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GEODYNAMIC STUDIES IN THE GÓRY STOŁOWE NATIONAL PARK AREA

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ABSTRACT
Geological structure, including main faults and faults zones, of the Góry Stołowe National Park originated in Neogene. Displacements on faults in the Poříčí-Hronov and the Czerwona Woda fault zones have been revealed at present times. A network of 11 research points was established to register this process and phenomena associated with it. The first measurement, consisting of GPS and gravimetric observations, was performed in 2008. It has been complemented with relative measurements of the faults in selected places where crack-gauges have been installed. Accuracies of the first GPS measurements indicate ability to detect horizontal movements with accuracy of several millimetres.

KEYWORDS: geodynamic studies, GPS observations, gravimetry, relative measurements

1. INTRODUCTION

Cretaceous rocks building up the Góry Stołowe Mts. constitute the highest structural level in the Intra-Sudetic Synclinorium (ISS). The Intrasudetic Fault (ISF) and the Poříčí-Hronov Fault Zone (PHFZ) define NE and SW borders of the ISS respectively. The Czerwona Woda Fault Zone is a natural continuation of the PHFZ in the Góry Stołowe National Park (GSNP). Ongoing tectonic activity in this area started in late Cretaceous and reached its maximum in Tertiary. Displacements of some faults exceed 150m. Recent evidence indicates that this activity has not yet finished with proofs of (weak) earthquakes in the Poříčí-Hronov Fault Zone, as well as damaged road surfaces near some faults. These facts constitute well-grounded foundation for complex geodynamical investigations in this area.

This paper describes general geological structure of the Góry Stołowe Mts. in the GSNP region, as well as, organisation of the control and measurement system consisting of: GPS, gravimetric and relative observations of rock blocks. Description of the first measurement of the research network with GPS technique and preliminary results of data processing have also been presented.

2. GEOLOGICAL SETTING OF THE GÓRY STOŁOWE AREA

The Góry Stołowe area (GS) is mostly built of the upper Cretaceous (Cenomanian-to-Santonian) rocks (Wojewoda, 2008). The morphology, river network as well as hydrogeology of the GS directly corresponds to lithology and tectonic structures of the basement rocks.

The Cretaceous of the GS constitutes the uppermost structural level in the Intra-Sudetic Synclinorium (ISS), however, it is not included into the sedimentary-volcanic succession of that unit (late Devonian to Triassic succession (cf. Nemec et al., 1982). Late Cretaceous marine sedimentation started over the ISS, during and/or after the inversion of that area. This points to at least 125 (!) Ma period of non-deposition or denudation on the ISS area, since the late Triassic up to the late Cretaceous. It is recorded as a discordance between the synclinal structure of the ISS and platform-like Cretaceous formation (Fig. 1).

The basement of the ISS consists of metamorphic and magmatic rocks of various age, similar to those surrounding ISS (cf. Malkovský et al., 1974; Tasler et al., 1979). ISS is a regional, complex synclinal unit with its longer axis trending WNW-ESE, extending over a distance of app. 60 km long. The area of the GS is situated over a lower-order synclinal unit referred as Karłów-Batorów Depression (KBD) and in the southeast a part of the ISS (Fig. 1). Cretaceous sediments constitute part of the Cretaceous Bohemian Basin infill, therefore they extend beyond the ISS boundaries, making up the major infill of the Nachod Basin (NB) and the Upper Nysa Kłodzka Trough (UNKT) (Wojewoda, 1997). The PHFZ

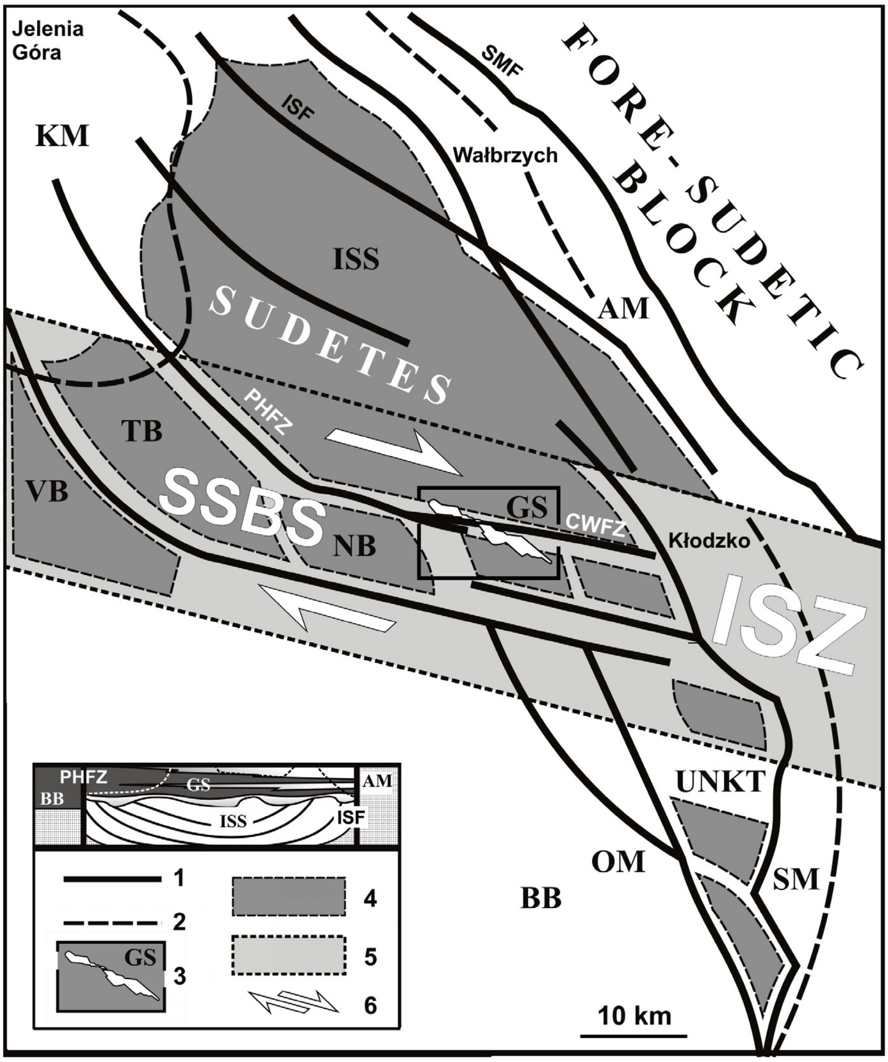

Fig. 1 Regional geological setting.
Explanations: 1 – evidenced fault; 2 – supposed primary extent of Cretaceous sedimentary cover; 3 – Góry Stołowe Mts. area in Figure 2; 4 – sedimentary successions in Sudetes; 5 – Intrasudetic Shear Zone (ISZ); 6 – presumed direction of strike slip; KM – Karkonosze Massif; AM – Góry Sowie Massif; OM – Orlica Massif; SM – Śnieżnik Massif; VB – Vrhlabi Basin, TB – Trutnov Basin; NB – Nachod Basin; ISS – Intrasudetic Synclinorium; UNKT – Upper Nysa Kłodzka Trough; BB – Bohemian Basin; SMF – Sudetic Marginal Fault; ISF – Intrasudetic Fault; PHFZ – Poříčí-Hronov Fault Zone; CWFZ – Czerwona Woda Fault Zone; SSBS – South Sudetic Basin Suite.

continues throughout the GS area as the Czerwona Woda Fault Zone (CWFZ, Wojewoda, 2008).

The trend of the ISS axis, facial changes in Cretaceous sediments as well as major tectonic dislocations over the GS area are similarly oriented (WNW-ESE) and they evidently influence the river network as well as the shape of the most important geomorphic features – bluffs and ridges. These primary geological features resulted from a post-Variscan tectonic rearrangement of the Sudetes area. The most important role in this process is attributed to the Intra-Sudetic Shear Zone (ISZ) (Wojewoda, 2007). Geodynamic activity of the IFZ led to formation of several rhomboidal pull-apart depressions (basins), originating since the late Devonian up to the Tertiary, that nowadays form altogether so called South Sudetic Basin Suite (SSBS). Distribution of modern depositional areas as well as the trend of sandstone massifs is also determined by the ISZ (Figs. 1 and 2).

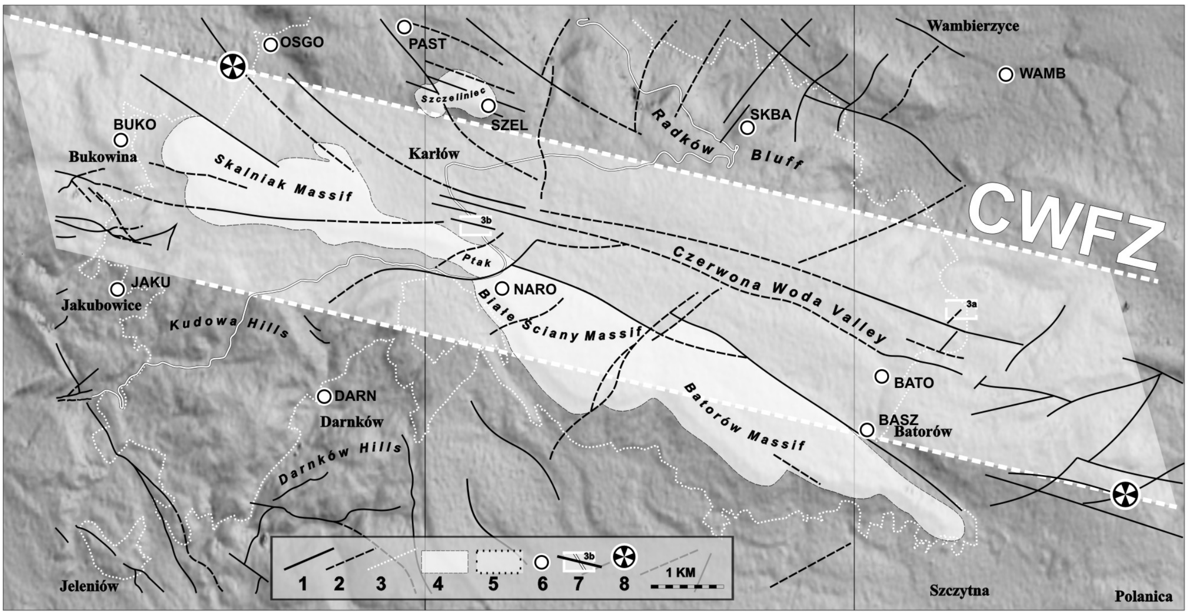

Fig. 2 Location scheme of the geodetic measurements network in Góry Stołowe Mts. area. Explanations: 1 – evidenced fault; 2 – presumed fault; 3 – Góry Stołowe National Park area; 4 – upper Cretaceous sandstone massifs; 5 – Czerwona Woda Fault Zone (CWFZ); 6 – geodetic network measurement point; 7 – structures presented in Figures 3 a and b; CWFZ – Czerwona Woda Fault Zone; 8 – TM-71 crack-gauge.

Morphotectonic features of GS seem to correlate with recent activity of the CWFZ, Jakubowice-Darnków Fault, Duszniki Fault and numerous SW-NE oriented second order faults. Tectonic transport indicators, both in the basement rocks and in the Permian and Cretaceous sediments, show significant horizontal component of displacement along the faults (Fig. 3a). Neotectonic, modern fault activity is additionally indicated by road pavements and building walls destruction in direct vicinity of individual faults (Fig. 3b). All these facts are good enough reasons for setting up a geodetic research network and starting of geodynamic studies in this area.

3. ORGANIZATION OF THE GEODYNAMIC CONTROL AND MEASUREMENT SYSTEM IN THE GSNP

During organisation of geodynamic studies in the GSNP experience acquired in similar studies on geodynamic research areas in the Sudetes and the Fore-Sudetic Block has been utilised (Cacoń, 2004). The studies are based on four-segment control and measurement system consisting of: satellite GPS, precise levelling, Total Station and gravimetric measurements, as well as observations of relative displacements with crack-gauges. Satellite and gravimetric measurements in the 2008-2010 period will be carried out once a year. Measurements of relative movements with TM-71 crack gauges will be realised at a monthly interval.

SATELLITE-GRAVIMETRIC RESEARCH NETWORK

The network consists of eleven points located in correlation with geological structure and in relation to the main tectonic structures of this area (Fig. 2). In June 2008 nine points have been installed. These are concrete pillars with heads for forced centring of satellite antenna (Fig. 4a). The points have been set up in loose formations below the ground-freezing level and on parent rock. Two points (SKBA, NARO) located on sandstone rocks are made of metal pins with casing for connection with rigid stands, concreted in drilled holes (Fig. 4b). Point (SZEL) located on the edge of Szczeliniec Wielki Mt. is, since 1993, included in the regional geodynamic network “GEOSUD” (Cacoń et al., 2004). Satellite GPS network points are also used as stands for gravimetric measurements. In the surroundings of the point SZEL a geodetic micro-network for observing mass movements of rock blocks has been organised. This network will be measured by means of Total Station and precise levelling in yearly intervals. Observations of mass movements in the vicinity of point SZEL are an extension of similar work realised in the Szczeliniec Wielki Massiff (Cacoń et al., 2008).

RELATIVE OBSERVATIONS OF CRUST BLOCKS

Location of the two TM-71 crack-gauges is shown in Figure 2. These have been placed on PHFZ tectonic faults near Ostra Góra village (Fig. 5a) and in the CWFZ near Szczytna village (Fig. 5b). Installation

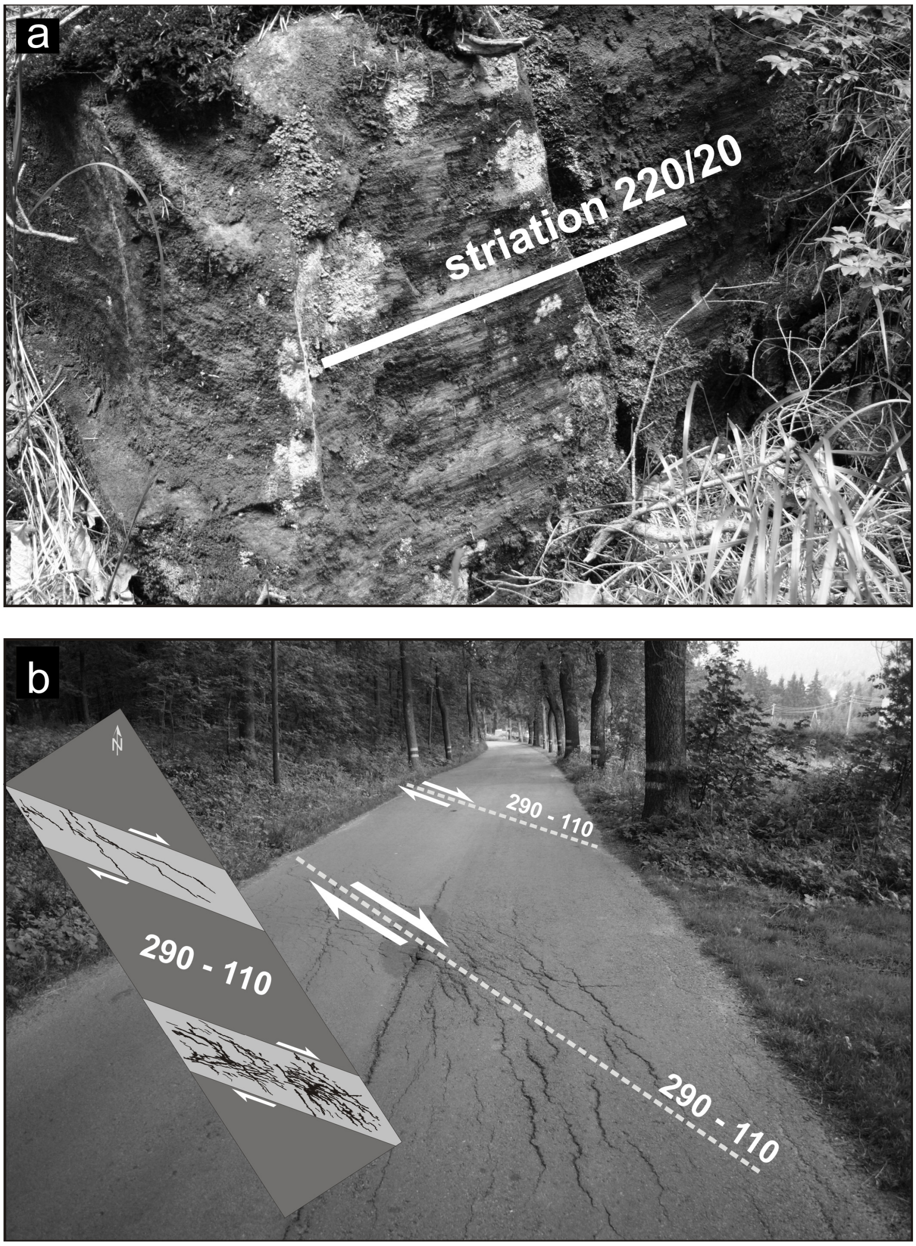

Fig. 3 Tectonic sub-horizontal striation (a) and low angle Riedel shears in bitumen pavement above an active fault plane (b).

of the devices shown in Figure 5 was done in November 2008.

4. DESCRIPTION OF THE FIRST MEASUREMENT CAMPAIGN OF GEODYNAMIC NETWORK GSNP

The first GPS measurements of the geodynamic network was carried out from the 11th to 14th of September 2008 (DOY 255-258) in 10-hour sessions for two or four days. Table 1 presents the campaign's plan and satellite antenna used. Such an organisation of the GPS observations has been used to obtain 1 mm horizontal accuracy of measurements (N, E coordinates) (Melicher, 2001).

BERNESE GPS Software V. 5.0. has been used for calculations of the network with the assumptions shown in Table 2 (Dach et al., 2007).

Such an approach was used previously for calculating GPS measurement results, i.a. for the DOBROMIERZ network (Cacoń et al., 2002; Kapłon, 2008). A self-defined arrangement of independent vectors (Fig. 6) has been prepared taking into consideration komplete repeatability of measurements on points: BASZ, NARO, OSGO

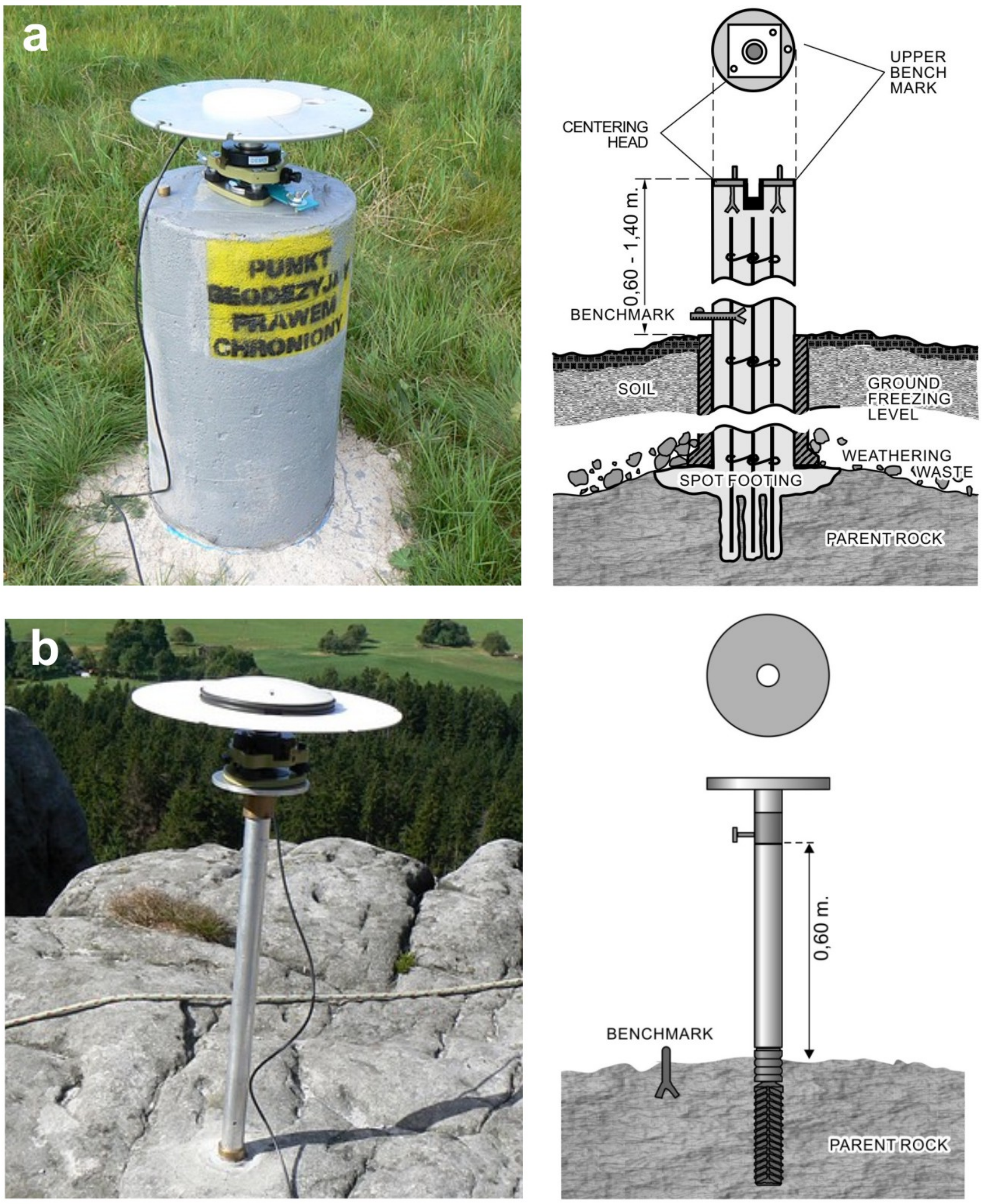

Fig. 4 Stabilisation of research points.

Table 1 Plan of the 2008 measurement campaign with antenna symbols and types.

Point	DOY			
	255	**256**	**257**	**258**
SZEL			ASH700718B	ASH700718B
BASZ	ASH700718B	ASH700718B	ASH700718B	ASH700718B
BATO	ASH700718B	ASH700718B		
BUKO			ASH700936D_M	ASH700936D_M
DARN			ASH701975.01Agp	ASH701975.01Agp
JAKU	ASH700718B	ASH700718B		
NARO	ASH701975.01Agp	ASH701975.01Agp	ASH701975.01Agp	ASH701975.01Agp
OSGO	ASH700718B	ASH700718B	ASH700718B	ASH700718B
PAST			ASH701975.01Agp	ASH701975.01Agp
SKBA	ASH701975.01Agp	ASH701975.01Agp		
WAMB	ASH700718B	ASH700718B		

Fig. 5 Detailed location of the TM-71 crack-gauges.

Table 2 Assumptions made for computation process of the **GSNP** network.

Parameter	Assumption
Orbits	Precise CODE
Ionosphere	CODE Model
Troposphere	Estimation of parameters at 1H interval
Ambiguity solution	L1, L2 (SIGMA strategy) (Dach et al., 2007)

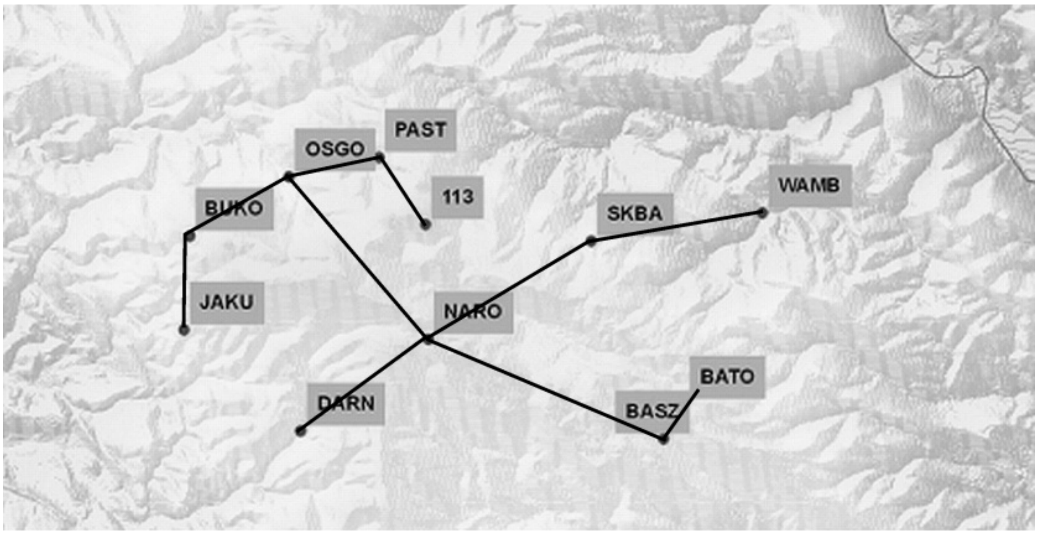

Fig. 6 Arrangement of independent vectors.

(4-day observations). Ambiguity resolution of 90.4 % - 100 % was achieved.

Solutions made for each daily session were combined by means of the ADDNEQ2 module (Dach et al., 2007) to estimate accuracy of a given solution. Two comparisons have been made:

- Calculated unweighted RMS errors for the components of points' coordinates representing repeatability of coordinates (Fig. 7),
- Calculated RMS errors for each session in comparison to the combined solution (Fig. 8).

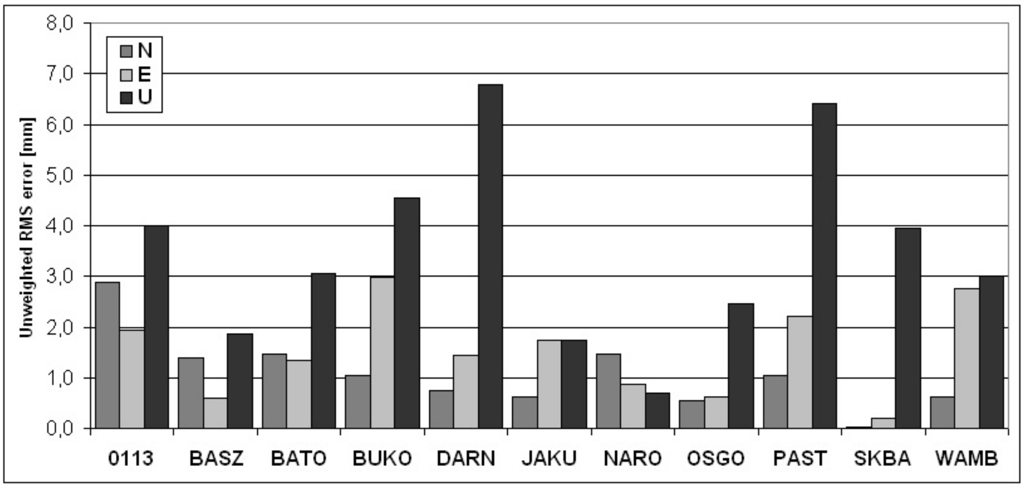

Fig. 7 Unweighted RMS error of coordinate components calculated for daily sessions.

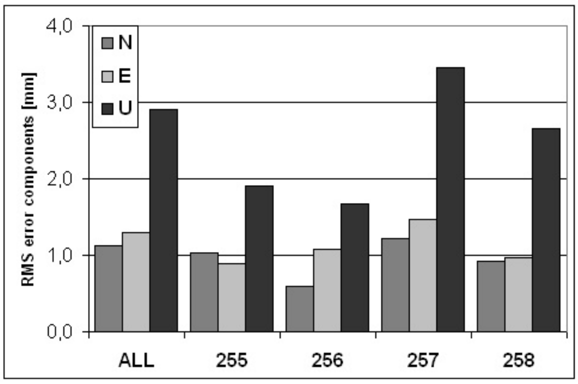

Fig. 8 RMS errors for each session as compared to the combined solution.

Information in Figure 7 shows that the repeatability of the calculated coordinates is retained and comparable to the 1 mm accuracy estimated for horizontal components. It is confirmed by the results obtained for the second comparison (Fig. 8) for which daily solutions fit to the combined solution on the N 1.1 mm, E 1.3 mm, U 2.9 mm accuracy was achieved. Errors of horizontal coordinates at the 2-3 mm level (BUKO, PAST, WAMB) indicate the need to reorganize measurement campaigns, e.g. extension of session to 4-day observations or 2 twenty-four hours measurements on all the points. This proposal is in accordance with the results presented by Kontny (2003) for the GEOSUD network measurements. It will also provide conditions for more satisfying error values of the "U" coordinate. This concerns in particular points DARN and PAST, where 2-day observations in 10-hour cycles have been made. Linking of the network to the closest permanent observation stations EPN (WROC, SNEC, GOPE, BISK, TUBO) remains to be considered. This task will be possible to realise with combined processing of observations from several years of measurement campaigns at the stage of calculating points' movements or velocities with Bernese software (Dach et al., 2007).

5. CONCLUSIONS

The geodynamic studies on the GSNP area commenced in 2008 are a part of a wide program of geo-ecological studies that also cover: geological, hydrogeological, geomorphological, soil and climatic problems. During organisation of these geodynamic studies experiences from two similar research programs carried out on geodynamic areas of the Sudetes with control and measurement system have been utilised. Results of the first GPS measurements, carried out on the research network points, indicate that repeated measurements in this network can detect horizontal movements of the basement's rock blocks with several mm of accuracy. Measurements of the acceleration of the force of gravity with accuracy ±6.7 μGal, carried out on the research network points significantly improve "geometrical" parameters of the points' movement and will add to better physical interpretation of geodynamical changes in the geo-ecological environment of the Park. Observations of relative movement of geological structures with use of the TM-71 crack-gauges will be used for registering micro-displacements of these structures at the (0.1-0.5) mm level.

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