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GEODYNAMICS OF SOUTH-EASTERN PART OF THE CENTRAL EUROPEAN SUBSIDENCE ZONE

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ABSTRACT

Geodetic geodynamic studies were conducted in the Wrocław Plain, situated in the SE part of the Central European Subsidence Zone (CESZ). The boundaries of this plain coincide with the outline of the rhomboidal Cainozoic Wrocław Basin. This area has been chosen for detailed examination taking into account the results of previous geodynamic research, pointing to constant subsidence of the Wrocław region. Analysis of drainage network and changeable thicknesses of the Neogene and Quaternary strata also indicates weak, although stable subsidence of the central part of the Silesian Lowland and relative, small-scale uplift of the Fore-Sudetic region situated in the south and an area placed north of the Odra River valley. The studies consisted in measuring elevation changes of benchmarks along lines of precise levelling during 1956-1999 period, establishing a GPS network points, as well as measuring and processing of GPS data acquired during 2008-2010 time span. Displacements of benchmarks of precise levelling lines point to block-type mobility of structures located in the SE part of the CESZ, while GPS measurements indicate deformations related to bending of the Cainozoic sedimentary cover underlain by metamorphic bedrock and Permo-Mesozoic strata. Three years of observations enable us to distinguish two zones typified by compressive deformations being coincident with subsiding areas. One of these zones strikes NW-SE and marks the CESZ axis, the second one, oriented NNW-SSE, follows the orientation of a deeply buried Carboniferous-Permian tectonic graben (the Eastern Fore-Sudetic Basin) and a much shallower trough filled with Cretaceous strata in the Opole region. Uplift typifies the Fore-Sudetic Block as well as areas situated close to Opole town and north of the Odra River valley.

KEYWORDS: geodynamic research, neotectonics, Odra Fault Zone, Lower Silesia, Central European Subsidence Zone

1. CENTRAL EUROPEAN SUBSIDENCE ZONE

The Central European Subsidence Zone (Aizberg et al., 2001; Garetsky et al., 2001; Stackebrandt, 2004) extends from the North Sea through Northern Germany and Western Poland to the Sudetes and Kraków-Częstochowa Upland (Fig. 1). Its length exceeds 1,000 km and the width amounts to 300 km diminishing towards the SE, attaining ca. 70 km near Wrocław. In the SE part, the zone forms a narrow wedge that separates the eastern part of the Fore-Sudetic Block from the Middle-Polish uplands and farther to the southeast it joins the "Nysa bay" of the Carpathian Foredeep Basin. Connection between the CESZ and the Carpathian Foredeep led to establishing a new drainage direction from the Western Carpathians to the northwest. The present-day outflow from this region follows the upper Odra River valley (Badura and Przybylski, 2004). Hence, in the Late Miocene, the subsidence zone found its termination in the Morava Gate, in front of the Western Carpathians.

The neotectonic Central European Subsidence Zone is placed in the NE part of the West-European Platform, which embraces an area comprised between the Central European Uplift and the East-European Platform including the Fennoscandian Shield and Baltic-Belarus Syneclise. The axis of this zone follows the Late Palaeozoic Central European Basin System (CEBS) (Dadlez et al., 1998; Scheck et al., 2002; Otto, 2003; Scheck-Wenderoth and Lamarche, 2005); an area repeatedly deformed since the Late Carboniferous. The northern margin of both CESZ and CEBS is marked by the Tornquist-Teisseyre Zone; the southern one is delimited by WNW-ESE to NW-SE trending faults of the Elbe Fault System (EFS).

The latter separates the CEBS from Variscan mountains and intramontane sedimentary basins associated with the Central European Uplift Zone (Scheck et al., 2002). This zone is bordered to the north by the Elbe Line and Odra Fault Zone, and to the south by the Elbe Zone.

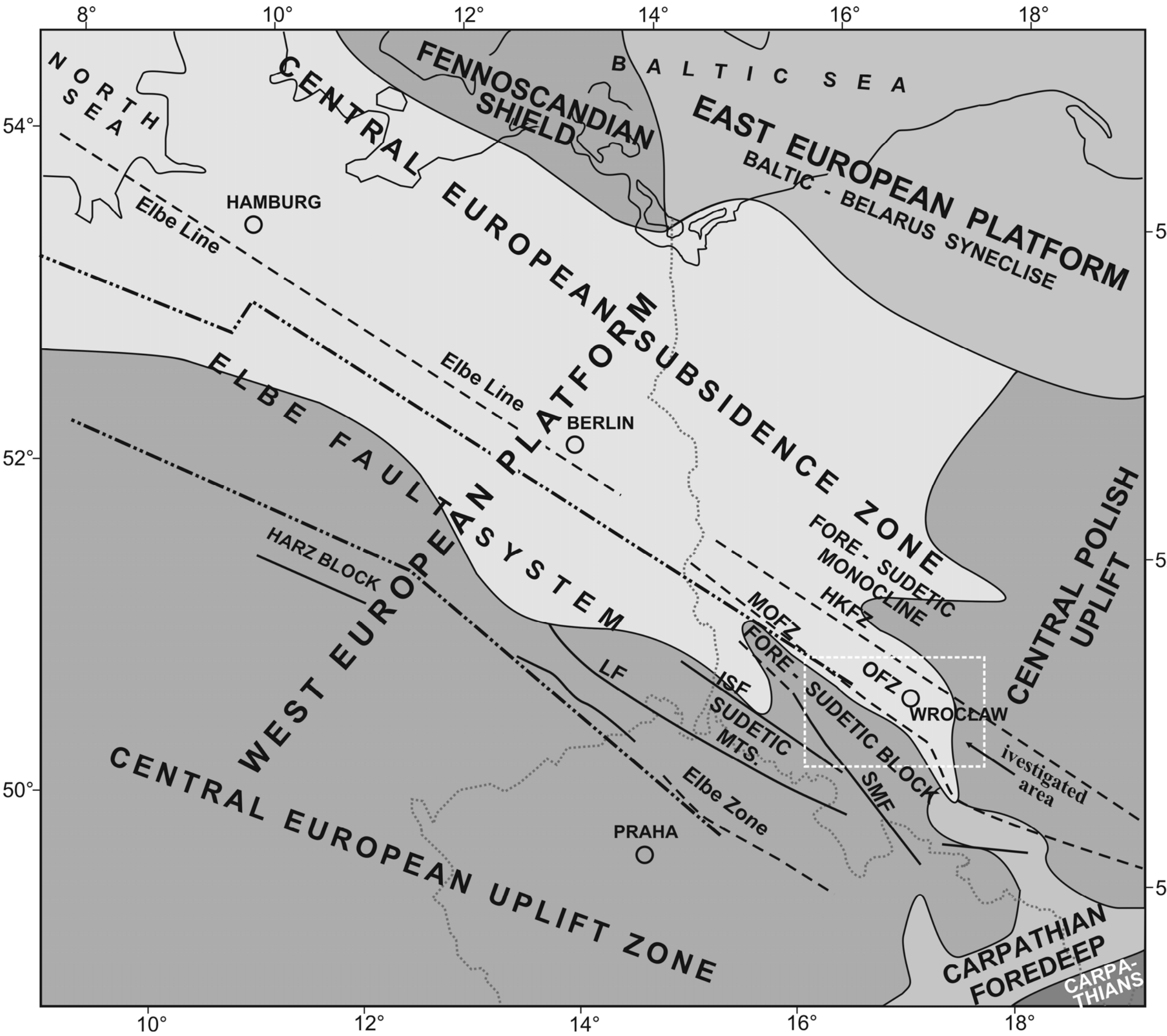

Fig. 1 Neotectonic structural subdivision of the Central European Subsidence Zone (modified from Aizberg et al., 2001; Scheck et al., 2002). ISF - Intra-Sudetic Fault, LF - Labe Fault; SMF - Sudetic Marginal Fault, MOFZ – Middle Odra Fault Zone, HKFZ - Hamburg - Kraków Fault Zone, OFZ – Odra Fault Zone.

The Elbe Line is a deep-seated fault zone registered by seismic surveys (Thybo, 1990, 2001), which continues into the Odra Fault Zone. In the Polish literature, faults belonging to this zone bear different names (Middle Odra dislocation zone, Odra Fault, Middle Odra Fault; cf. Cwojdziński and Żelaźniewicz, 1995; Żelaźniewicz and Aleksandrowski, 2008; Reicherter et al., 2005 and others). The zone tends to be identified with the Silesian-Lusatian, Hamburg-Kraków or Lubliniec-Kraków fault (Otto, 2003) and considered to mark the boundary between the Fore-Sudetic Block and Fore-Sudetic Monocline (Cymerman, 2004). The CESZ axis coincides in part with the trend of the Middle Odra Fault Zone (Scheck et al., 2002). The southern boundary of the EFS is marked by the Elbe Zone, comprising faults separating the Silesian-Lusatian Block from the Bohemian Highland in the south.

The EFS fault zone has been repeatedly reactivated since the Late Variscan orogeny in different regimes: transtensional at the turn of the Permian and Triassic, extensional in the Mesozoic, and transpressional at the turn of the Late Cretaceous and Palaeogene (Otto, 2003). In the last stage, NW-directed collision between the African and European plates led to tectonic inversion of the Alpine foreland. Mountain ranges of the Central European Uplift Zone became uplifted by 1,000 m and subsidence in the CEBS attained 2,500 m (Garetsky et al., 2001).

The late Eocene, Oligocene and Middle Miocene witnessed marine transgressions, which entered Lusatia and sometimes also the NW part of Lower Silesia (Kockel, 1988; Standke et al., 1993). Two Pleistocene transgressions in NE Germany took place in the Hosteinian and Eemian interglacials (Ludwig, 2001a,b; Stackebrandt, 2004). The drainage pattern in

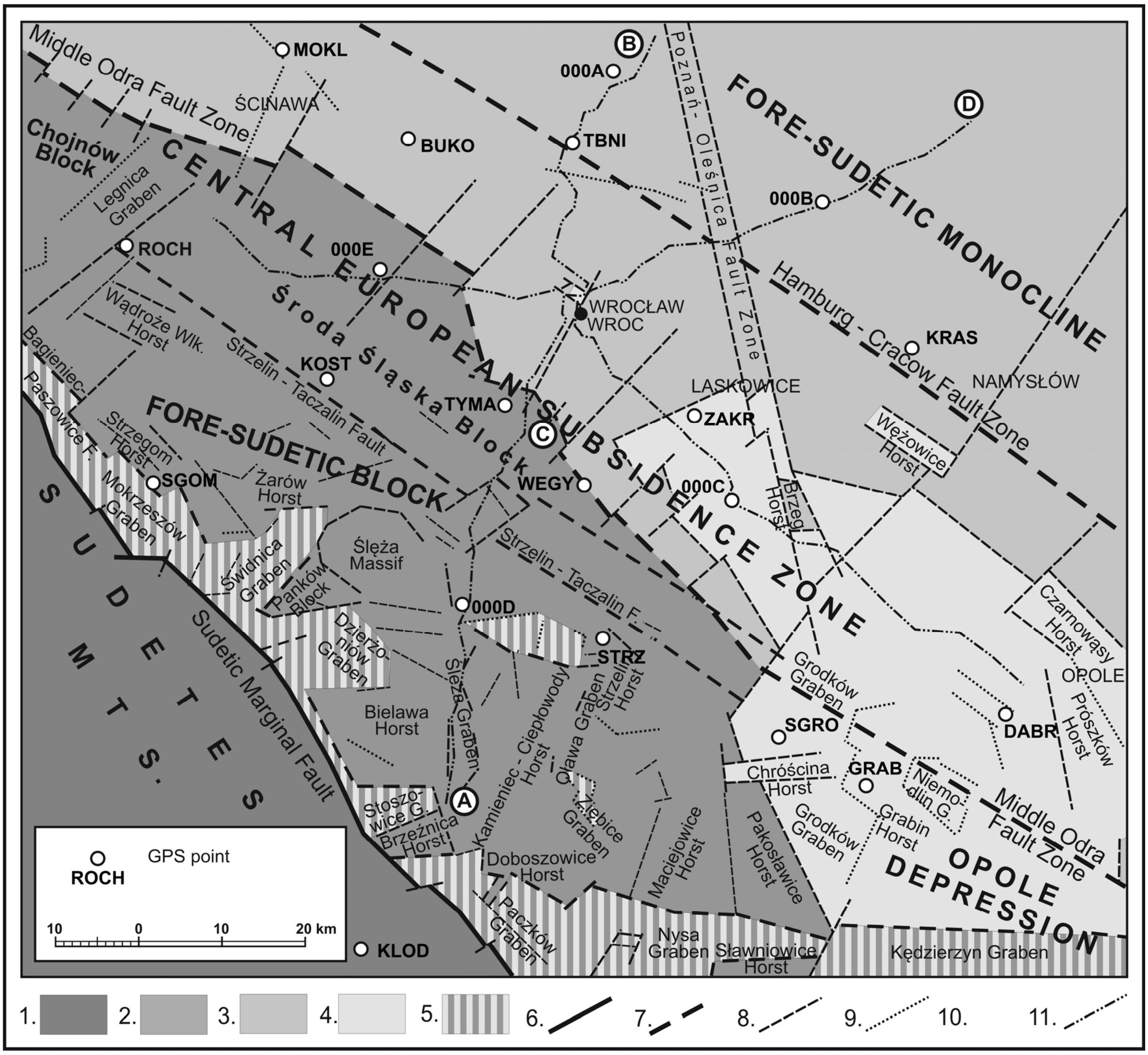

Fig. 2 Location of the GPS points with geological structure shown in the background. 1 - northern part of the Bohemian Massif – Sudetes Mts., 2 - Fore–Sudetic Block, 3 - Wrocław Monocline; 4 - Opole Depression, 5 - grabens, 6 - Sudetic Marginal Fault, 7 - main faults, 8 - other faults, 9 - topolineaments, 10 - GPS network points and their code names, l1 - precise levelling lines.

Poland, Germany and the eastern part of The Netherlands clearly follows topographic slope of the CESZ area towards the North Sea (Reicherter et al., 2005).

CENTRAL EUROPEAN SUBSIDENCE ZONE IN SW POLAND

In Lower Silesia, the sub-Cainozoic basement of the CESZ includes Fore-Sudetic Block and Fore-Sudetic (Wrocław) Monocline, separated by the Middle Odra Fault (cf. Cymerman, 2004). This fault trends WNW-ESE and, locally, NW-SE. From Oława town to the east, it is overlain by Upper Cretaceous strata that fill a Late Cretaceous-Neogene trough, traditionally called the Opole Depression (Kotański and Radwański, 1977). The eastern boundary of the CESZ is marked by exposures of Triassic and Upper Cretaceous rocks building the Kraków-Częstochowa Upland. This boundary has a wavy-like trace related to the presence of alternating sub-Cainozoic ridges and depressions oriented NW-SE. One of such fossil ridges has been found near Niemodlin. It is likely that it continues farther to the NW, up to Trzebnica (Fig. 2).

Roughly to the north of the Namysłów-Trzebnica-Oborniki Śląskie line, the basement of the sub-Permian-Mesozoic monocline includes Carboniferous rocks. They belong to the South-Wielkopolska Block (Żelaźniewicz and Aleksandrowski, 2008). The fault separating the Fore-Sudetic

Block from the South-Wielkopolska Block is also called the Middle Odra Fault or Silesian-Lusatian Fault, the extension of which is the Hamburg – Kraków Fault (Otto, 2003; Dörr et al., 2006; Mazur et al., 2006). Identical names pertaining to different faults in different regions make sometimes proper interpretation of geological events difficult.

The southern boundary of the CESZ follows the Sudetic Marginal Fault's morphotectonic escarpment (Scheck et al., 2002; Stackebrandt, 2004). Badura et al. (2004) placed this boundary in the Fore-Sudetic Block along the Strzelin-Taczalin fault zone, between Wądroże Wielkie (benchmark ROCH) and Grodków (benchmark SGRO; *cf.* Fig. 2). The fault zone is also accompanied by a relatively low morphotectonic step (Badura, 1999; Birkenmajer and Pécskay, 2002) and coincides in this segment with the Southern Odra Fault (Cwojdziński and Żelaźniewicz, 1995), showing a throw of 50-100 m. No pre-Neogene rocks can be found north of this fault.

Grabens and horsts of the so-called "Sudetic orientation" (NW-SE; Fig. 2) dominate in the western part of the Fore-Sudetic Block, while in the middle part a N-S orientation prevails following the boundary between the Bohemian Massif and Moravo-Silesian Zone (Brunovistulicum). Throws of the faults within sub-Cainozoic basement in the latter area range between 50 m and 200 m, increasing up to 800-1,000 m along the western margin of the Kędzierzyn Graben. The Upper Oligocene-Lower Miocene basalts occur near Wądroże Wielkie, Strzegom, Niemcza, Henryków and Strzelin (Birkenmajer et al., 2002, 2004; Badura et al., 2005; Awdankiewicz, 2005). Relatively small-size rhomboidal troughs and horsts occur in the Opole Depression filled with Cretaceous strata. The bounding faults are oriented NW-SE and NE-SW. These brittle faults probably developed due to post-Alpine compression active in the CESZ, combined with mobility of N-S-oriented faults in the basement of the Moravo-Silesian Zone.

The sub-Cainozoic basement of the Fore-Sudetic Monocline bears narrow tectonic grabens, the longest of which, Mosina-Oleśnica graben, trends NNW-SSE. From this structure branch off smaller, NE-SW oriented grabens. Highs in the Triassic bedrock, usually trending NW-SE, are clearly marked in the NE part of the study area. Less distinctly marked horsts of the same orientation are registered throughout the entire Fore-Sudetic Monocline. Fault throws range between 20 m and 100 m.

A distinct topolineament can be traced at the foot of the Trzebnica Hills, north of the Odra River valley (Badura and Przybylski, 2005). The lack of wellbore data makes it impossible to decide whether it is a neotectonic structure. The topolineament continues less clearly to the ESE; only close to Namysłów it is accompanied by a few metres high fossil tectonic escarpment.

2. STATE OF RECENT GEODYNAMIC RESEARCH IN SOUTH-WESTERN POLAND

The first stage of geodynamic research in SW Poland included precise levelling, based on which two maps of recent vertical crustal movements were constructed (Wyrzykowski, 1985; Kowalczyk, 2006). Differences between these maps result from different periods of the measuring and adopted reference levels. The main tendencies are, however, similar. Lower Silesia, like nearly all of Poland, is dominated by subsidence showing variable rates. The lowland part of Lower Silesia displays two zones of intensive subsidence (up to 3 mm/yr^{-}): between Bad Muskau and Wrocław and along the middle and lower course of the Nysa Kłodzka River. The remaining areas tend to reveal lowering movements not exceeding 1 mm yr^{-1} (Kowalczyk, 2006). Slower subsidence is confined to a relatively narrow, W-E trending, belt that marks the northern extent of metamorphic bedrock in the Fore-Sudetic Block close to Trzebnica Hills and along the upper Odra River valley.

Recent crustal movements in main fault zones of the Sudetes and Fore-Sudetic Block have been measured using GPS techniques since 1996, within the GEOSUD geodynamic network (Cacoń and Dyjor, 2002). Epoch measurements were conducted annually until 2007. The results of data processing and interpretations pertaining to recent tectonic activity of the Sudetic Marginal Fault are discussed at large by Kontny (2004), Badura et al. (2007) and Kapłon and Cacoń (2009), who conclude about recent compression at the boundary between the Sudetes and Fore-Sudetic Block.

In 2007, a new geodynamic network (Geodynamic Network of the Wrocław Basin; GeoNetWB) was established embracing the SE part of the CESZ between Legnica, Wrocław and Opole, *i.e.* an area located in the Middle Odra Fault Zone. This area lies in a zone of subsidence that extends between the North Sea and the north-western part of the Carpathian arc (Kockel, 1988; Aizberg et al., 2001; Stackebrandt, 2004; Badura et al., 2004). Recent activity of this zone is documented by the results of repeated precise levellings pointing to intensified subsidence in the Wrocław region (Grzempowski et al., 2009).

3. GEODYNAMIC NETWORK OF THE WROCŁAW BASIN

The Geodynamic Network of the Wrocław Basin (GeoNetWB) extends along the Legnica – Wrocław – Opole line and covers an area of appr. 6,000 km^2 (Fig. 2), 120 km long and 65 km wide. The network consists of 20 points stabilized as concrete blocks. Three of them are the part of the GEOSUD network and five are the part of the GPS levelling network for the city of Wrocław (Cacoń et al., 1999).

The GeoNetWB includes the most important structural units distinguished by geological methods. The oldest structural stage is associated with the

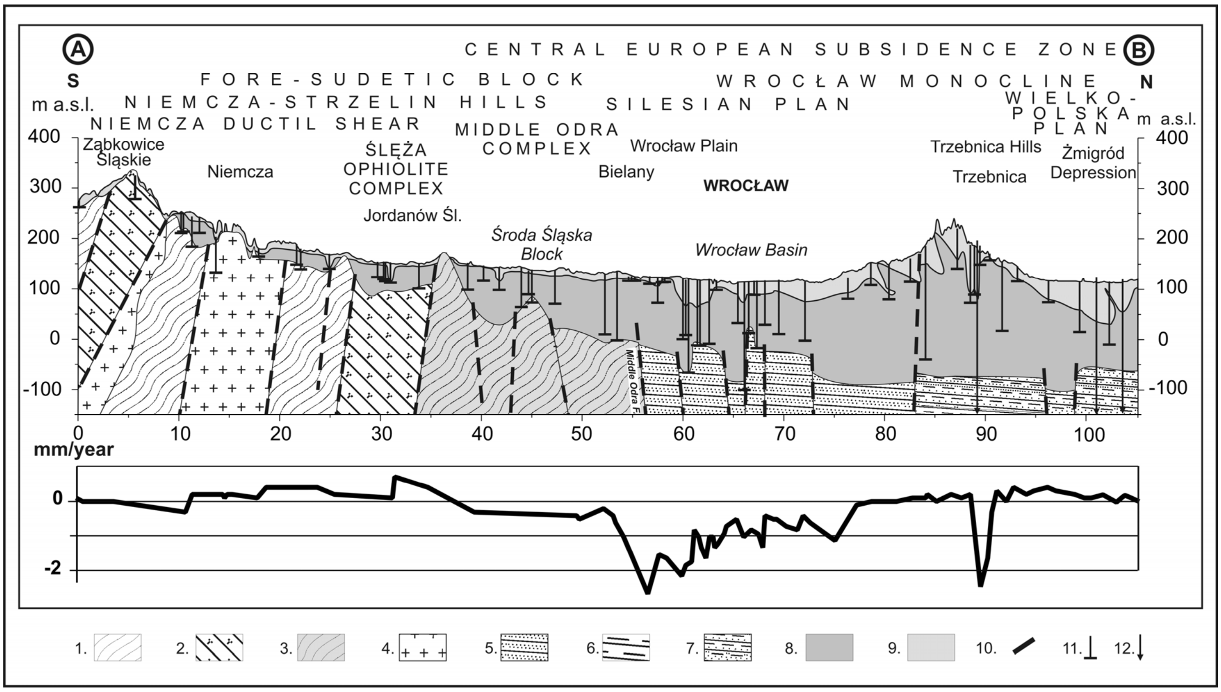

Fig. 3 Geological cross–section and velocities of vertical displacements (calculated on the basis of 1975-1999 measurements) along the Ząbkowice Śl. – Wrocław – Trzebnica line. Niemcza Ductile Shear Zone and Ślęża Ophiolite Complex: 1 - metamorphic schists, gneisses and amphibolites, 2 - serpentinites; Middle Odra Complex: 3 - metamorphic schists, gneisses, granitoids and amphibolites, 4 - Variscan granitoids; Wrocław Monocline: 5 - Lower and Middle Triassic sandstones, 6 - Middle Triassic dolomitic limestones, marls, claystones, 7 - Upper Triassic claystones, limestones, dolomites, 8 - clays, sands, lignites, 9 - tills, fluwioglacial sands, gravels, loesses; 10 - faults; 11 - wells; 12 - deep wells.

Variscan orogeny, after which a Late Palaeozoic graben was formed in the Fore-Sudetic Block. Mesozoic deformations are especially well visible between Wrocław and Opole, where Cretaceous strata are preserved in a tectonic trough. The last, neotectonic stage includes Late Oligocene through recent tectonic movements.

Previous interpretations of neotectonic movements occurring in the Fore-Sudetic Block assumed reactivation of main faults that were already formed in the Variscan orogeny, an in the Opole Depression also during the Late Cretaceous – Early Palaeogene orogeny.

Tectonic motions of the South-Wielkopolska Block can have a bearing on the displacements of the Jażwiny (000A), Cieśle (000B) and probably also Trzebnica (TBNI) and Krasowice (KRAS) benchmarks. The Late Palaeozoic eastern Fore-Sudetic Basin is situated in the eastern part of the Fore-Sudetic Block between Grodków and Laskowice Wrocławskie (Kiersnowski, 1995). Benchmarks Stary Grodków (SGRO) and Godzikowice (000C) are located exactly upon this tectonically-controlled basin.

Benchmarks Moczydlnica Klasztorna (MOKL), Bukowice (BUKO), Trzebnica (TBNI), Jaźwiny (000A), Cieśle (000B) and Krasowice (KRAS) are situated in the Fore-Sudetic Monocline. In the middle part of the GPS Network, the permanent station WROC is located.

Benchmarks Zakrzów (ZAKR), Godzikowice (000C), Stary Grodków (SGRO), Grabin (GRAB) and Dąbrowa (DABR) are situated in the Opole Depression, in the eastern part of the Fore-Sudetic Monocline.

The Neogene Late Alpine tectonic movements affected the entire study area. To the north of the Sudetes, this area became part of the CESZ. Rates of subsidence increased towards the north. In the southern part of the Fore-Sudetic Block, numerous exposures of crystalline rocks extend up to the Strzelin-Taczalin fault. In this area, benchmarks Strzegom (SGOM), Radzików (000D) and Strzelin (STRZ) have been mounted. The Strzelin – Taczalin fault throws the northern part of the Fore-Sudetic Block by ca. 50-100 m. This part, covered by Cainozoic strata, contains the benchmarks Rosochata (ROCH), Kostomłoty (KOST), Źródła (000E), Tyniec Mały (TYMA) and Węgry (WEGY). During planning of the benchmark locations, results of analysis of vertical changes recorded by repeated precise levelling have been taken into account (Grzempowski et al., 2009).

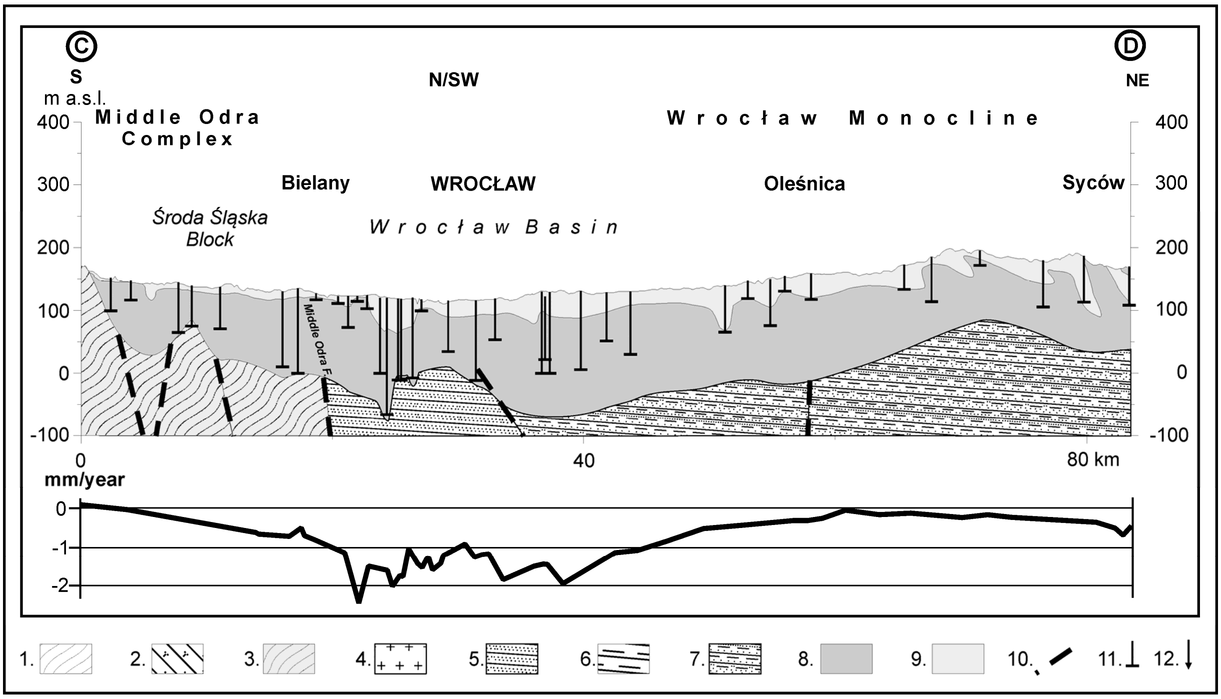

Fig. 4 Geological cross–section and velocities of vertical displacements (calculated on the basis of 1956-1999 measurements) along the Wrocław – Syców line. See Figure 3 for explanations.

Velocities of vertical displacements calculated on the basis of measurements conducted from 1975 to 1999 on precise national levelling lines along the Ząbkowice Śląskie – Wrocław – Trzebnica geological cross–section are shown in Figure 3. There are also presented velocities of vertical displacements, which were calculated on the basis of measurements from 1956 to 1999 on a national levelling line along the Syców – centre of Wrocław geological cross-section (Fig. 4). Velocities of vertical displacements in both figures (Figs. 3, 4) point to subsidence of the axial area of the OFZ in relation to the benchmarks located outside the northern and southern margins of this zone.

4. CHARACTERIZATION AND RESULTS OF 2008-2010 GPS CAMPAIGNS

GPS measurements of the network's benchmarks were carried out three times (2008, 2009, 2010), each time in 48 hours sessions (2 × 24 hour). Coordinates and velocity calculations were performed using the ADDNEQ2 module of the Bernese Software v. 5.0 (Dach et al., 2007).

For the combined solutions from the three campaigns, mean errors of coordinates in N and E axes are ±1.4 mm and ±1.7 mm, respectively. Maximum mean errors of the horizontal coordinates reach ±3.6 mm in N and ±3.9 mm in E directions. The calculated values of intraplate velocities range from –5.0 mm yr^{-1} to +2.6 mm yr^{-1} for N coordinate, and from -7.4 mm yr^{-1} to +2.8 mm yr^{-1} for E coordinate.

Modulus of the displacement vector of the points from the first to the last measurements reached a maximum of 15 mm. Vectors of the GPS point displacements in 2008 – 2010 period and error ellipses at significance level of 95% are shown in Figure 5. Significant displacements exceeding errors of measurements (vector displacements crossing the ellipses' boundaries) occurred at benchmarks located near the axis of the OFZ (MOKL, BUKO, 000E, WEGY, ZAKR and SGRO) as well as at 000D, ROCH and DABR.

Based on the results of GPS measurements, a continuous model of the points velocity was determined and horizontal strains in principal directions (Fig. 6) were calculated. For significant strain, values exceeding strain error (strain lines crossing contours of ellipses) at significance level of 95 % should be accepted. The calculated horizontál strain at GPS benchmarks range from -3.5 mm/10 km/year to +3.4 mm/10 km/year.

5. INTERPRETATION OF GEODETIC DATA

Repeated precise levelling measurements conducted along N-S trending transects point to subsidence of the Wrocław Basin. The Ząbkowice Śląskie - Syców transect (Fig. 3) shows the strongest correlation between geodetic and geological data, while for the Bielany Wrocławskie-Trzebnica transect (Fig. 4) the lack of deep boreholes makes comparison between topography of the sub-Cainozoic surface and trends of vertical movements difficult. Our paper

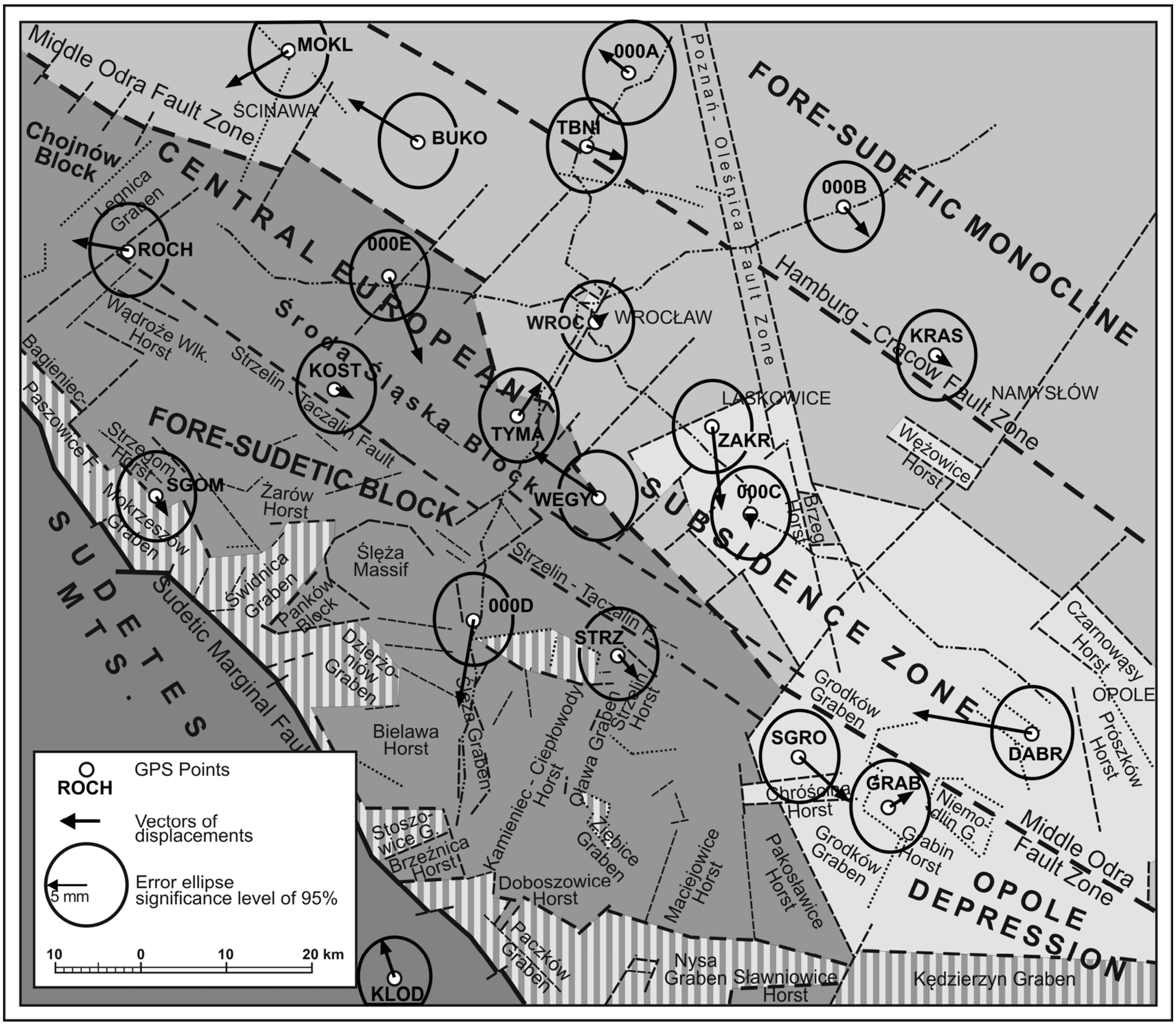

Fig. 5 Vectors of points displacements in 2008–2010 period.

focuses on displacements recorded along the two most important precise levelling lines. Details concerning transects marked in Figure 2 have already been presented by Grzempowski et al. (2009). The E-W trending transects do not show distinct displacements, except those occurring in the western part of Wrocław city, in the Bystrzyca fault zone. The Wrocław-Opole transect is much more difficult to interpret, most probably due to the lack of sufficient wellbore data. In the Opole Depression there occur rheologically similar poorly consolidated Lower Coniacian marls and Upper Miocene clays (Alexandrowicz, 1973). Moreover, the Upper Cretaceous strata are strongly normal-faulted into numerous horsts and grabens (Kotański and Radwański, 1977; Badura and Przybylski, 1994, 1995).

GPS measurements confirm the presence of horizontal displacements in the CESZ area (Figs. 5, 6). This zone is typified by stronger deformation in the Wrocław Basin and SE of Wrocław, i.e. between Oława and Grodków. All benchmarks of the Wrocław region (WROC, TYMA, ZAKR, WEGY and 000C) are placed in the Odra Fault Zone, separating the Fore-Sudetic Block and the Fore-Sudetic Monocline. In the marginal part of the latter, the sub-Cainozoic surface shows a hilly landscape pointing to either Miocene erosion or small-scale vertical displacements along the boundary between this unit and the Fore-Sudetic Block (Badura, 1999). Analyses of the sub-Quaternary and sub-Cainozoic surfaces (Badura et al., 2004) indicated that in the Wrocław region a rhomboidal trough, called the Wroclaw Basin, occurs, its long axis being oriented NW-SE.

Compressive strain recorded close to the KRAS benchmark is probably associated with a „bay” of the CESZ close to its eastern boundary with the Central Polish Uplift. Stronger compressive strains have also been recorded in an area comprised between Oława and Grodków (benchmarks SGRO, GRAB). In the Grodków area, geological structure of the Fore-

Sudetic Block changes: subcrops of the Lower Palaeozoic metamorphic rocks associated with the Western Sudetic Saxothuringian Zone disappear and in the sub-Triassic basement occur rocks typical for the Eastern Sudetes, *i.e.* the Moravo-Silesian Zone. Both these units are separated by the Brzeg-Nysa Shear Zone (Cymerman, 1991; Cymerman et al., 1997), above which a 1,100 m deep, Late Palaeozoic graben-like Fore-Sudetic Basin was formed (Kiersnowski, 1995; Dadlez et al., 1998). Subsidence within this graben probably continued in the Triassic and even in the Late Miocene times. Close to Grodków, the E-W trending Meta-Carpathian Swell was broken leading to migration of the CESZ-related depocentre towards the SE, into the "Nysa bay" of the Carpathian Foredeep. It is likely that this area still undergoes subsidence, as indicated by the N-S trend of the Nysa Kłodzka River valley (Przybylski, 1998). The valley axis coicides with maximum thicknesses of Neogene strata between Strzelin Hills and Opole (Badura et al., 2004).

Geological interpretation of the Grabin benchmark's (GRAB) behaviour is not clear. The benchmark is situated on an uplifted horst (Badura and Przybylski, 1994, 1995), the basement of which is built up of gneisses and Upper Cretaceous and marine miocéne strata. The structure occurs to the east of a Permian graben, hence, one would expect extensional strain (Fig. 6) and not compressive one. The benchmark at Dąbrowa (DABR) reveals extensional strain. This benchmark is located on an elongated, narrow horst oriented NW-SE. The horst became undermined by the Odra River forming a *ca.* 20 m high escarpment, at the base of which Coniacian clayey marls occur (Alexandrowicz, 1973).

Compressive strains recorded near Legnica (ROCH) and Ścinawa (MOKL) are probably associated with the NNE-SSW trend of a tectonic graben, the depth of which changes from 150 m near Legnica to 300 m near Ścinawa. In the Ścinawa area, the Odra River created in the Late Pleistocene a presumably neotectonically-controlled water gap. Formation of this gap changed the drainage pattern over a large portion of central Lower Silesia.

The Kostomłoty (KOST) benchmark is placed on the hanging wall of the Strzelin-Taczalin Fault. Extensional strain recorded at this locality appear to reflect subsidence of the northern part of the Fore-Sudetic Block.

As already expected, extensional strain was recorded in the Fore-Sudetic Block near Strzelin (STRZ) and Łagiewniki (000D), situated within the Niemcza-Strzelin Hills horsts (Badura, 1999). Geological data from this area indicate that N-S oriented hills are being recently uplifted, whereas river valleys follow narrow tectonic grabens.

The Strzegom benchmark is situated in a zone of numerous tectonic steps throwing down the Strzegom Hills horst towards the Mokrzeszów Graben (Dyjor and Kuszell, 1977; Kural, 1979). That is probably why this benchmark shows only minor horizontal displacement towards the SE (Fig. 5).

Following previous predictions, three benchmarks located north of the Wrocław Basin (TBNI, 000A and 000B) point to recent uplift. Relative vertical movements of the northern margin of the basin near Trzebnica appear to confirm the presence of a WNW-ESE trending fault along the southern side of the Trzebnica Hills. This side terminates with a distinct topolineament pointing to a ca. 30 m uplift of the hills, probably in the Holsteinian interglacial (Badura and Przybylski, 2004). Analysis of precise levelling data confirms present-day relative uplift of the northern margin of the Wrocław Basin (Grzempowski et al., 2009).

The present-day state of recognition of geological structure provides no clues as to the origin of extensional strain in areas situated close to benchmarks 000A and 000B.

Benchmark BUKO is located on an inferred NE-SW trending fault, on which the Odra River valley changes its course from NW-SE to WNW-ESE.

Extension at benchmark 000E reflects uplift of the northern fragment of the Fore-Sudetic Block, indicated as well by benchmark elevation changes in this region (Grzempowski et al., 2009).

6. CONCLUSIONS

The results of repeated precise levelling during a 43-year-long timespan point to subsidence of the Wrocław Basin (Figs. 4, 5), of rates increasing outside the basin margins. The highest rates of vertical movements are confined to Wrocław city, partly due to anthropogenic factors. It should be noted, however, that vertical deformations observed during 1956-1999 period attain significant values at a distance up to 15 km away from the city limits and relatively diminish close to the southern margin of the Wrocław Monocline. Results of GPS measurements point to compressive strain in the axial part of the CESZ southwest of Wrocław (benchmarks ZAKR, 000C) along W-E direction, and in the Opole Depression (benchmarks SGRO, GRAB) along NNW-SSE direction. Strain directions in this zone appear to follow a N-S oriented deep-seated Permian graben (Kiersnowski, 1995) and the regional Brzeg-Nysa Shear Zone (Cymerman, 1991; Cymerman et al., 1997).

Extensional strain occurs at the southern CESZ margin, along the W-E direction in the uplifted part of the Fore-Sudetic Block (benchmarks 000D and STRZ), as well as at the northern margin of this zone, along W-E and NW-SE directions (000A, TBNI, BUKO). Horizontal extension at benchmarks 000B and 000E can be a result of vertical deformations increasing towards Wrocław, as indicated by precise levelling.

In the western part of the GeoNetWB network, compressive strains prevail. They are probably associated with a local tectonic knot where N-S and

NW-SE trending faults intersect one another. The N-S oriented Legnica – Ścinawa graben is abutted on to the east by the diagonal Strzelin-Taczalin fault, which throws down the Fore-Sudetic Block by approx. 100-150 m.

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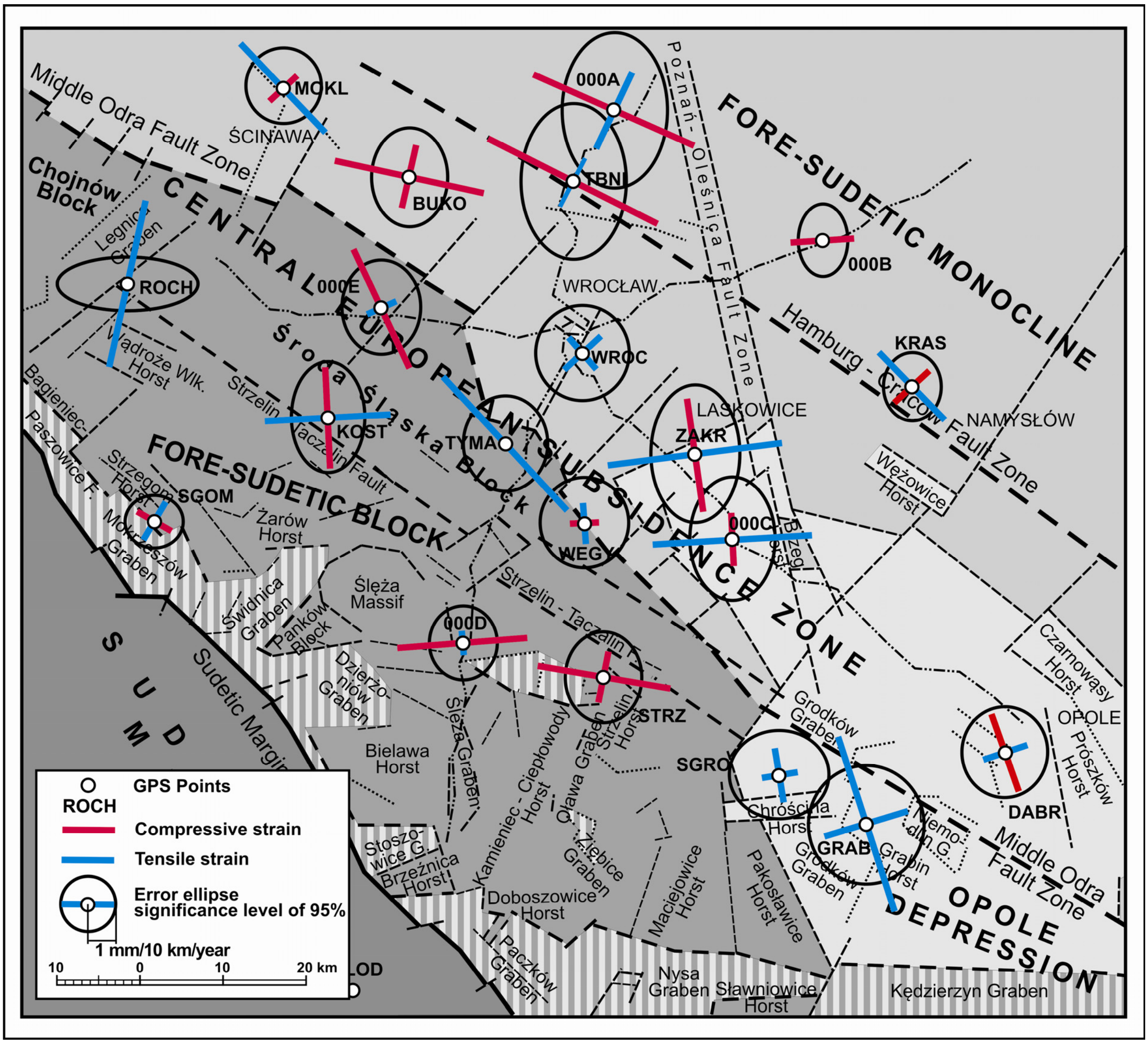

Fig. 6 Horizontal strain in the study area calculated on the basis of velocities of GPS points obtained from measurements in 2008-2010 period.