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RECENT LOCAL GEODYNAMICS IN THE CENTRAL PART OF THE STOŁOWE MTS.

Stefan CACOŃ [1)]*, Jan KAPŁON [1)], Bernard KONTNY [1)], Josef WEIGEL [2)], Otakar ŠVÁBENSKÝ [2)] and Jiři KOPECKÝ [3)]

[1)] *Institute of Geodesy and Geoinformatics, Wrocław University of Environmental and Life Sciences, Grunwaldzka 53, 50-357 Wrocław, Poland, tel/fax.: +48713205617*
[2)] *Department of Geodesy, Brno University of Technology, Veveři 95, 662 37 Brno, Czech Republic, tel.: +420-541147211*
**Corresponding author's e-mail:* stefan.cacon@igig.up.wroc.pl

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ABSTRACT
The paper presents results of epoch satellite GPS and gravimetric measurements performed on the geodynamic network in central part of the Stołowe Mts. between 1993 and 2009. The research results show significant changes of gravity on most of the points and significant horizontal movement of one point in the central part of the area. The results confirm present day activity of the zone where faults Polický, Bělský and Czerwona Woda Fault Zone exists. In addition, they correspond with the studies of seismic activity in this part of the Sudety Mts.

KEYWORDS: Stołowe Mts., geodynamics, GPS, horizontal velocities, gravimetry

INTRODUCTION

The Stołowe Mts., the southeastern part of the Sudety Mts. Belongs to the northeastern part of the Bohemian Massif. The mountains cover an area from Polanica Zdrój through Batorów and Karłów in Poland and Police nad Metují and Adršpach in the Czech Republic to Mieroszów again in Poland (Fig. 1). The typical plate form of these mountains with gentle slopes often turns into high rock cliffs made of ashlar sandstone blocks. The present day layout of the region was shaped mainly in the Upper Cretaceous period, when the strongest tectonic movements had occurred, followed by later wind and water erosion processes, as well as other phenomena. Tectonic movements of smaller intensity still exist as demonstrated by seismic activity of this area. Work by Karnik et al. (1984) showed that in the area of the Stołowe Mts. in the 1883-1979 period 10 earthquakes of the 4 to 7º MSK-64 magnitude had taken place. According to Schenk et al. (1989) these phenomena are connected, mainly with the present day activity of the Pořiči-Hronov faults zone as is confirmed by the 1979 earthquake of the 5º MSK magnitude. The earthquake prediction prepared by Schenk et al. (1991) indicates that in the area of the Stołowe Mts. and their surroundings earthquake of magnitude up to 6.5º MSK is probable.

The paper presents the results of satellite GPS and gravimetric geodynamic measurements in the area of the central part of the Stołowe Mts performed in the period of 1993-2009.

DESCRIPTION OF RESEARCH NETWORK AND EPOCH MEASUREMENTS

The gravimetric and satellite network consists of 8 points (Fig. 2) located, in relation to geological and tectonic structure, between Szczeliniec Wielki (919 m a.s.l.) and Ostaš (700 m a.s.l.). It has been set up in the spring of 1993 using concrete pillars with heads for forced centering of satellite antenna and for placing gravimeters during epoch measurements.

Measurements of the research network were carried out, in similar atmospheric conditions, in September of 1993, 1994, 1996, 2002 and 2009. Characteristics of epoch satellite GPS observations have been given in Table 1.

During the 1993-1996 period measurements were carried out in several sessions using connecting points between sub-networks. Afterwards measurements were carried out simultaneously on all of the points. Session lengths differ significantly between measurements but because of short vector lengths in the network, satisfactory results even for 1.5h sessions are expected.

Leica GeoOffice v. 6.0 software was used to process all of the observations from 1993 to 2009. Available IGS products: precise orbits, ionosphere models for 1993-2009 measurements were used in calculations. Up to 1993 these products had been unavailable therefore broadcast orbits and standard ionosphere model implemented in the software were used.

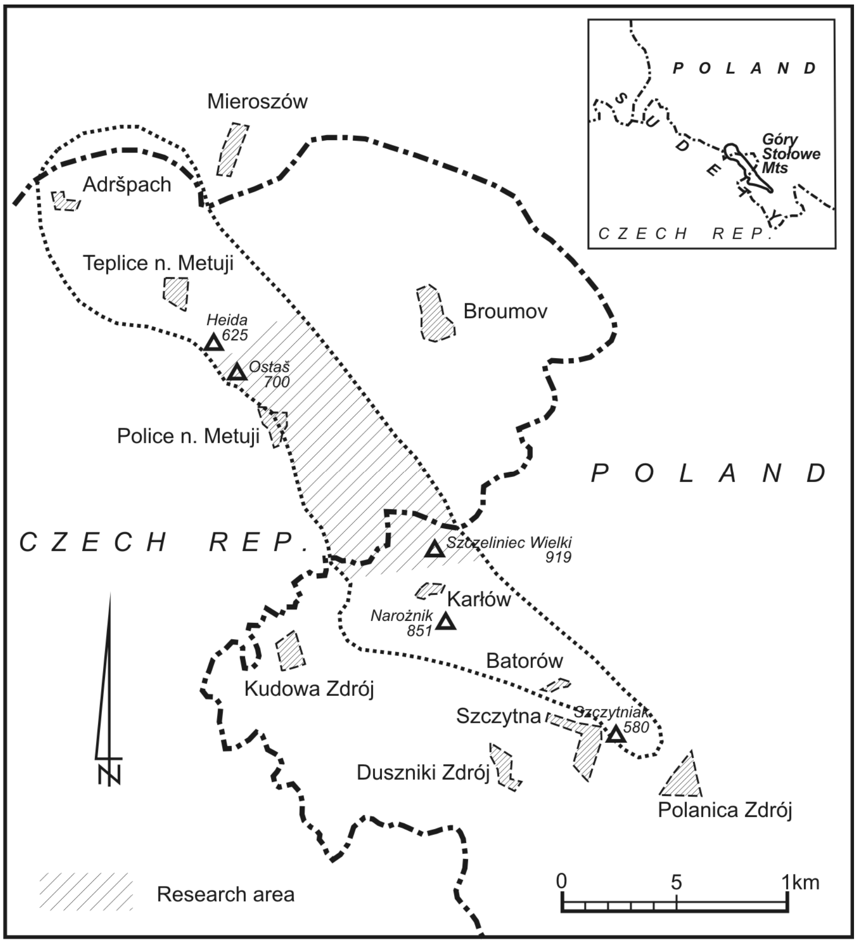

Fig. 1 Stołowe Mts.

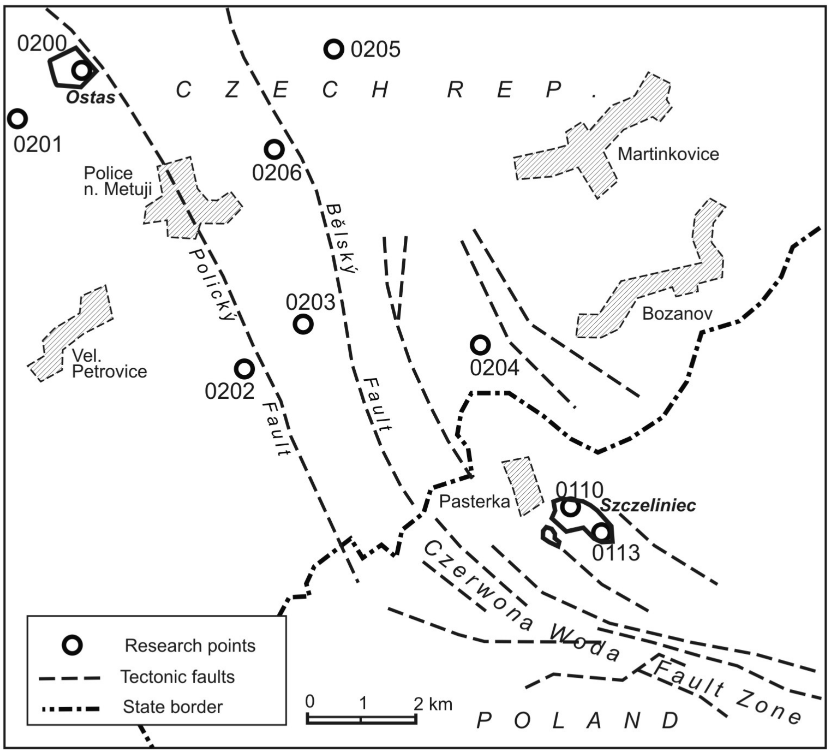

Fig. 2 Research network in the central part of the Stołowe Mts.

Table 1 Conditions of satellite GPS observations.

Year	Antenna type	Session length	Number of sessions per day
1993	ASH700228D	1h 30min	3
1994	ASH700228D	1h 30min	3
1996	ASH700228D, ASH700718B	1h 30min – 4h	2
2002	ASH700228D, ASH700718B, ASH700936D_M	9h	1
2009	LEI_AT502, LEI_AX1202GG, ASH701975.01Agp	2 x 10h	1

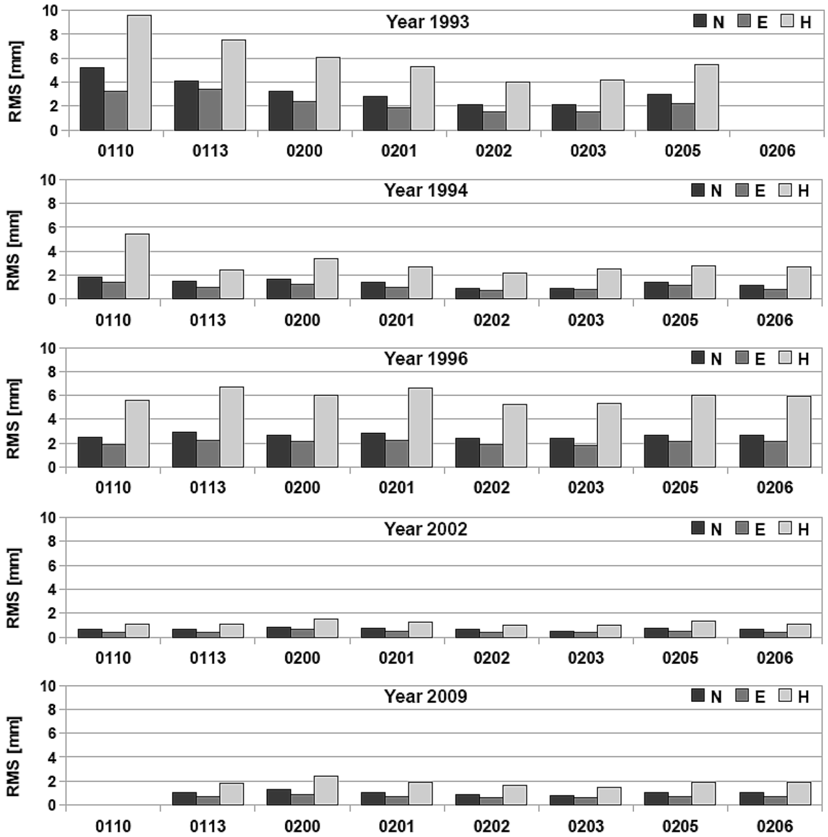

Fig. 3 Mean errors of coordinates from epoch adjustments with point 0204 assumed stable.

Network adjustment was carried out in connection to, assumed stable, point 0204 located in the eastern part of the network. It has also been reference for calculating displacements between 1996 and 2002 performed by Cacoń et al. (2003). In the result coordinates in local system and mean coordinate errors presented in Figure 3 have been obtained.

The calculated error values decrease noticeably in the last two years of measurements. This indicates that the decision to extend observation sessions has been correct. The greatest errors were noted for the 1993 adjustment what may be caused by the lack of IGS products. It is also clear that simultaneous measurement of the entire network is better than session solutions.

Gravimetric measurements (contract agreement) have been done with the La Coste & Romberg apparatus by M. Barlik's team from the Warsaw University of Technology. Observations on all of the network's points were carried out in 1994, 2008 and 2009. Unfavorable weather conditions, primarily strong wind, did not allow measurements on points 0204 and 0205 in 1996, 1998 and 2002. Measurements of the acceleration of gravity on the Szczeliniec (0113) were carried out eight times between 1997 and 2009. Observations of all of the research network points have been done using the profile method to eliminate drift from the results of measurements. Processing of results included correction due to height of the instrument over measured point and corrections of the Sun and the Moon influence on the gravimeter readings. Measurements in particular years have been tied to fundamental points in Karłów and Police nad Metují. The acceleration of gravity values of these points were corrected in 2009 basing on the nearest National Gravimetric Network (POGK'99) point in Kłodzko. Accurate corrections to the local values of gravity have been introduced to the network points determined from 1993 to 2009. The gravity on the fundamental point in Karłów in 2009 is 981020,655 mGal. This value has been calculated with ±17μGal mean error.

RESULTS OF SATELLITE GPS MEASUREMENTS

Coordinates obtained by adjustment and the corresponding variance covariance matrix were used to determine velocities of coordinate changes. To calculate velocities, procedures based on a linear model with least square (LS) solution, developed by the authors in the Matlab™ environment, have been used. This approach was used by Brockmann (1997), Kontny (2003), Bosy (2005) as well as Kapłon and Cacoń (2009) to estimate velocities in the regional network GEOSUD. It allows using data available from all the measurement periods.

Observation equations of a linear model of horizontal velocities (a) (1):

$$y + v = a\left(t - t_0\right) + b = Ax,$$
$$v = Ax - y = \left[\left(t - t_0\right)I \quad I\right] \times \begin{bmatrix} a \\ b \end{bmatrix} - y, \tag{1}$$

are solved on the account of minimizing condition of the least squares method (LS) for the weighted sum of squared velocities estimation residuals (v). Knowing the weight matrix (P) as the inverse of the covariance matrix consisting of coordinates covariance matrices from the epoch solutions (C_y) (2):

$$v^T P v = \min,$$
$$P = C_y^{-1}, \tag{2}$$
$$\left(A^T P A\right)x - \left(A^T P y\right) = 0,$$

as the result coordinates for a reference epoch and velocity components of point location are obtained (x). In addition to them we obtain the estimates of the mean errors of coordinates and velocities, located in the diagonal of the resultant covariance matrix (C_x) (3):

$$x = \left(A^T P A\right)^{-1} A^T P y,$$
$$C_x = \hat{\sigma}_0^2 \left(A^T P A\right)^{-1}, \tag{3}$$
$$\hat{\sigma}_0^2 = \frac{v^T P v}{n - k}.$$

To assess quality of the developed model residua values of velocity components are used. The residua of the velocities are shown below (Fig. 4) as well as velocities and their mean errors. The maximum residual values amount to ±15 mm and are sporadic (0201). It is noticeable that measurements carried out in 1993 show the greatest divergence from the rest. This may be caused by very short measurement sessions and lack of IGS products unlike the other measurements.

Figure 7 contains map of determined velocities together with the confidence error ellipses $\alpha = 95$ %. It is noticeable that significant linear velocities have been recorded for point 0203 only. Assuming outlying direction and value of velocity of the point 0203 it is possible that this may be the result of the self-movement of the measuring pillar.

RESULTS OF GRAVIMETRIC MEASUREMENTS

Results of gravimetric measurements in the research network carried out between 1993 and 2009, after correction and reference to POGK'99, became the basis for analysis of relative changes of acceleration of gravity. Accuracy of gravity changes on particular points in the analyzed periods was assessed with a mean error of $m_{\Delta g} = \pm 24$ μGal.

Figures 5 and 8 shows linear velocities of gravity changes on particular research points. These velocities were obtained using the LS method (1, 2, 3) similar as for the GPS data. All epoch gravity acceleration values were treated as equally erroneous with the $m_{\Delta g}$ error. Insignificant velocities within the accuracy limits for the 1993-2009 period, refer to observations on points 0201, 0202, 0203, 0204 and 0110. Significant velocities with the probability 95 % ($v_{\Delta g} \geq \pm 2m_{v\Delta g}$) have been recorded on points: 0200 (-4.23μGal/year), 0205 (-4.57μGal/year), 0206 (-3.88μGal/year), 0113 (+5.85μGal/year). It is characteristic, that velocities are changing from the negative values in the NNW part of the network (0200, 0205) to the positive values at sites on top of the Szczeliniec Wielki in the SE part of the network (0110, 0113). Character of these changes is shown in Figure 8.

PRELIMINARY INTERPRETATION OF GEODYNAMIC MEASUREMENTS

Results of five epoch satellite GPS measurements and eight gravimetric observations in the 1993-2009 period on research network points in the area of central part of the Stołowe Mts. constitute a basis for assessment of present day geodynamic conditions of this region.

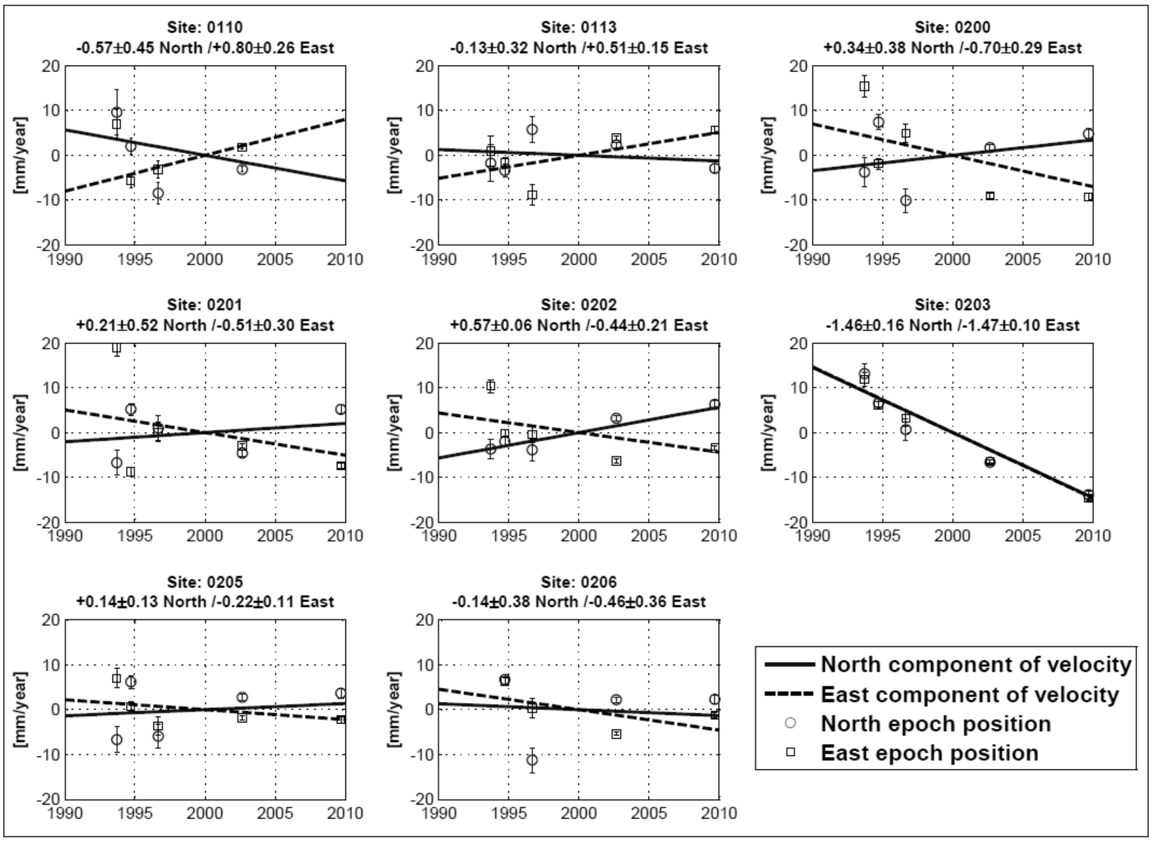

Fig. 4 Estimation residua of horizontal linear velocities.

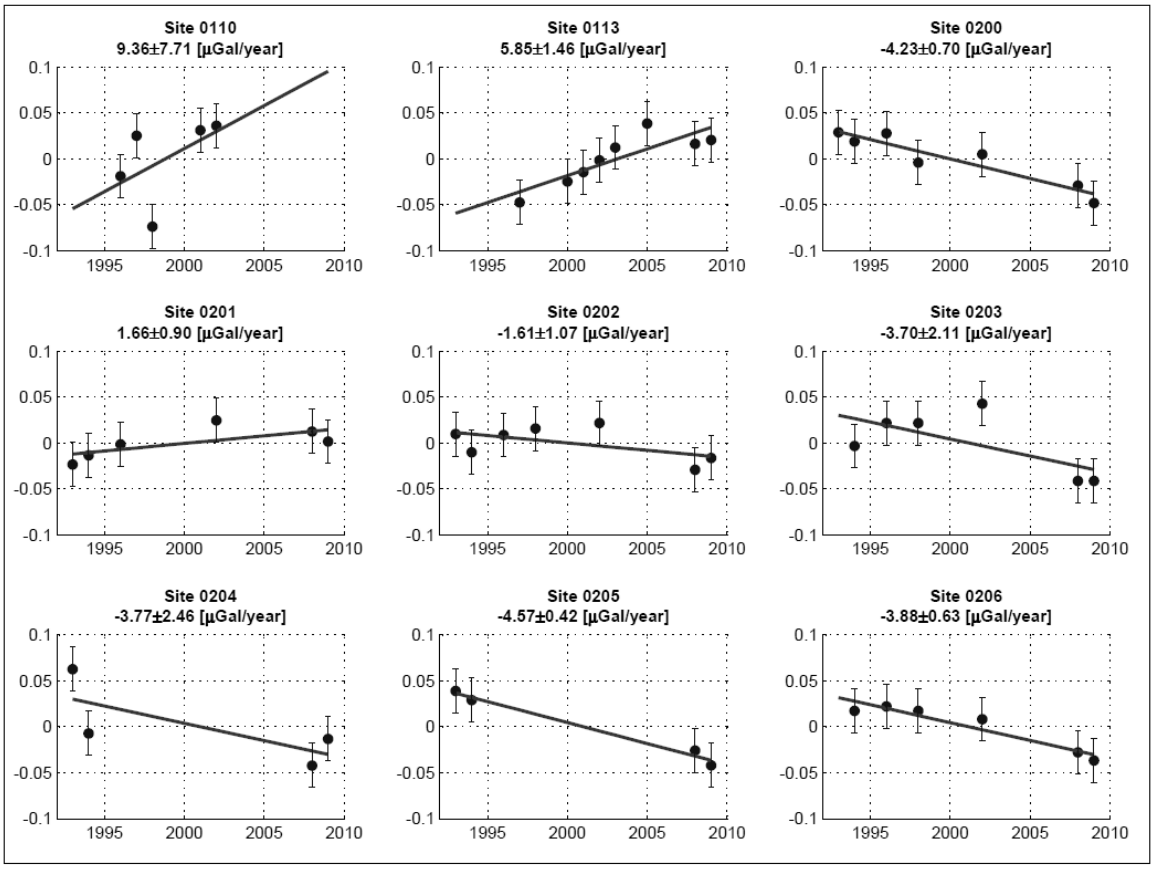

Fig. 5 Estimation residua of gravitational force acceleration linear velocities.

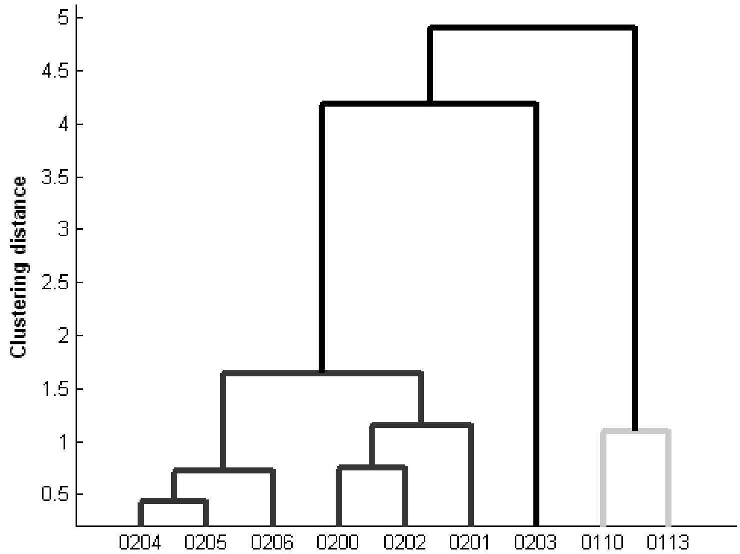

Fig. 6 Agglomeration dendogram of the Stołowe Mts. network points.

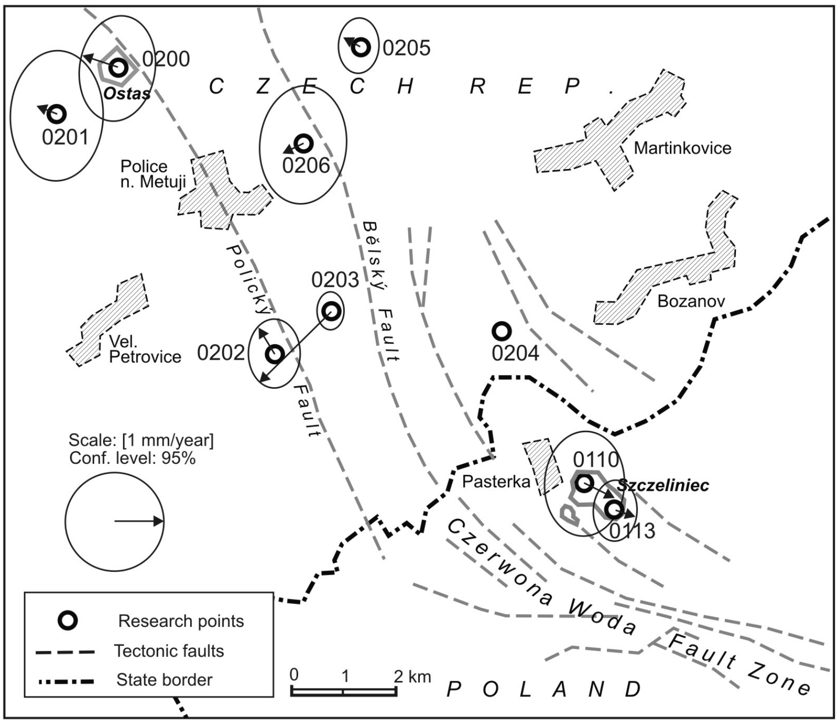

Fig. 7 Horizontal velocity vectors and their confidence ellipses at the 95 % level.

Horizontal velocity vectors of points (Fig. 5), except on point 0203, are within the confidence ellipses (α=95 %). For points: 0200, 0201, 0202, 0205 these vectors maintain NW direction. Direction of velocity vectors of two points (0203 and 0206) located in the central part of the Polický and Bělský Fault zone is SW with point 0203 moving with significant velocity 2mm/year. Two points on the Szczeliniec (0110 and 0113) move with insignificant velocity in SE direction.

Velocities of acceleration of gravitational force on these same points of the research network (Fig. 5) proves the existence of the acceleration of gravitational force velocities pattern for the area of interest. A negative trend of velocities in the NNW part of the network is decreasing towards SE direction

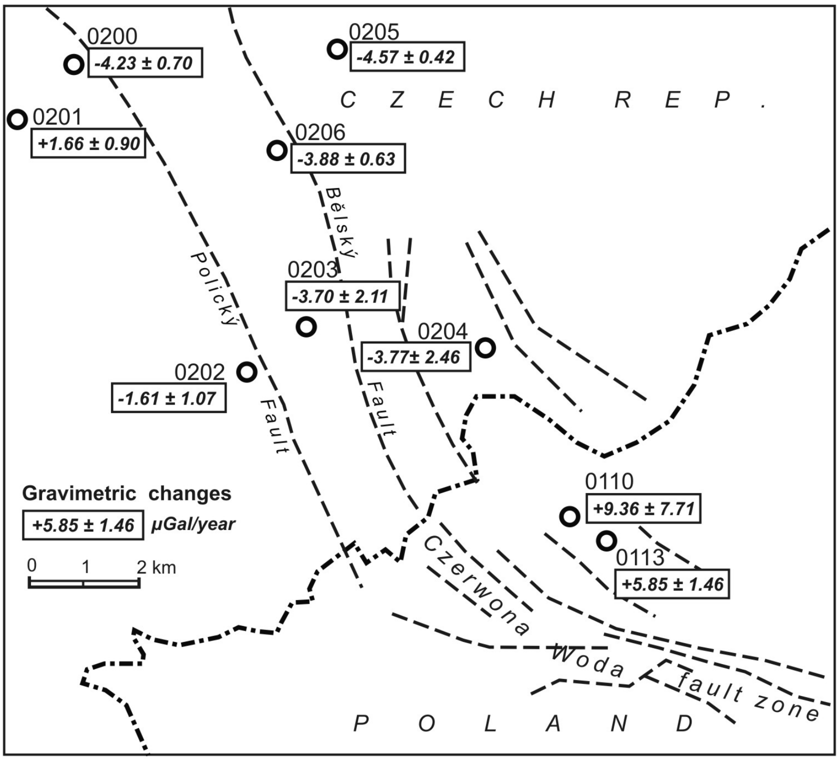

Fig. 8 Velocities of gravity changes and their mean errors on research network points in the 1993-2009 period.

and finally is positive in Szczeliniec Wielki Massif: 0113 (+5.85 μGal/year) and 0110 (+9.36 μGal/year). These positive changes may be interpreted as tendency to lower the Szczeliniec Wielki Massif.

To achieve a connection between estimated velocities and tectonic structure of the research area, the agglomeration (Fig. 6) was made with the use of three dimensional vector of standardized GPS and gravimetric velocities. Standardized Euclidean distances have been used as measure of similarity in agglomeration, and Ward method as linkage method using square sum of distances within all groups. The results (Fig. 6) indicate the occurrence of similarity zones correlated with the known tectonic structures in the research area. These are comparable to earlier results presented by Cacoń et al. (2003). The division includes: group 1 – NE of the Bělský Fault (0204, 0205 and 0206), group 2 – NW side of the Polický Fault (0200, 0201 and 0202), group 3 – SE of the Czerwona Woda Fault Zone (Szczeliniec Wielki, 0110, 0113). Site 0203 located between the Polický and Bělský Faults was classified as outlying. These facts should be taken into consideration in further interpretations concerning recent geodynamic conditions of this area.

CONCLUSIONS

The results of epoch satellite GPS and gravimetric measurements carried out in the research network in the central part of the Stołowe Mts. in 1993-2009, indicate present-day geodynamic activity of the area including the Polický, Bělský Faults and Czerwona Woda Fault Zone located in close neighborhood to the Pořiči-Hronov fault zone. In the Polish part of the Stolowe Mountains, in the area of the Góry Stołowe National Park, geodynamic research has been started in 2008 (Cacon et al., 2009). The results of this research will contribute to the assessment of present-day activity in this part of the Sudety Mts.

Significant and insignificant horizontal movements of points and significant changes of gravity in the past 16 years have been registered. Agglomeration of the research points with the use of the estimated velocities indicates correlation of the behavior of the benchmarks and the location of the main tectonic zones within the research area. These data correspond with the results of seismic activity researches presented in the cited publications and confirm that the research area is tectonically active.

These facts substantiate the necessity to continue this research of both learning and practical significance.

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