RECENT EARTH CRUST MOVEMENTS IN THE SUDETY MTS. — GEOSUD PROJECT

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Abstract

Sudetes mountain belt on the border of Poland and the Czech Republic owes its present-day orographic picture to the intensive tectonic movements of Neogene. Geological investigations indicate that this activity has not yet ceased. During the past ten years complex geodynamic investigations have been undertaken in the frames of the GEOSUD Programme (GEO dynamics of SUDety Mts.). Periodical satellite GPS and gravimetric observations combined with feeler gauge measurements, carried out in regional research network and three geodynamic research areas confirm recent mobility of this region. In the paper principles of above-mentioned investigations, values of test point displacement and changes in gravitational field are presented. Threats to water dams located in tectonically active areas are also indicated.

1. Introduction

Polish part of the Sudety Mts. and the Fore-Sudetic Block make up the northern border of the Czech Massif. The region owes its present-day orographic picture to the intensive tectonic movements, culmination of which had occurred in Neogene. Geological and geodetic investigations conducted for the last hundred years prove that these movements have not yet ceased. Recent tectonic mobility of the region has been confirmed by historical records, which describe dozens of earthquakes of the magnitude up to 5,5° on the MSK scale, dating back to the X century. Precise levelling measurements repeated every 20 to 30 years, since the end of the nineteen century show vertical movements of the earth's crust in the Sudety Mts. and its surroundings in the – (1,5–6,0) mm/year limits.

Geodynamic investigations in the region have intensified in the past decade. At the beginning the study has been concentrated on three geodynamic research areas: "The Śnieżnik Massif" (since 1992), "The Paczków Graben" (since 1993) and "The Stołowe Mts." (since 1993). Repeated satellite GPS, geodetic, gravimetric and relative feeler gauge measurements show substantial vertical and horizontal movements of the upper lithosphere. In 1996 complex investigations have been started on the regional "GEOSUD" programme (GEOdynamics of SUDety Mts.). Periodical observations in geodynamic research areas have been united into one control and measurement system that covers the Eastern Sudetes and Fore–Sudetic Block. The year 1997 has brought integration of the "GEOSUD" network and the "SILESIA" network covering the eastern part of the Czech Sudetes and Northern Moravia (Czech Republic) region. In 2000 geodynamic research network has been further expanded in the western direction within the framework of "GEOSUD II" Project.

Geodynamic investigations carried out in the Sudety Mts. and adjacent areas, carry apart from scientific aspects also practical significance due to the threats to water dams caused by tectonic movements.

2. General characteristics of the neotectonic movements in Sudety Mts. and its surroundings

Northern part of the Czech Massif including Sudety Mts. and the Fore-Sudetic Block had formed, during the Alpine orogeny, a resisting block for the folding Western Carpathians. Compression

stresses from the developing nappes in the Carpathian Mts. had caused intensive tectonic fractures of the fault type. Main tectonic zones that have developed in the northern part of the Czech Massif, as a result of these processes (Fig. 1) are: Lusatian Thrust Zone passing into the Jilovice Fault Zone in the east and Elbe Lineament in the west. The Ohre Rift adjoins the zone from the SW. In the NE part there is a group of faults such as: the Sudetic Marginal Fault, Mid–Sudetic Fault and the zone of the Mid–Odra River faults. In the limits of these faults the Sudety Massif had been uplifted (Schenk et al, 1986; Dyjor, 1986). The Sudetic Marginal Fault forms the morphological and tectonic border that separates the Sudety Mts. from the Fore–Sudetic Block. The zone of the Mid–Odra River faults separating this block from the Fore-Sudetic Monocline made up by Permian and Triassic deposits, forms a consecutive border.

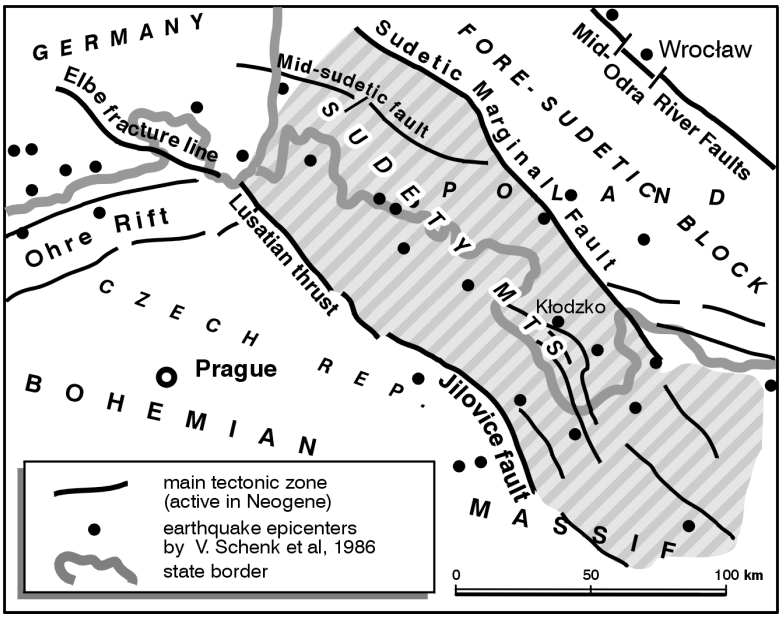


Fig. 1. Geotectonical scheme of the major fault zones active in Neogene

The most intensive tectonic movements had occurred in the Neogene, in zone adjacent to the Sudetic Marginal Fault. Regional tectonic grabens and horsts that had developed at that time had reached displacement amplitudes of 500 to 700 metres. In the Eastern Sudetes these are: Paczków Graben and Kamieniec Ząbkowicki Horst, and in the central part of the region Roztoka–Mokrzeszów Graben and Strzegom Horst (Dyjor 1983). Basaltic volcanism and hydrothermal processes had accompanied these strong compression movements. Tectonic activity had pronounced itself in the uplifted mountain belts such as: Izerskie, Karkonosze, Orlickie, Bystrzyckie, Sowie and Bardzkie Mountains as well as the Śnieżnik Massif.

Tectonic movements in the Quaternary had been influenced by continental glaciations, which had occurred in the period from 800 to 100 thousand years ago. Glacioisostatic unstressing had marked the stage after the withdrawal of the glaciers. Accompanying vertical movements had reached amplitudes of up to 150 m in the Upper Odra Valley.

Tectonic movements occurring in Upper Pleistocene continue to the present day. This is confirmed by the results of precise levelling measurements (Wyrzykowski, 1985).

3. Organisation of geodetic geodynamic research

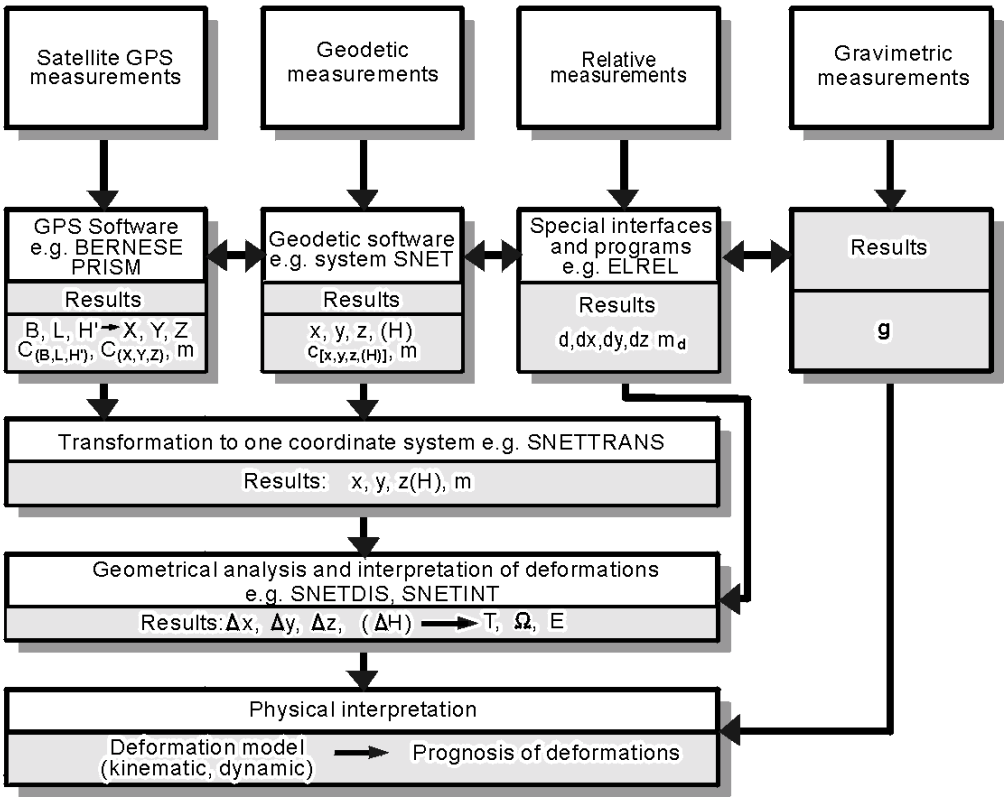
3.1. “GEOSUD” monitoring and measurements system

The system consists of three geometric measurement segments that allow recording of absolute (ΔX, ΔY, ΔZ (ΔH)) and relative (dx, dy, dz) spatial changes. The fourth segment includes

monitoring of dynamic changes in the gravity (Δg) on the research points. Scheme of the system is shown in table 1 presenting both the measurement and computation stages. Computation algorithm has been developed by Cacoń and Kontny (1993). Periodical measurement processes employ satellite GPS techniques, precise levelling, angular–linear networks and feeler gauge observations. Computation procedures implement standard software such as BERNESE and self–developed one (SNET, ELREL series).

Table 1. Block schemes of the measurements and monitoring system and its computation procedures

	Characteristics of observation segments			
	Segment I	**Segment II**	**Segment III**	**Segment IV**
Observations (instruments)	Satellite (GPS) precise levelling	- satellite (GPS) - total station - precise levelling	- feeler gauge - clinometer - extensometer	gravimeter
Frequency of observations	1 - 5 years	12 months	30 days of permanent	1 - 5 years
Accuraccy spatial deformations	± (0,5 - 5) mm	± (0,5 - 2) mm	±(0,01-0,1) mm	±(0,012 - 0,016) mGal



The monitoring and measurements system has been also successfully implemented on engineering objects (Cacoń, 1998a). Principles of geodynamic investigations organisation on three geodynamic research areas in Eastern Sudety Mts. and adjacent areas, as well as results of periodic observations up to 1997 have been described in paper by Cacoń (1998b).

3.2. The "GEOSUD" project

The "GEOSUD" project comprises polish part of the Sudety Mts. and the Fore–Sudetic Block (Fig. 2.). Points making up the geodynamic research network have been placed on crystalline rock outcrops. These have been marked with concrete pillars equipped with heads for forced centring of measurement instruments.

Selected, representative, points from research networks established on geodynamic research areas: "Śnieżnik Massif " (A), "Paczków Graben" (B) and "Stołowe Mts." (C) have been included in the eastern part of the "GEOSUD" network. Fig. 3 shows I geological-tectonic cross-section through the Paczków Graben with marked location of test points. The remaining points, located with respect to geological and tectonic structure of the area, are shown on Figure 2. Permanent GPS Observation Station "Wrocław" plays an important role in the "GEOSUD" network.

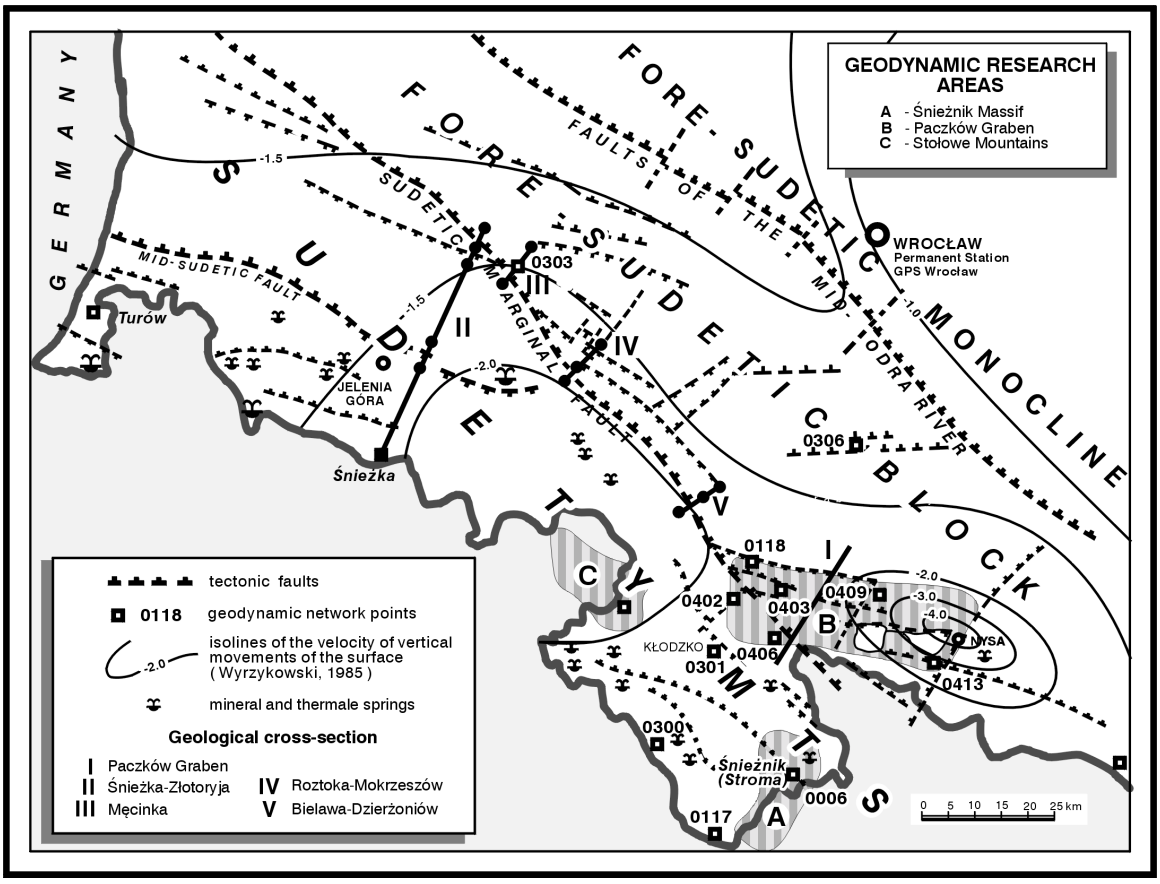


Fig. 2. Area of the GEOSUD project

"GEOSUD II" project being a territorial extension of geodynamic investigation in Sudetes and the Fore–Sudetic Block (central and western parts) has been started in the year 2000. New research points have been located on four geodynamic profiles cutting across major faults such as: the Sudetic Marginal Fault, the Mid–Sudetic Fault and others. Geological cross–sections presented on Fig. 2 relate to the following profiles:

- No. II Śnieżka–Złotoryja (Fig. 4),
- No. III Męcinka (Fig. 5),
- No. IV Roztoka–Mokrzeszów (Fig. 6),
- No. V Bielawa–Dzierżoniów (Fig. 7).

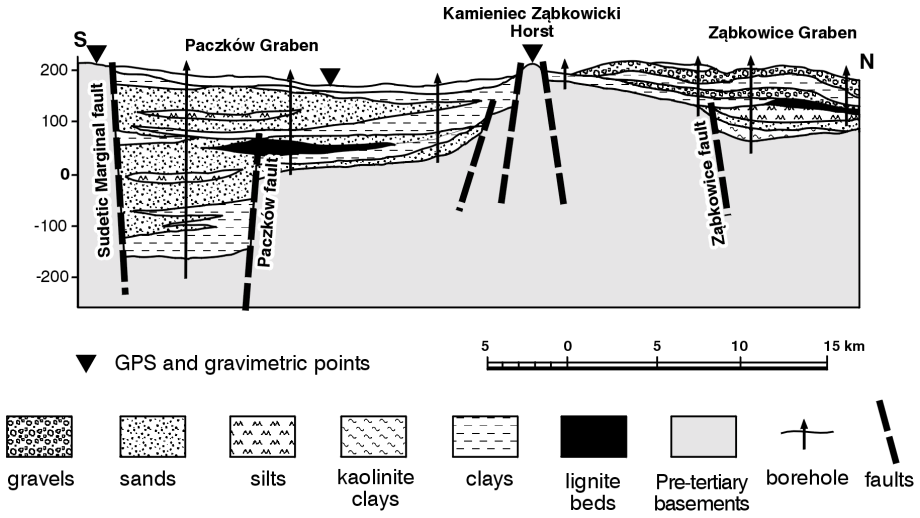


Fig. 3. The Paczków Graben (I) geological cross–section

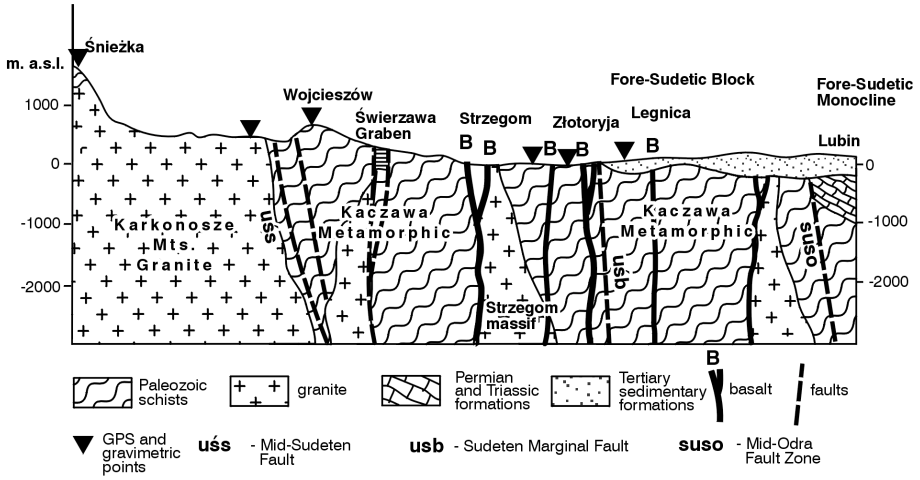


Fig. 4. The Śnieżka–Złotoryja (II) geological cross–section

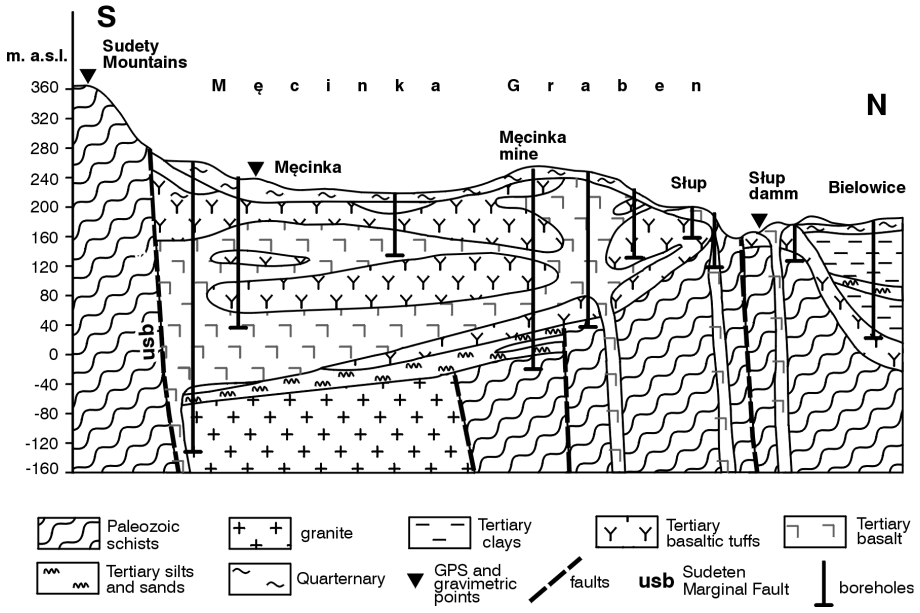


Fig. 5. The Męcinka (III) geological cross–section

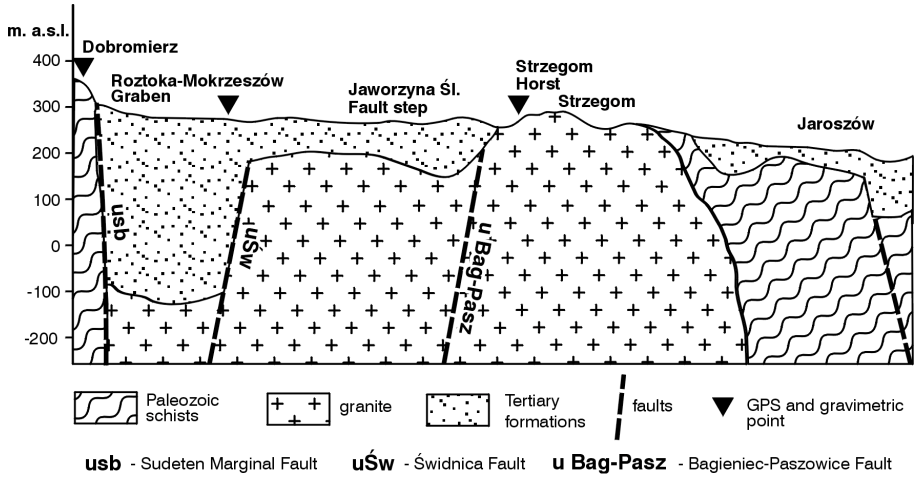


Fig. 6. The Roztoka–Mokrzeszów (IV) geological cross–section

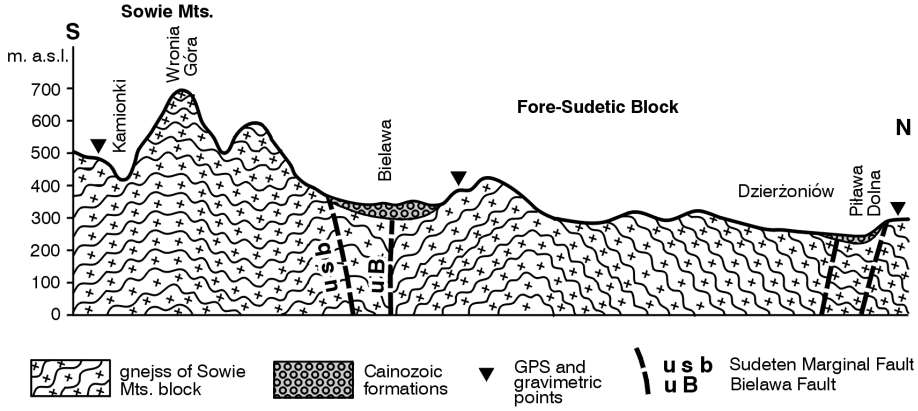


Fig. 7. The Bielawa–Dzierżoniów (V) geological cross–section

Detailed information explaining locations chosen for the specific research points on these profiles has been given in papers by Cacoń and Dyjor (1999, 2000).

4. Preliminary results of geodynamic investigations in the "GEOSUD" network

4.1. Satellite GPS observations

The GPS observation programme on the "GEOSUD" network points has been taking place in September every year since 1997. Ashtech Z–12 receivers have been used for static observations in 2 × 24 h sessions. GPS data has been processed using BERNESE v.4.2 software, CODE precise ephemeris and with control to the closest (Borowiec, Pecny, Penc, Wrocław) permanent GPS stations (EUREF/IGS). Strategy of data processing has been described in the article by Bosy and Kontny (1998). Fig. 8 shows estimation of position accuracy of selected "GEOSUD" network points in relation to permanent stations from 1998 and 1999. Changes in vector lengths in the same interval and significant horizontal displacements of points are shown on Fig. 9. On the grounds of above data translation vector of Sudetes Block (C) in relation to Fore–Sudetic Block (B), and the Fore–Sudetic Monocline (C) regarded as stable, has been obtained (Fig. 10). Movement of 6,2 mm in the NW direction confirms mobility of this part of the Central Europe. Above information has been taken from work by Kontny, Bosy and Cacoń (2000).

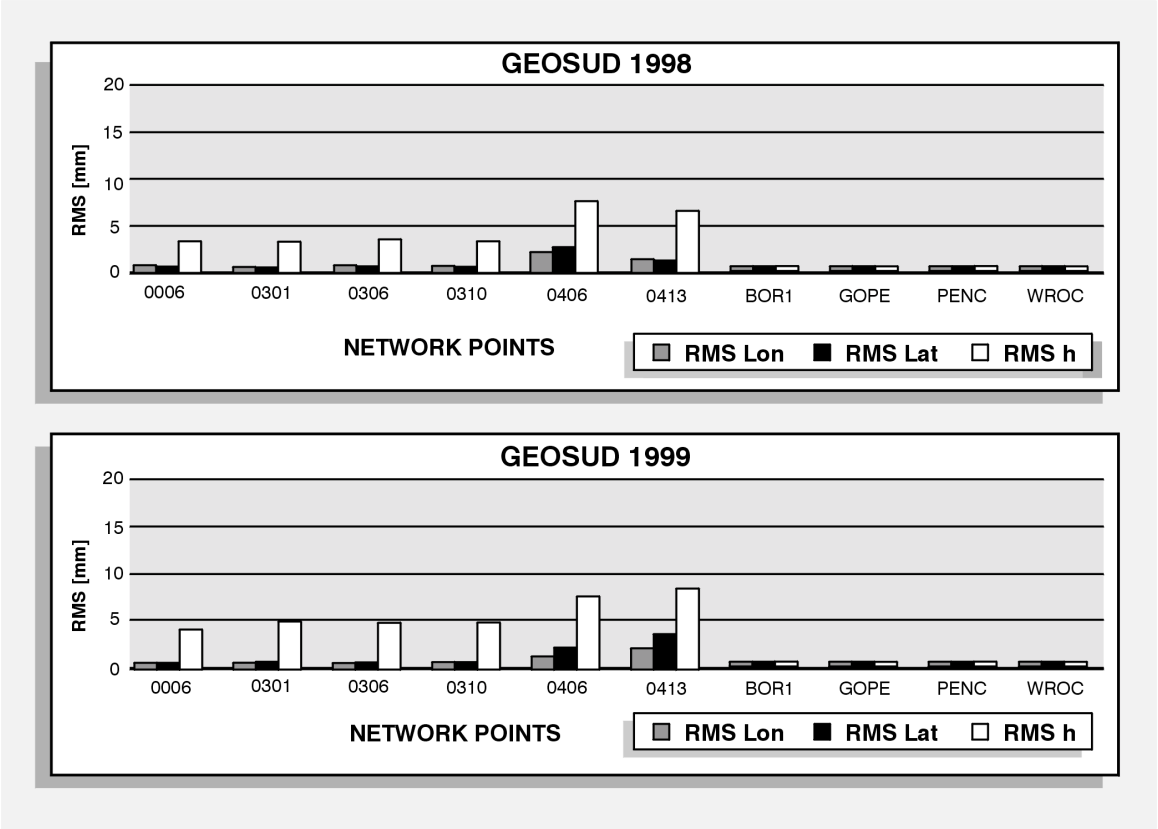


Fig. 8. The RMS errors of the GEOSUD network points for the 1998 and 1999 campaigns

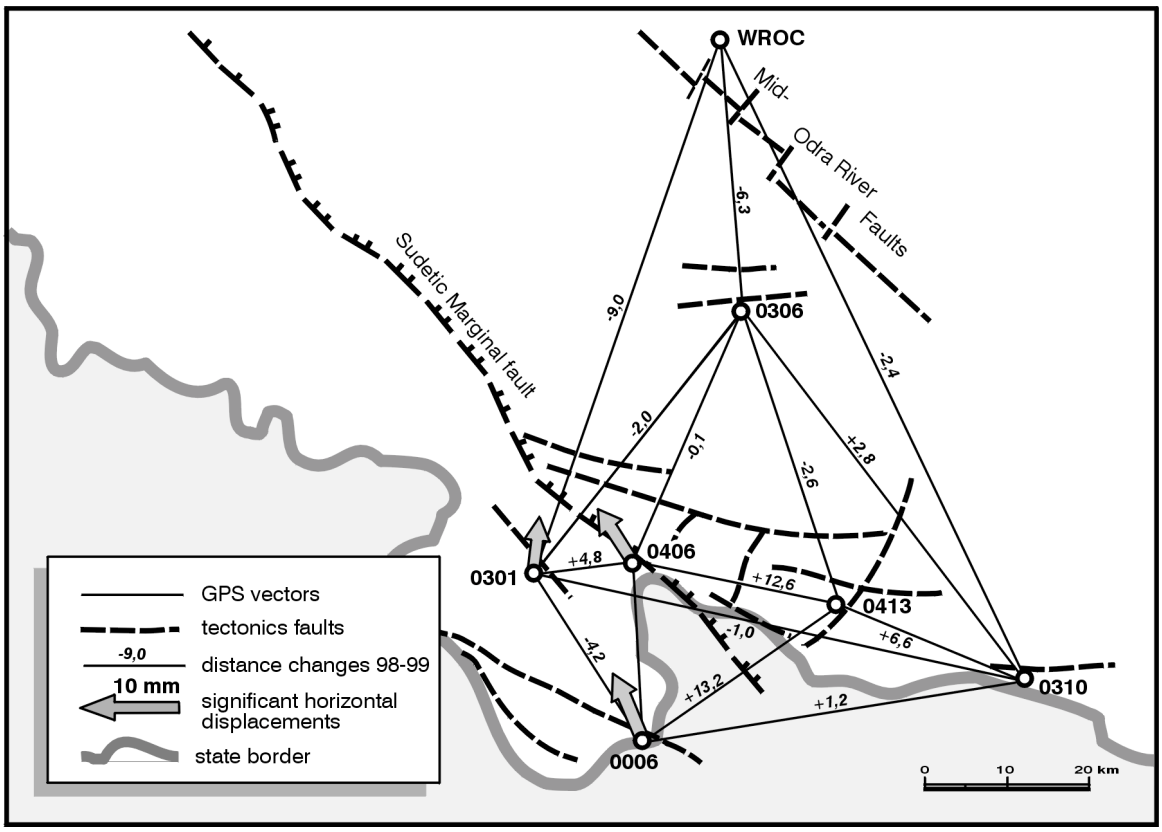


Fig. 9. Changes in vector distance in the 1998–1999 period

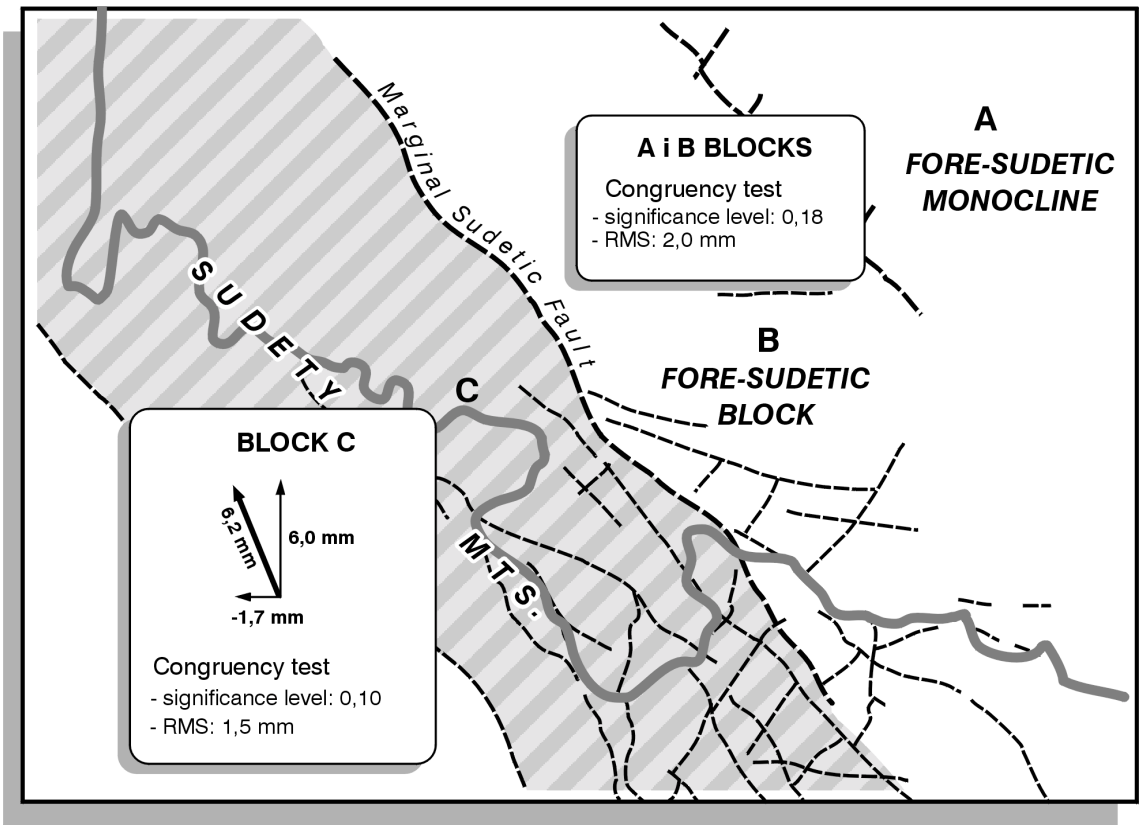


Fig. 10. Relative movement of the Sudetes Block in relation to Fore–Sudetic Block and the Fore–Sudetic Monocline

4.2. Gravimetric observations

Gravitational field measurements on the three geodynamic research areas, as well as other points of the "GEOSUD" network have been carried out since 1992 in time correlation with satellite GPS observations. Principles of gravity measurements with the La Coste & Romberg (1992, 1993, 1994) and Scintrex CG–3 (since 1994) apparatus, as well as results from the 1992-1998 period have been given in the paper by Barlik and Cacoń (1999).

Table 2 contains values of gravity changes on selected "GEOSUD" network points, with particular attention given to the "Paczków Graben". The following factors have been taken into account to select test points:

- location on crystalline rock outcrops,
- the greatest, significant changes of gravity during the 1993–2000 period.

Table 2. Gravity changes on selected points of the "GEOSUD" network

Point number	Gravity changes Δg [mGal]					Comments
	1993–1994	1994–1996	1996–1997	1997–1998	1998–2000 (1997–2000)*	
0113	–	**– 0,044**	+ 0,026	–	+ 0,022*	
0301	–	–	**+ 0,073**	**– 0,052**	– 0,005	
0402	**– 0,050**	**– 0,031**	**+ 0,048**	– 0,010	**– 0,030**	Paczków Graben
0406	– 0,040	– 0,019	**– 0,107**	**+ 0,065**	– 0,037	
0403	– 0,020	– 0,028	– 0,022	**– 0,044**	– 0,004	
0409	+ 0,010	+ 0,010	**– 0,095**	+0,024	– 0,024	
0413	**– 0,060**	**+ 0,058**	**– 0,104**	– 0,022	+ 0,002	
0310	–	–	**– 0,057**	**– 0,038**	+ 0,005	

Significant values of gravity changes (Δg), marked in bold, exceed twice the value of root mean square (RMS) error $\pm\sigma_{\Delta g}$ with α = 95% probability. The error values are in the ±(0,011 – 0,016) mGal limits for the given time period.

It is important to note, that changes of gravity in the Paczków Graben correspond with the changes of the vertical co–ordinate of the research points obtained from satellite GPS observations. This confirms vertical mobility of the ground, registered as a result of Ist class levelling network measurements comparison in the 1975–1994 period, along the Paczków Graben (Cacoń and Deeb, 1996).

Preliminary interpretation of these results shows their connection with movements of the earth crust near tectonic faults. This strengthens the hypothesis about continuity of tectonic movements in the region.

5. Tectonic movements as a hazard to water dams

Several water dams have been built and more are planned near the Sudetic Marginal Fault and the Mid–Sudetic Fault. The most significant tectonic hazard to water dams occur for the "Nysa" and "Otmuchów" water reservoirs in the Paczków Graben (Fig. 11) and "Dobromierz" reservoir on the IV Roztoka–Mokrzeszów profile (Fig. 6). Detailed information concerning risks for the Nysa dam has been presented in an article by Cacoń and Deeb (1996). These have been the result of locating the dam on a bunch of Tertiary tectonic faults covered by sediments 10 to 40 m thick. Significant lowering of benchmark below the dam reaching values of – 93 mm, give a reason for concern. Changes of gravity on points adjacent to the dam (0409 and 0413) substantiate these fears. The catastrophic flood, which has occurred in the Paczków Graben, in 1997, further implies the need of precise correlation of obligatory dam deformation measurements and recent movements of the earth crust.

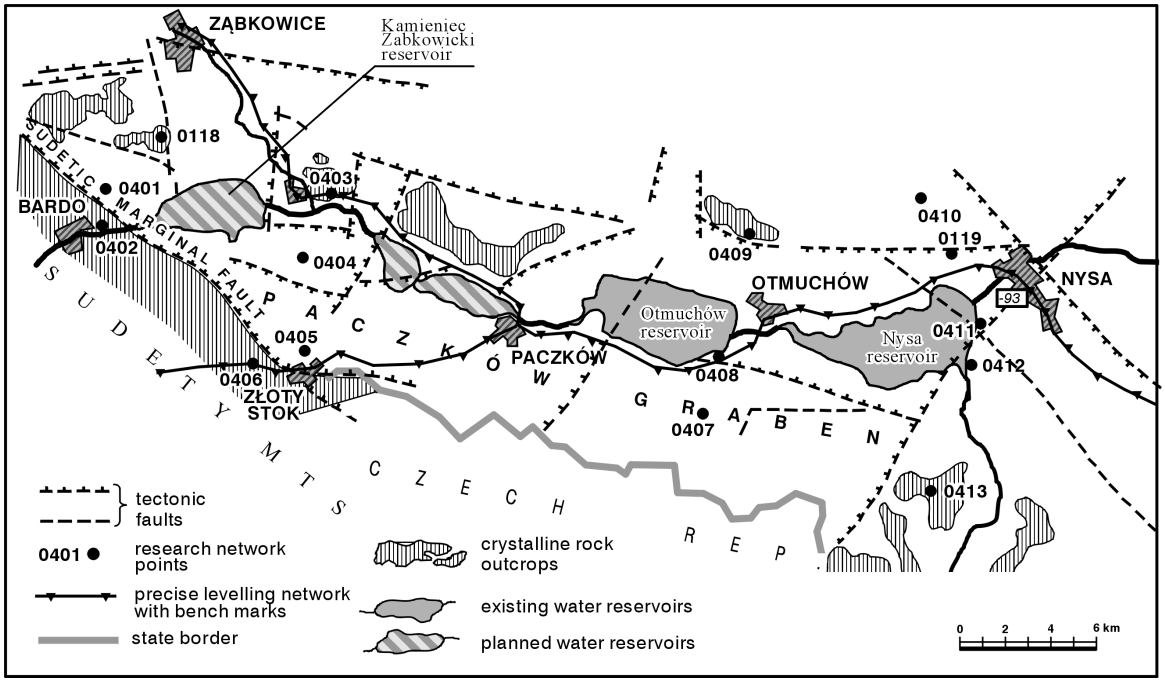


Fig. 11. Area of the Paczków Graben with the water reservoirs

The author's experience has been used in work concerning proper organisation and protection of deformation monitoring processes on the planned Kamieniec Ząbkowicki dam in the western part of the Paczków Graben. The grounds for interpretation of the future dam deformations in cause – effect aspect are being prepared (Cacoń, 1989).

6. Conclusion

Presented information and results of geodynamic investigations in the polish Sudetes and the Fore–Sudetic Block confirm mobility of this part of the Central Europe. Quantitative data of vertical and horizontal movements of the "GEOSUD" research network points correspond with gravity changes and thus prove that tectonic movements that had culminated in the Neogene have not yet ceased.

Recorded changes, apart from scientific values, also have practical applications. This is connected with the need for reliable safety evaluation of numerous dams located on or near active tectonic faults.

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