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RESEARCH ON THE MARGINAL SUDETIC FAULT ACTIVITY WITH USE OF GPS AND PRECISE LEVELING TECHNIQUES

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ABSTRACT
This paper presents results of the research on tectonic activity of the marginal sudetic fault (MSF). Velocities of points obtained from processing GPS observations in the GEOSUD network and results of national precise leveling networks have been analysed. Results of 1996–2005 GPS measurements and results of measurements of selected points for the 2006–2007 period were taken considered. The velocities calculated by means of the *Bernese GPS Software 5.0* were used to test hypothesis on present-day strike-slip movement activity of the marginal sudetic fault. The relationship between the calculated velocities and the length of projection onto the fault's line was studied. The second part contains analysis of relative vertical velocities of benchmarks, making up the 1st and the 2nd class national precise leveling lines crossing the fault line, to study its vertical activity. Velocities of horizontal and vertical changes of points on both sides of the fault were compared with models described in literature.

KEYWORDS: marginal sudetic fault, tectonic activity, GPS measurements, precise leveling

1. INTRODUCTION

Geodynamic studies in the Lower Silesia region have up to now included determination of movement of tectonic structures, both one-dimensional (vertical movements) based on precise leveling measurements (Gierwielaniec and Woźniak, 1983; Wyrzykowski, 1985; Kowalczyk, 2006) and two-dimensional (horizontal movements) with the use of GPS technique (Kontny, 2003; Bosy et al., 2006). Determination of three-dimensional components of movements has been carried out on selected research areas only, using combined: leveling, GPS, Total Station and relative observations. These researches focused on determining movements of points representing rock blocks undergoing mass movements on the Szczeliniec Wielki and Ostaš (Cacoń et al., 1994) and also on determining movements of tectonic blocks (Sudety Mts. Massif, Fore-Sudetic Block, Fore-Sudetic Monocline (Kontny, 2003)).

In this work an attempt to verify the hypothesis on present-day activity of marginal sudetic fault with the assumption of partial elasticity of blocks (Sudety Mts. Massif and Fore-Sudetic Bock) separated by this fault has been made. Source data from the earlier mentioned papers including vectors of horizontal velocities of the geodynamic network GEOSUD points and relative vertical velocities of benchmarks in precise leveling lines have been used for this purpose. Velocities of research points were presented as the distance from the fault function after being projected onto the direction of expected movements – horizontal along the fault line (*strike-slip*) and vertical (*normal slip*).

2. RESEARCH NETWORK

The research network covers the Polish part of the marginal sudetic fault from Czerna (NW) to Złoty Stok (SE). In this area the research network GEOSUD (Fig. 1) has been established. It consists of 39 points and covers the zone from Złotoryja to Złoty Stok. Additionally the MSF cuts seven 1st or 2nd class national leveling lines (Figs. 1 and 6).

GPS measurement data is from the 1996-2007 period, leveling data includes three measurement campaigns of the 1st class network (1953-58, 1975-80, 1999-2002) and two measurement campaigns of the 2nd class network (1955-1958, 1980-1990).

3. DATA PROCESSING METHODOLOGY AND RESULTS

3.1. *ANALYSIS OF HORIZONTAL CHANGES*

Estimation of horizontal velocities in the ITRF2000 system was performed with the *Bernese GPS Software v. 5.0* (Dach et al., 2007). Files containing previously created (Kontny, 2003) sets of normal equations from daily sessions carried out in

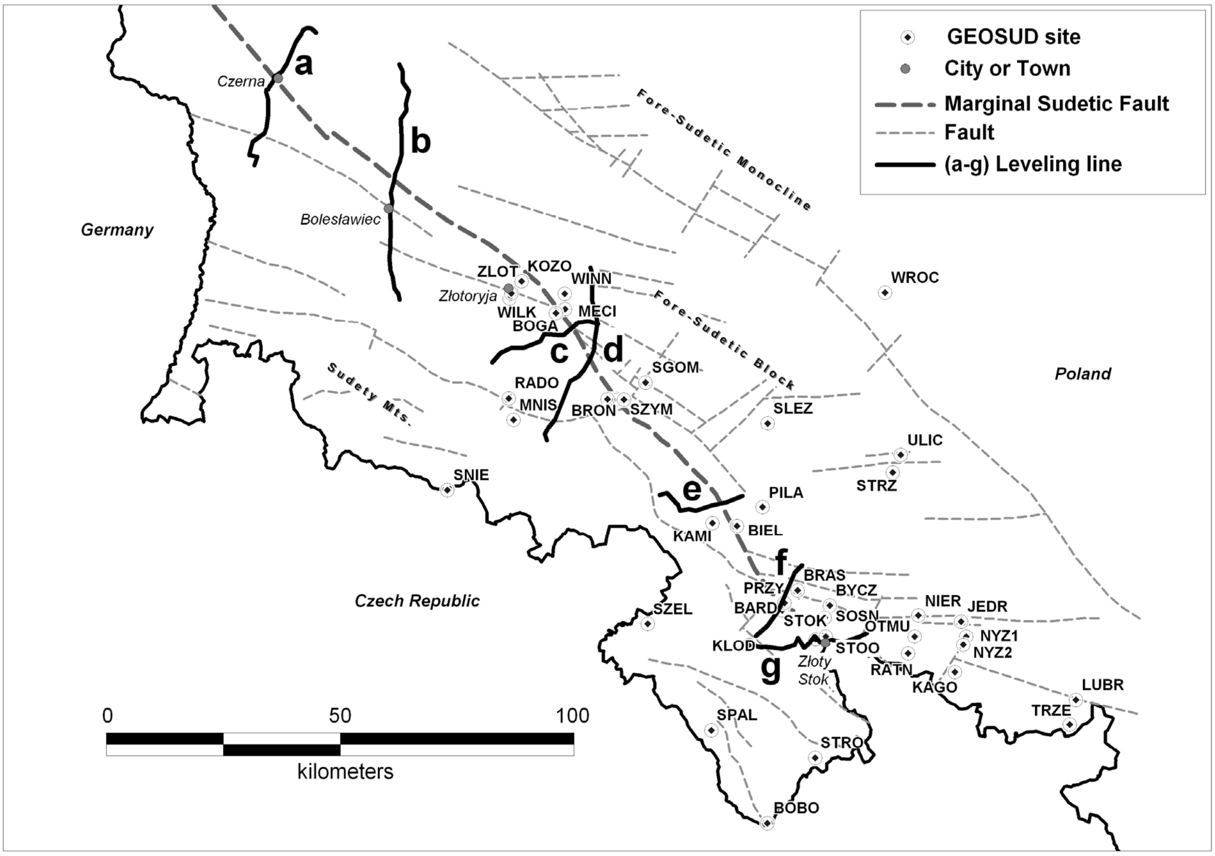

Fig. 1 Research network GEOSUD points and national leveling network benchmarks used in this work.

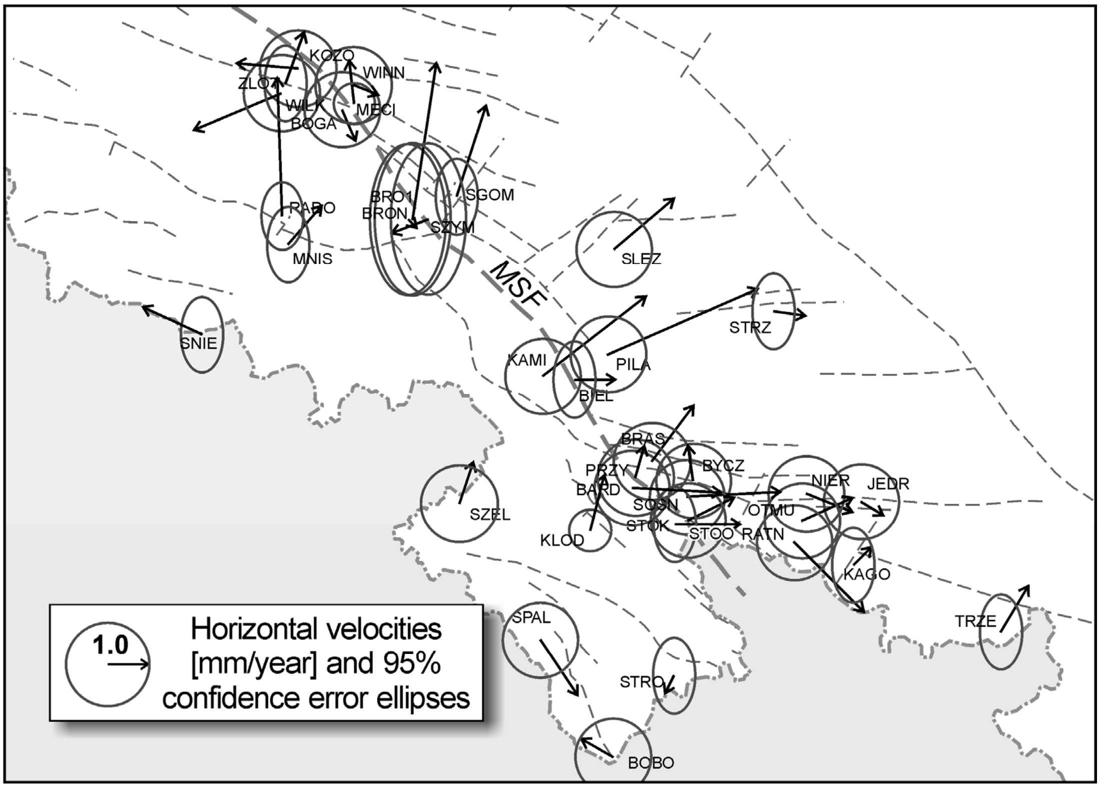

Fig. 2 Intra-plate horizontal velocities of the GEOSUD network points.

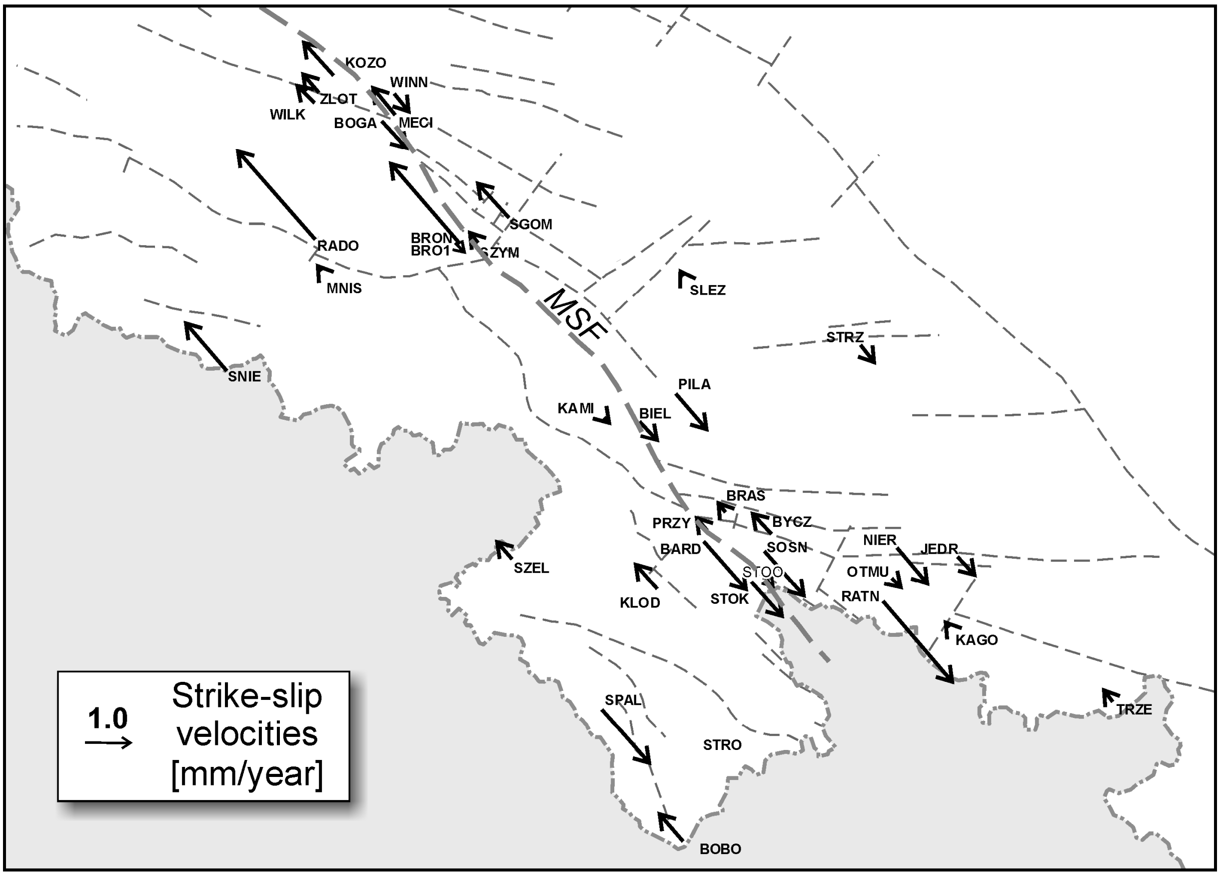

Fig. 3 Strike - slip velocities of the GEOSUD network points.

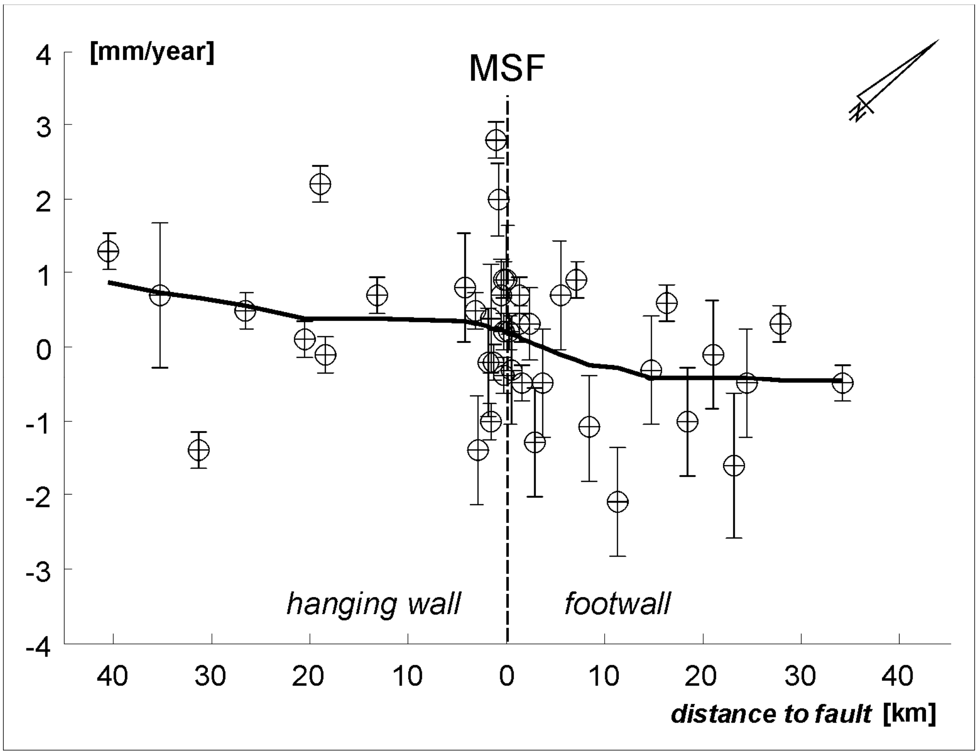

Fig. 4 Strike – slip velocities and their estimation mean errors, presented as distance to the fault line function.

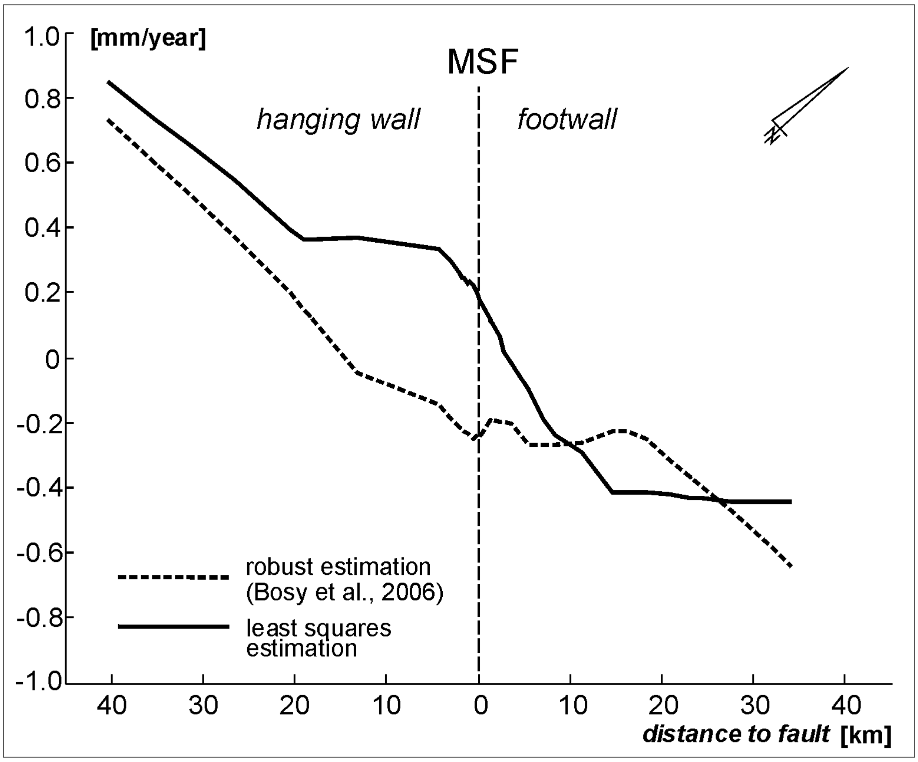

Fig. 5 Trends of horizontal movement velocities calculated from GEOSUD network points velocities obtained with the robust and ordinary least squares methods.

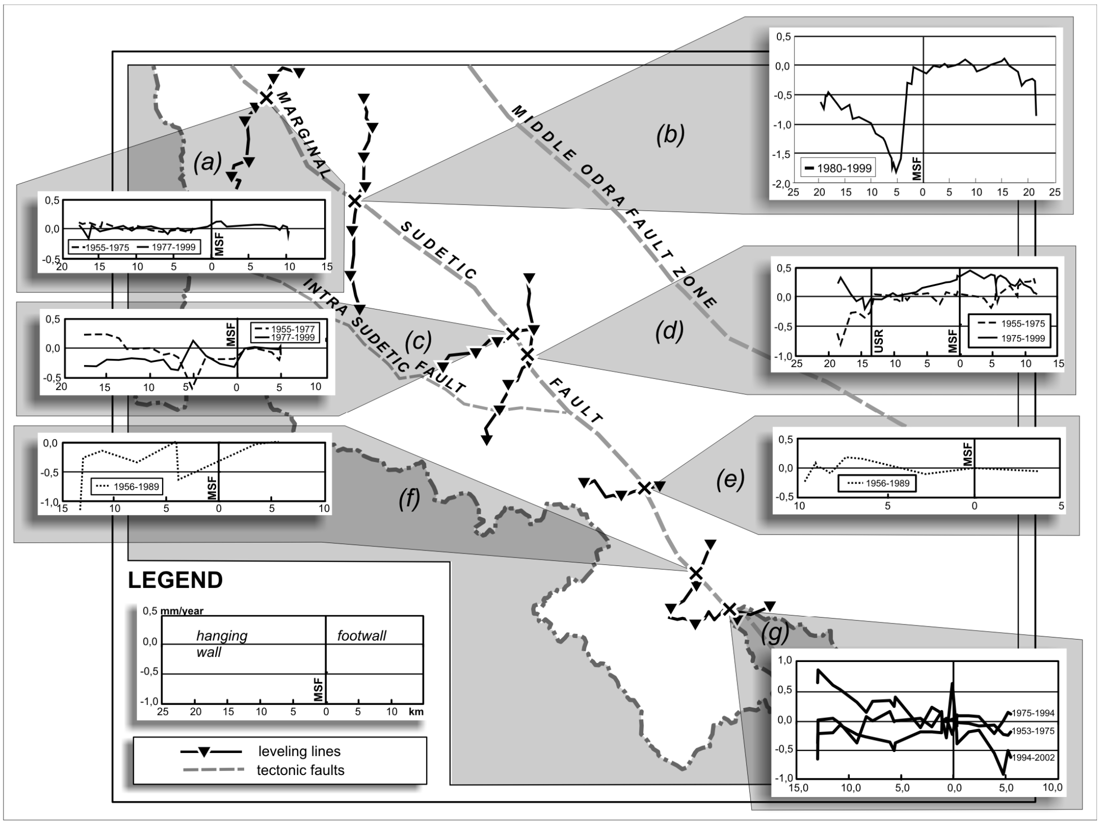

Fig. 6 Velocities of relative vertical changes [mm/year] determined in 1st and 2nd class leveling lines.

GEOSUD projects were used in calculations. These sets have been combined in the ADDNEQ2 module of the Bernese Software and adjusted using LS (least squares) method. A minimum constrain assumption for the adjusted coordinates of daily sessions into epoch coordinates of reference stations EPN: BOR1, GOPE, PENC, WROC, WTZR has been made. As a result, coordinates of research points for the 1997.0 epoch and velocities in the ITRF system were obtained. Taking into consideration movement of the Eurasian plate caused by the thrust of the African plate the trend was removed by subtracting the plate's APKIM2000 model velocity from the ITRF2000 system velocity (Drewes and Angermann, 2001). Calculated, in this way, intra-plate velocities have been presented in Figure 2.

The calculated velocities of research points were tied to the marginal sudetic fault's activity through projection of vectors onto the fault line. Strike-slip velocities along the fault line were obtained (Fig. 3). Then the velocities were put together with distances of points from the fault line (Fig. 4).

Analysis of measurement data (1953-2007), considering the period without tectonic activity (with exception of the Bolesławiec area), has been made. Decrease of movement velocity of the fault walls with decrease of the points' distances from the fault line has been anticipated. This assumption is typical for the stress accumulation (inter-seismic) phase and has been confirmed through geodetic observations (Scholz, 2002).

To test the hypothesis a regression function of the points' velocities in relation to their distance to the fault was defined. Considering non-linear character of inter-seismic changes and highly dispersed values of the velocities obtained, as well as uneven distribution of measured points, regression analysis using locally (by ranges) weighted LOWESS polynomial function (Cleveland, 1979) was performed. This is one of the methods for smoothing datasets. The analysis was performed with the least squares method for a defined percentage of points in a given range of the dataset. A robust weighted LOWESS function variation in the form of a "*bisquare*" weighted function was used for trend analysis (Holland and Welsh, 1977).

$$w_i = \left[1-\left(r_i/6M\right)^2\right]^2, \; for\ r_i < 6M$$

$$0, \; for\ r_i \geq 6M$$

$$M = median\left(\left|r\right|\right)$$

where, (w_i) – is the weight of regression for point i, (r_i) – residual value of the regression function for point i. The estimation of the regression function values for the ranges is an iterative process with minimization of the influence of the most outlying observations (Matlab, 2005). The results calculated in Matlab are presented in Figure 4.

To check the applicability of using the least squares (LS) method, the trend line of strike-slip changes was compared with the trend line determined for the 1996-2005 data by Bosy and others (2006). Obtained discrepancies (Fig. 5) are similar to the errors of determining the velocities of lateral movement (Fig. 4). This fact confirms that the applied data processing approach has been correct and indicate changes of velocities that are related to the distance of research points from the fault line.

3.2. ANALYSIS OF VERTICAL CHANGES

Processing of the leveling data, made available by the Central Office for Geodetic and Cartographic Documentation, included height changes measured between 1953 and 2002 for the seven lines crossing the fault (Figs. 1 and 6). Ordinate (Y-coordinate) of benchmarks was determined independently for each line in a given campaign, with one benchmark assumed to be stable. Then height changes of benchmarks between campaigns were determined using LS method and the assumption of movement minimization. The height changes have been presented as velocities because of different periods between measurements campaigns (Fig. 5). Taking into account oscillating character of the determined velocities noticeable for the lines: *c, d, g,* average velocities were calculated and presented as benchmark's distance to the fault line function. Trend line was fitted using the same method as in the case of horizontal velocities (Fig. 7). Highly dispersed values of velocities on the fault's hanging wall indicate heterogeneous model of vertical changes occurring along the fault line.

One should notice the subsidence zone in the leveling line "*b*" near the town of Bolesławiec. Fig. 8 shows location of main tectonic discontinuities across which the described leveling line runs. The maximum subsidence value has been registered on the benchmarks close to the Warta Bolesławiecka – Osiecznica Fault (WOU). Locations of earthquake epicentre records from the IRIS database (*IRIS, 2007*) are also included in the illustration. The epicentres recorded cannot be connected with locations of the faults because of the nearby location of the Legnica-Głogów Copper Mining Area (LGOM) and mining operations near Bolesławiec. However, the results of leveling observations combined with tectonic data point to the Bolesławec area as the zone of the greatest vertical changes in the Polish part of the marginal sudetic fault.

4. DISCUSSION

The direction of lateral movement changes is convergent to the trend of changes for fault zones in Central Europe obtained with finite element method by Jarosinski and others (*2006*).

The expected movement of the fault's walls has been caused by compressive forces acting between the

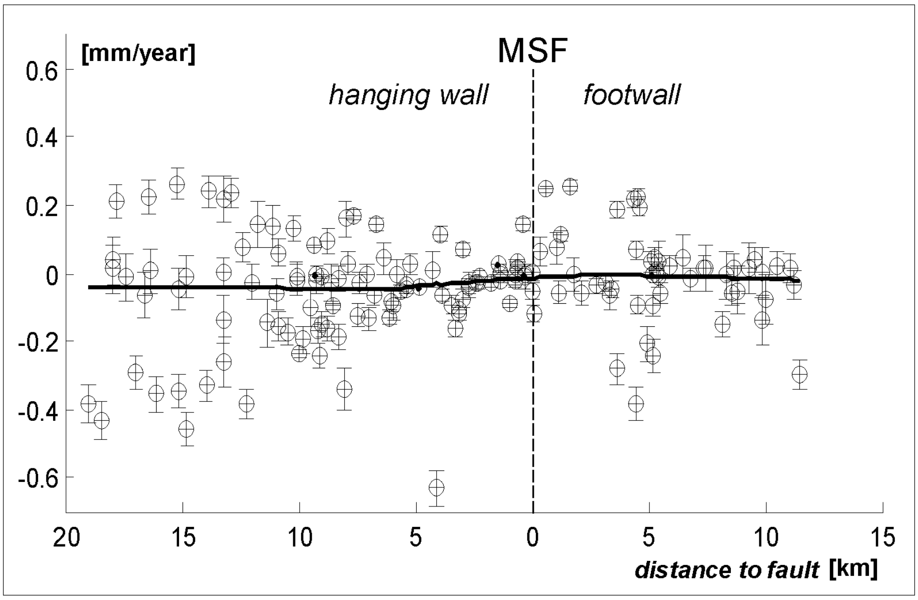

Fig. 7 Vertical velocities and their estimation mean errors presented as distance to fault line function.

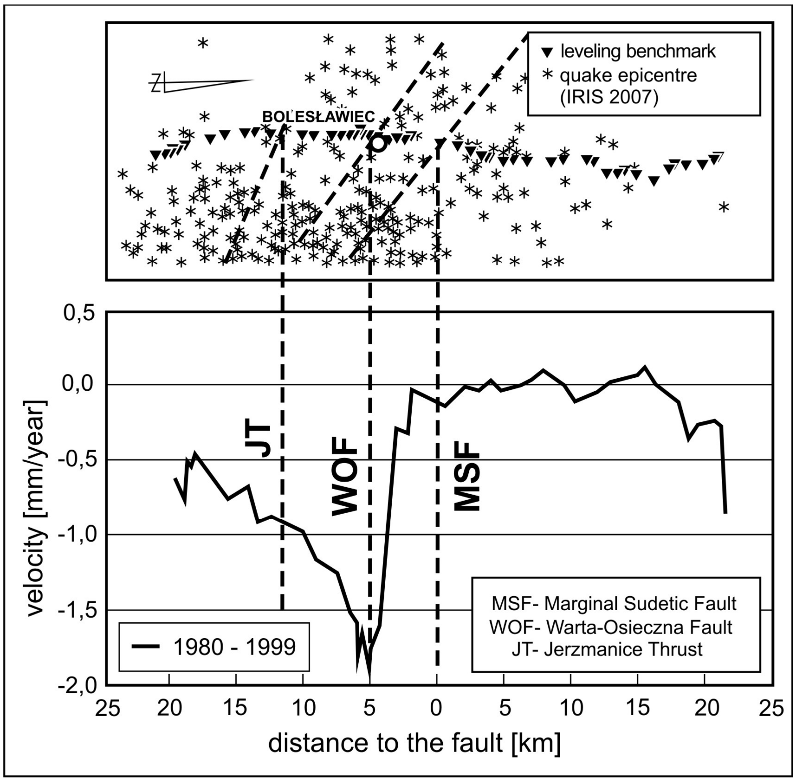

Fig. 8 Subsidence zone in the town of Bolesławiec area, location of faults and thrusts and earthquake epicentre records (1953-2007) from the IRIS database (IRIS, 2007).

African Plate and the East-European Craton (Jarosiński, 2006). Consequently the hanging wall of MSF (SW) should demonstrate greater movement than the footwall (NE). This is only partially confirmed by the obtained trend of strike-slip changes. The velocities of the hanging wall reach 0.8 mm/year, whereas for the footwall 0.5 mm/year (Fig. 5). The vertical changes are also greater on the hanging wall side.

Robust regression of the lateral velocities has revealed relationship between the decreasing value of velocity and decreasing distance from the fault line.

This indicates partially elastic character of the interaction between the Sudety Mts. Massif and the Fore-Sudetic-Block. The lack of present-day tectonic shaking connected to the MSF activity and the results of lateral movement velocity regression may imply that stresses are cumulating along the fault line. This would agree with the so-called seismic cycle theory and the simple elastic rebound model for the intra-seismic phase (Scholz, 2002).

The vertical changes registered in the Bolesławiec area could be the results of a complex process influenced by anthropogenic factors, stresses in the earth's crust and tectonic structure.

5. CONCLUSIONS

The determined velocities of strike-slip movements indicate that MSF activity is consistent with the *simple elastic rebound model* (Scholz, 2002), which is characteristic for the inter-seismic phase. However, the complexity of the area's tectonic structure, unrepresentative, for every tectonic structure, number of points and, particularly, existence of faults adjoining the MSF, do not allow the conclusion on the stresses build up in the fault's plane to be formulated. This cannot be verified through geological studies either, as no measurement data on earth crust stresses (*breakouts*) exist for this area. Vertical changes of benchmark heights occur mainly on the fault's hanging wall and have heterogeneous character. For the period of available leveling data no changes indicating normal character of present-day MSF activity have been observed.

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