarks.

Levelling Line	Changes of elevation differences in 1956 – 1975 (18 years) 1958 – 1980 (22 years)* period [mm]	Changes of elevation differences in 1975 – 1999 (24 years) 1980 – 1999 (19 years)* period [mm]	Changes of elevation differences in 1956 – 1999 (43 years) 1958 – 1999 (41 years)* period [mm]	Length [km]	Mean error of the changes of elevation differences [mm]
Syców – Wrocław	-7	**-25**	**-32**	56	10.5
Ząbkowice Śl. – Wrocław	-25	**-28**	**-54**	83	12.9
Karczów – Wrocław	**-36***	-18*	**-54***	92	13.6
Kawice – Wrocław	-	-9	-	53	7.3
Krotoszyn – Wrocław	-	-22*	-	83	12.9

Changes of height differences marked with * have been determined for the years given in the second position of the header and result from the year of measurement campaign presented in Table 1

1975(80) – 1999 period significant changes of height differences occurred between Syców – Wrocław and Ząbkowice Śl. – Wrocław nodal benchmarks. It must be emphasized that in all of these periods changes increase with the same negative sign in the direction of the nodal benchmark in Wrocław. Changes of height differences between the nodal benchmarks in the Kawice – Wrocław and Krotoszyn – Wrocław levelling lines did not exceed the double mean error value of their determination in the 1975(80) – 1999 period.

3.2. ANALYSIS OF CHANGES OF HEIGHT DIFFERENCES AND DETERMINATION OF BENCHMARK RELATIVE MOVEMENTS

The movements of points in the national precise levelling lines have been presented as relative to a selected benchmark in each analysed line because no line closures have been possible for these periods and because of changes in the run of the encircling lines.

Mean error of height difference $m_{\Delta hi}$ has been calculated for each "i" measurement with the aim to assess the significance of the changes of height differences.

$$m_{\Delta hi} = m_o \cdot \sqrt{L} \,,$$

where: m_o - unit mean error (mean error for 1 km of levelling measurements)

L - length of a levelling line in km

and the mean error of determining change of height difference between "i" and "j" measurements:

$$m_{d\Delta hij} = \sqrt{m_{\Delta hi}^{\,2} + m_{\Delta hj}^{\,2}}$$

The accuracy of the 1st order national precise levelling line measurements given by mean error for 1 km of levelling m_0, has been assumed to be 1 mm/km. The change of height difference has been assumed to be significant if double value of mean error was exceeded:

$$d\Delta h \rangle 2 \cdot m_{d\Delta hij} \,,$$

Analysis of changes of height differences in national precise levelling lines has shown, in the 1956(58) – 1999 period, significant changes for 78 % of sections in the Ząbkowice – Wrocław – Syców line and 69 % in the Wyrębiny – Wrocław line. The values of changes of height differences in these lines reach 55 mm (Table 3). Two sections in the Ligota – Poniatowice – Ignaszów area with absolute values of 130 mm and 136 mm are an exception. These are outlier observations from the rest, probably caused by local movement of a benchmark. In the Kawice – Wrocław and Krotoszyn – Wrocław lines, measured between 1975(80) and 1999, the absolute changes of height differences have reached up to 16 mm in the Jastrzębie – Środa Śl. section and up to 49 mm in the Trzebnica area. Significant changes of height differences occurred in 67 % and 40 % of sections respectively.

Basing on the analysis of changes of height differences benchmarks have been selected in relation to which relative movements of benchmarks have been determined. The following have been taken into consideration in the selection: no significant changes

Table 3 Changes of height differences in selected sections of levelling lines.

Levelling line	Total length (km)	Selected changes of height differences in levelling sections (mm)		Section Place	Number of sections analysed in a line	Number of sections with significant changes in a given period	
		1975 -1999 1980 -1999*	1956 -1999 1958 -1999*			1956 – 1999 1958 – 1999*	1975 – 1999 1980 – 1999*
Ząbkowice – Wrocław – Syców	139	17 39 12	25 55 34	Domasław - Rolantowice Wrocław - Wrocław Wrocław - Długołęka	45	35	33
Wyrębiny – Wrocław	92	6* 23* 4*	43* 25* 50*	Groblice – Oława Oława – Godzikowice Brzeg - Pawłów	23	16*	10*
Kawice – Wrocław	53	16	-	Jastrzębie – Środa Śl.	52		35
Krotoszyn – Wrocław	83	21* 49* 19*	- - -	Borowina - Borowina Trzebnica – Trzebnica Kryniczno - Psary	72		29*

Changes of height differences marked with * have been determined for the years given in the second position of the header and result from the year of measurement campaign presented in Table 1.

of height differences to neighbouring benchmarks, durable stabilisation on buildings with solid fundaments (e.g. churches) and location in relatively stable geological formations.

In the Ząbkowice Śl. –Wrocław – Syców line the changes have been determined in relation to a benchmark located in the Zwrócona place on an area of relatively thin Cainozoic deposits (about 10 m). The changes of height differences from this benchmark in relation to neighbouring ones did not exceed the tolerable values in the 1956 – 1999 as well as 1956 – 1975 and 1975 – 1999 periods.

Relative changes of benchmark heights in the Wyrębiny – Wrocław line have been determined in relation to a benchmark located in the Karczów place. The changes of height differences in its surroundings for the 1956 – 1980, 1980 – 1999 and 1956 – 1999 periods did not exceed the assumed criterion.

In the Krotoszyn – Wrocław line the relative changes of benchmark heights have been determined in relation to a benchmark located in the Rakłowice place, whereas for the Kawice – Wrocław one in relation to a benchmark in the Błonie place.

4. CHANGES OF BENCHMARK HEIGHTS IN RELATION TO GEOLOGICAL AND TECTONIC FORMATIONS

In order to interpret the relative changes of benchmark heights analysis of changes of height differences in tectonic fault areas has been carried out and geological cross-sections along analysed levelling lines have been made (Figs. 3-6). The relief of sub-Cainozoic and sub-Quarternary strata has been made basing on borehole and geophysical data. Some source data from Badura et al. (2004) has been used. On the basis of graphs of vertical movements and information from geological cross-sections benchmark classes whose movements show relation with the ground have been identified. Hierarchical clustering methods have been also used to support identification of benchmark clusters. Horizontal x, y coordinates and relative movements of benchmarks in the periods given in Tables 1 and 2 have been used as the statistical parameters describing the benchmarks. Euclidean distances have been calculated between the objects and classification has been done by means of single link (nearest neighbour) method. The analyses have been carried out in the STATISTICA software. Example analysis of point clusters is shown in Figure 2.

In the Ząbkowice – Wrocław line (Fig. 3) three benchmark classes have been isolated. The first group is made of benchmarks located on the Fore-Sudetic Block between Ząbkowice Śl. and Rolantowice. Relative movements in the 1956 – 1999 period amount to on average –3 mm. This section of levelling line runs across areas of relatively thin (0 to 50 m) Cainozoic deposits. An outlier benchmark in this group is a point in Łagiewniki place (–13 mm). In the next group of benchmarks in the Domasław – Bielany Wrocławskie section, where thickness of Cainozoic deposits increases to about 150 m, the average movement amounts to –29 mm. In the Rolantowice – Domasław section change of height difference is –25 mm in the direction of Wrocław. This group of benchmarks is located in the southern part of the **MOFZ** on the junction of the Fore-Sudetic Block and Fore-Sudetic Monocline. The third group consists of benchmarks located in the Wrocław area in the central part of the **MOFZ**, where average movement is –61mm and thickness of Cainozoic deposits reaches 180m. Changes of height differences between groups 2 and 3 occur in the region where the levelling line crosses the Ślęza River in the southern part of Wrocław. In t he next three levelling sections in this area the changes amount to –15 mm, –55 mm,

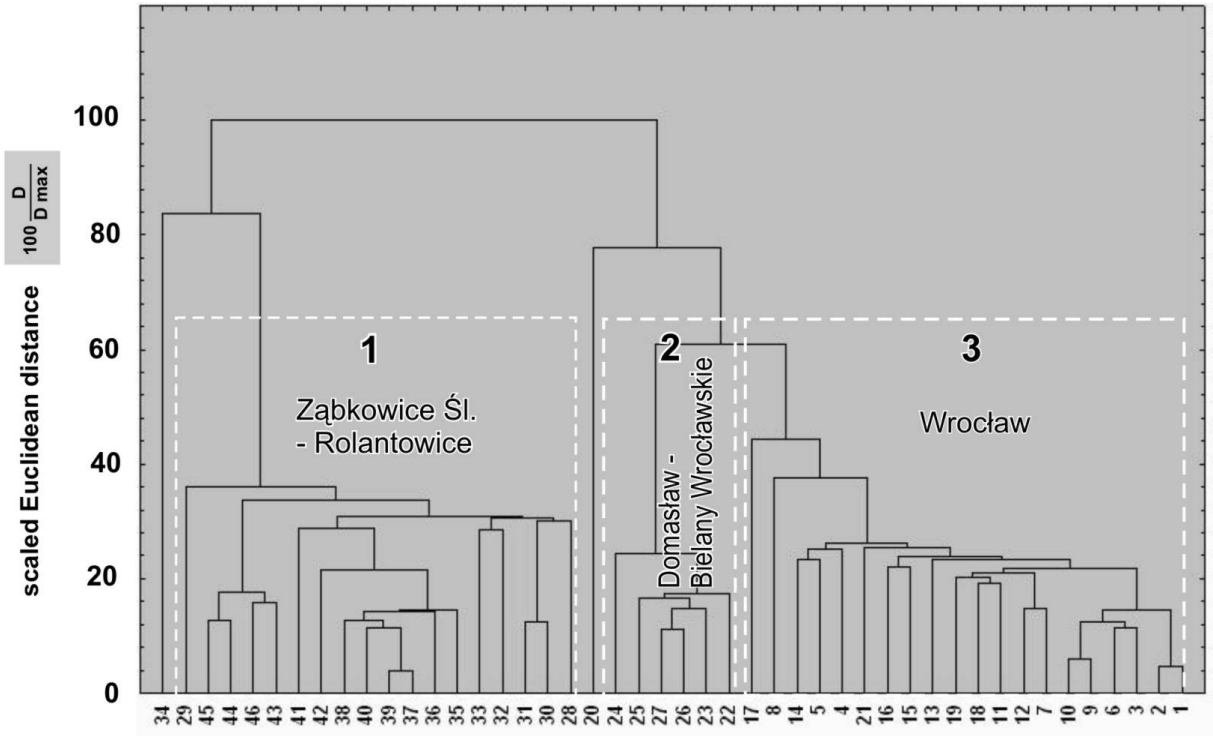

Fig. 2 Dendrogram of benchmark classification in the Wrocław – Ząbkowice Śl. line.

+40 mm. The greatest relative movements in the Ząbkowice Śl. – Wrocław – Syców line with values from –64 mm to 105 mm, occur in the 1956 – 1999 period in the southern part of Wrocław.

The Syców – Wrocław line (Fig. 3) is entirely located on the Fore-Sudetic Monocline. Three main classes of benchmarks have been isolated there. The first group includes benchmarks in the Syców to Borowa section. Average movement in this group, for the 1956 – 1999 period, is –14 mm with the exception of a benchmark in Poniatowice for which movement of –141 mm was calculated. This benchmark was excluded from further analyses due to movement value significantly differing from those of the neighbouring benchmarks. In the Borowa – Byków section separating two groups, the change of height differences amounted to –14 mm. The next group is made of 3 benchmarks between Byków and Długołęka. In this section a systematic increase of negative value of movements from –36 mm to –49 mm occurs in the direction of Wrocław. In the Długołęka – Wrocław section (approx. 4.4 km) change of height difference of –34 mm has taken place towards the Wrocław city centre. This section separates the third group of benchmarks covering the area of the city of Wrocław with –58 mm average value of movements.

In the Karczów – Wrocław line (Fig. 4) three classes of benchmarks have been isolated. The first is made of benchmarks between Karczów and Pawłów (average movement between 1958 and 1999 reached – 5 mm), the next two groups consist of benchmarks located between Oława and Brzeg (–29 mm) and benchmarks located in the Groblice – Wrocław city centre section (–48 mm). The benchmarks located within the limits of Oława and Brzeg form separate clusters on the dendrogram what indicates local character of movements. The boundary between the first and the second group coincides with a SW-NE fault in this area, perpendicular to this levelling line. The benchmarks in the Oława – Brzeg section are located on a geological unit whose limits are marked by faults perpendicular to the levelling line, the Grodków – Kępno fault on one side and the Laskowice Oławskie – Błaszki fault on the other (names according to Cymerman (2004)).

In the above presented levelling lines focus is given to movements in a longer period of measurements 1956(58) – 1999 because of significant values of movements exceeding several times the measurement errors. In general benchmark movements in this period agree in terms of sign with movements in the 1956(58) – 1975(80) period and are their continuation.

In the Krotoszyn – Wrocław line (Fig. 5) basing on the analysis of vertical movements of benchmarks in the 1975 – 1999 period three classes of points have been isolated Krotoszyn – Milicz, Miłochowice – Kryniczno and Psary – Wrocław city centre. Average movement in the first group amounts to –1 mm. In the

benchmark group in the Miłochowice – Kryniczno section average movement is –9 mm, however movement values of a sub-set of benchmarks in the limits of Trzebnica have not been included in the calculations. The movement values in this sub-set vary from –4 mm to –53 mm and were the result of local technogenous factors. The greatest average movement value of –22 mm occurred in the Psary – Wrocław group of benchmarks. The change of height difference in the Kryniczno – Psary section that separates two isolated groups amounted to –19 mm in the direction of Wrocław.

The Kawice – Wrocław levelling line (Fig. 6) runs in the **MOFZ** axis. Relative movements in this line are between +4 mm to –10 mm outside city limits. Greater movements take place mainly in the Środa Śl., up to –25 mm and Wrocław, up to –27 mm areas. From analysis of the movement graph of this line it can be stated that that movements and clusters of points have random nature and are not connected with geological structure. Analysis of changes of height differences presented in Table 2 shows lowering of the nodal benchmark in Wrocław in relation to other nodal benchmarks between –9 mm to –28 mm in the 1975(80) – 199 period. Change of benchmark heights between the nodal benchmark in Kawice and nodal benchmark in the centre of Wrocław is just –9 mm.

5. SUMMARY AND CONCLUSIONS

The presented analyses of relative changes of benchmark heights have shown significant vertical movements in the Wrocław part of the Middle Odra Fault Zone. The greatest relative vertical movements have been found in the Ząbkowice Śl. – Wrocław – Syców levelling line that runs perpendicularly to the zone, near southern border of the **MOFZ** in the Rolantowice – Domasław section and in the area of faults of the Poznań – Oleśnica direction in the Borowa – Byków – Długołęka section. Significant movements have also been found in the Karczów – Wrocław levelling line running along the axis of the **MOFZ** in the sections between Brzeg and Oława and Groblice towards Wrocław centre. Relative changes of benchmark heights in these lines point to systematic subsidence of the ground's surface in the region of the Wrocław basin in relation to the adjacent areas that are separated by regional and local faults. It can not be to stated to what extent theses vertical movements are the result of tectonic movements because of up to 200m thick Cainozoic deposits covering the **MOFZ**. Vertical movements of the ground's surface might be the result of a number of processes connected with compaction of these formations and dependent on the thickness of Cainozoic deposits, changes of water conditions correlated with the lie of the sub-Cainozoic stratum. Single determination of the changes of height differences in the Kawice – Wrocław and Krotoszyn – Wrocław lines does not allow formulating unambiguous conclusions on relations between the geological structure and vertical changes of benchmark heights.

ACKNOWLEDGEMENT

This work has been financed as a research project from the Polish science funds for the period 2007 – 2010.

REFERENCES

Aizberg, R., Garetzky, R.G., Karabanow, A.K., Kockel, F., Levkov, E.A., Ludwig, A.O., Lykke-Anderson, H., Ostaficzuk, S., Palijenko, V., Schwab, G., Šliaupa, A. and Stackenbrandt, W.: 2001, Neotectonic structural subdivision (beginning of Oligocene until the Recent), Supplement to Brandenburgische Geowissenschaftliche Beiträge, 8, 1, respectively to Abh. Naturwiss. V (NF), 35.

Badura, J.: 1999, The influrence of Cainozoic tectonic movements on geomorphological development of the Niemcza -Strzelin Hills, Quaternary Studies in Poland, Special Issue, 219–225.

Badura, J. and Przybylski, B.: 1999, Examples of young tectonic activity from the Sudetic Foreland, SW Poland - application of condensed contour map. Techn. Poszuk. Geolog. Geosynoptyka i Geotermia, 38–45.

Badura, J., Przybylski, B. and Zuchiewicz, W.: 2004, Cainozoic evolution of Lower Silesia, SW Poland: a new interpretation in the light of sub-Cainozoic and sub-Quaternary topography, Acta Geodyn. Geomater., 1, 3 (135), 7–29.

Cymerman, Z.: 2004, Tectonic map of the Sudetes and Fore-Sudetic Block, 1:200000, Polish Geological Institute.

Grzempowski, P. and Cacoń, S.: 2005, The cause analysis of benchmark movements in the city of Wrocław, Reports on Geodesy, No.3 (74), 271–281.

Kockel, F.: 1988, The palaeogeographical maps, In: R. Vinken (ed.), The Northwest European Tertiary Basin. Results of the International Geological Correlation Programme, Project No 124. Geol. Jb. Rh. A, 100, 423–427, Maps 1–7.

Kontny, B.: 2003, Geodetic research of contemporary kinematics of the main tectonic structures of the Polish Sudetes and the Fore-Sudetic Block with the use of GPS measurement, Scientific papers of the Agricultural University of Wroclaw, 468, dissertation CCII.

Kowalczyk, K.: 2006, Determination of a model of vertical crustal movements in the area of Poland, Doctoral thesis, UWM Olsztyn.

Krzyszkowski, D.: 1993, Origin of Quaternary sediment deformation in southwestern Poland: glacitectonic versus neotectonic, In: J. Aber (ed.) Glaciotectonics and Mapping Glacial Deposits, Can. Plains Res. Center. Univ. Regina, 46–50.

Piwocki, M.: 1992, Extend and correlation main Tertiary lignite seams on the Polish Lowlands (in Polish with English summary). Geological Review, 40, 5, 281–286.

Wyrzykowski, T.: 1989, Map of gradients of velocity of the recent vertical movements of Earth crust surface on the territory of Poland (in Polish); 1:2 500 000, Institute of Geodesy and Cartography, Warsaw 1985.

Reicherter, K., Froitzheim, N., Jarosiński, M., Badura, J., Franzke, H-J., Hansen, M., Hübscher, C., Müller, R.,

Poprawa, P., Reinecker, J., Stackebrandt, W., Voigt, T., v. Eynatten, H. and Zuchiewicz, W.:2008, Alpine tectonics north of the Alps, In: McCann T. (ed.), The Geology of Central Europe, 2, Mesozoic and Cenozoic. Geological Society, London, 1233–1285.

Żelaźniewicz, A. and Aleksandrowski, P.: 2008, Tectonic sudbdivision of Poland: southwestern Poland (in Polish with English summary), Geological Review, 56, 10, 904–911.

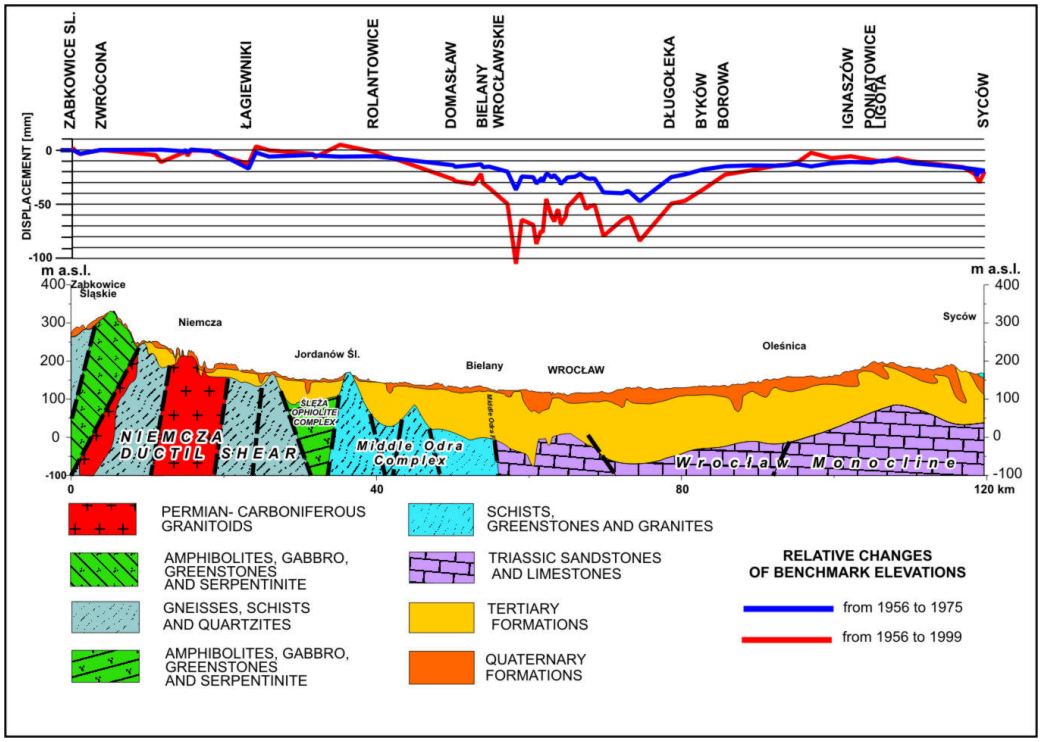

Fig. 3 Simplified geological profile along the Ząbkowice Śl. – Wrocław – Syców levelling line.

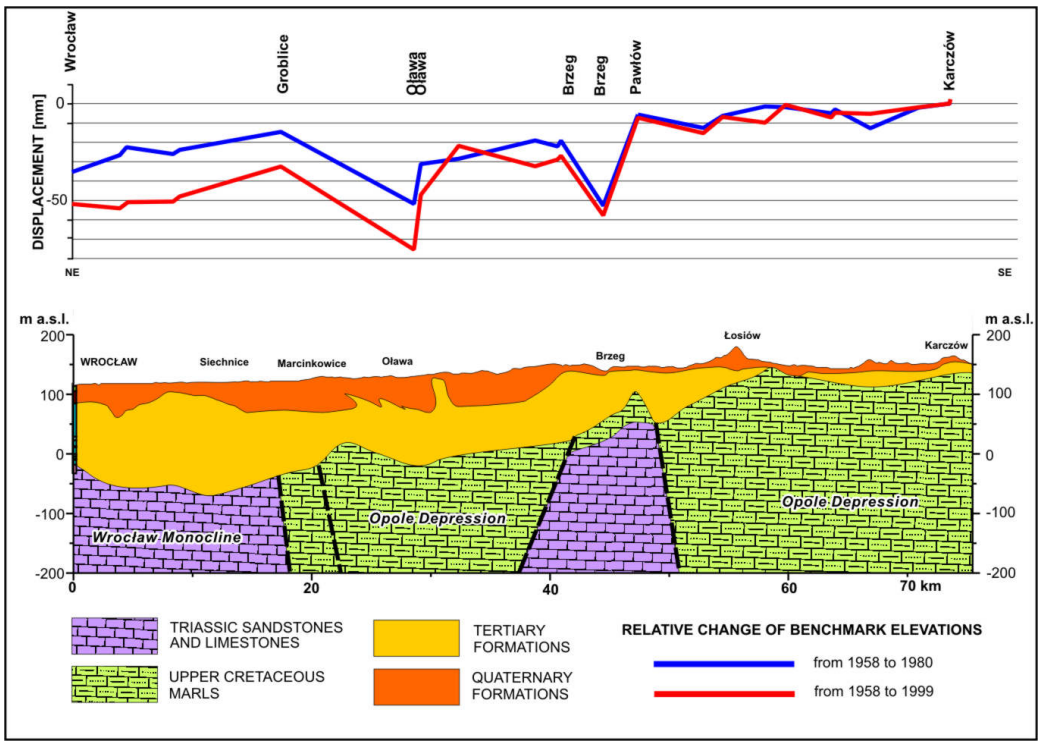

Fig. 4 Simplified geological profile along the Wrocław – Karczów levelling line.

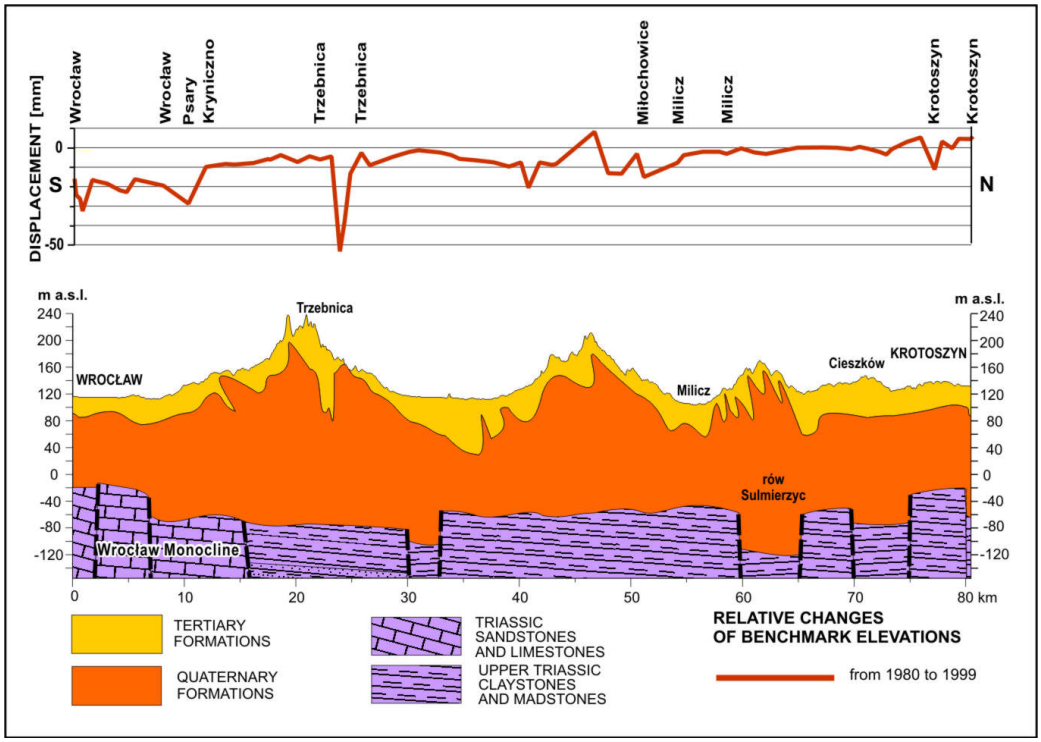

Fig. 5 Simplified geological profile along the Wrocław – Krotoszyn levelling line.

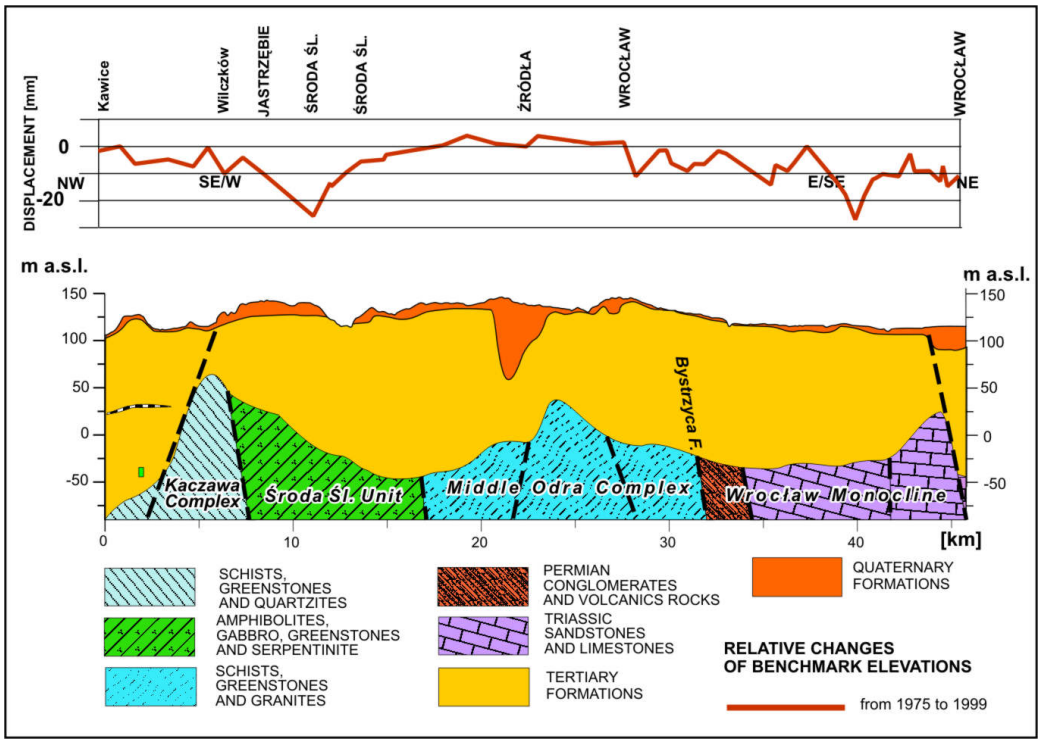

Fig. 6 Simplified geological profile along the Kawice – Wrocław levelling line.