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GEODYNAMIC STUDIES OF THE PIENINY KLIPPEN BELT IN THE CZORSZTYN-REGION IN 2001-2003

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ABSTRACT
The project was launched in the autumn 2000. The paper presents research programme in the context of up-to-now geodynamic studies of the area. Geodetic methods (terrestrial and satellite) and geophysical methods (gravimetric, seismic sounding, electric resistance profiling) have been applied. The results were compared with whose obtained earlier in the years 1970-80-90 in the same region by the Institutes of the Warsaw University of Technology. Aim of the project was to find how the construction of the dam on Dunajec-river and creation of the artificial lake have influenced recent activity of the region. Results of precise leveling and trigonometric leveling have proved significant (6-7 mm) vertical depression of the Pieniny Klippen Belt relating adjacent tectonic units: Magura nape (in North) and Podhale Flysh (in South). Horizontal movements between the control points monitored by laser-distance and satellite GPS measurements have demonstrated shortening at the northern contact of the Pieniny Klippen Belt and differentiated extension trend at the southern contact. The character of the motion corresponds with changes in the seismic wave velocities: increasing in the region of the northern contact and decreasing in the southern contact comparing with those of 1988. Such a behavior can be explained by the increase and decrease of the stresses in the basement resulting probably from the water loading of the artificial lake. Gravimetric measurements have shown inessential increase of gravity in the region of the Pieniny Klippen Belt. The results of geodynamic studies have proved recent activity of the area considerable enough to take it into account in the process of forecasting safety of the dam in Niedzica and the Czorsztyn Lake. For the same reason the studies should be repeated no later then after five years.

KEYWORDS: geodynamics, geodesy, Pieniny Klippen Belt

INTRODUCTION

First geodynamic studies of the part of Pieniny Klippen Belt near Czorsztyn started before the World War II. The studies were connected with plans of erecting the water dam on Dunajec-river and to create the artificial lake associated with the dam. Some geologists were claiming that tectonics structure of the area consisting of limestone rocks is extremely inappropriate for such construction. Danger for the region catastrophic floods of the river that appeared at sixties indicated the necessity of the solution such as dam and artificial water reservoir. The test-field of the Pieniny Klippen Belt is situated in Southern Poland close to the Polish-Slovak border. The Klippen Belt is a tectonic formation separating the outer from the inner Carpathians. The Polish part of the Klippen Belt forms a mountains group called the Pieniny Mountains. Regular geodynamic studies of the area were performed continuously from early sixties until 1995. Diversified vertical motion (on the level of some mm/year) and horizontal displacements (reaching 10 mm/year) were proved. Construction of the dam on Dunajec-river and creation of the artificial lake may contribute significantly recent crustal activity of the area. Short history of geodynamic studies was presented in Czarnecki et al. (2002). Among the studies, precise geodetic (leveling, laser distance, GPS satellite) and geophysical methods (shallow seismic refraction-sounding, electric resistance profiling, gravimetry) were applied. Construction works started in early nineties. Yearly repeated measurements were suspended in 1995. After completing the construction of the dam and reservoir the studies were resumed in 2001[1].

MAIN OBJECTIVES OF THE STUDIES

The studies have been concentrated at gathering the measurement results highlighting the changed geodynamic situation of the region due to the water dam construction and artificial lake creation. The research-team wanted to find answers to the following questions:

[1] The project sponsored by the State Committee for Research, Project No 9 T12 E 009 19, started in autumn 2000

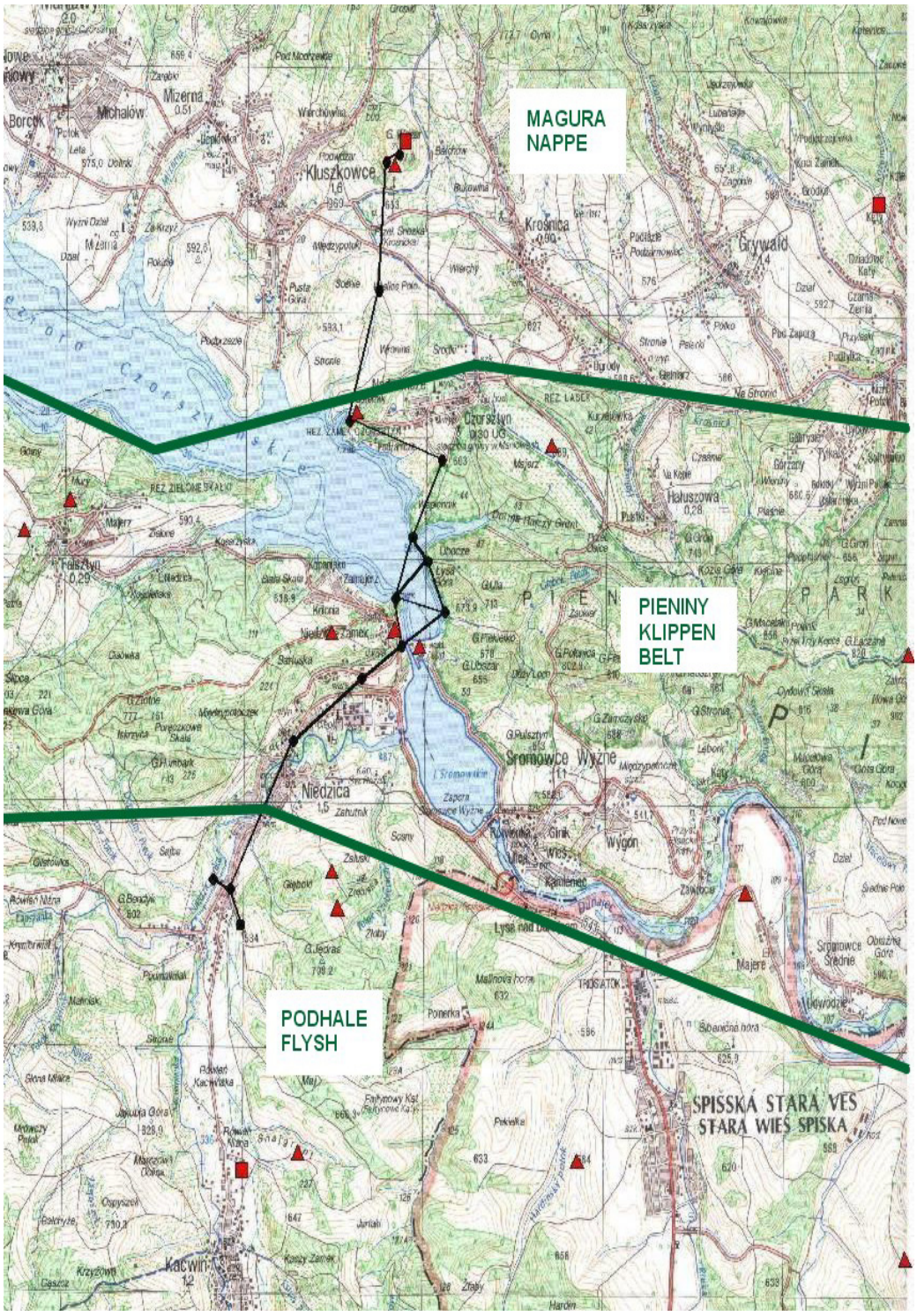

Fig. 1 The sketch illustrates the leveling control-line; bold lines separate approximately Pieniny Klippen Belt from adjacent tectonic units; sketch of the control line gives idea of its course

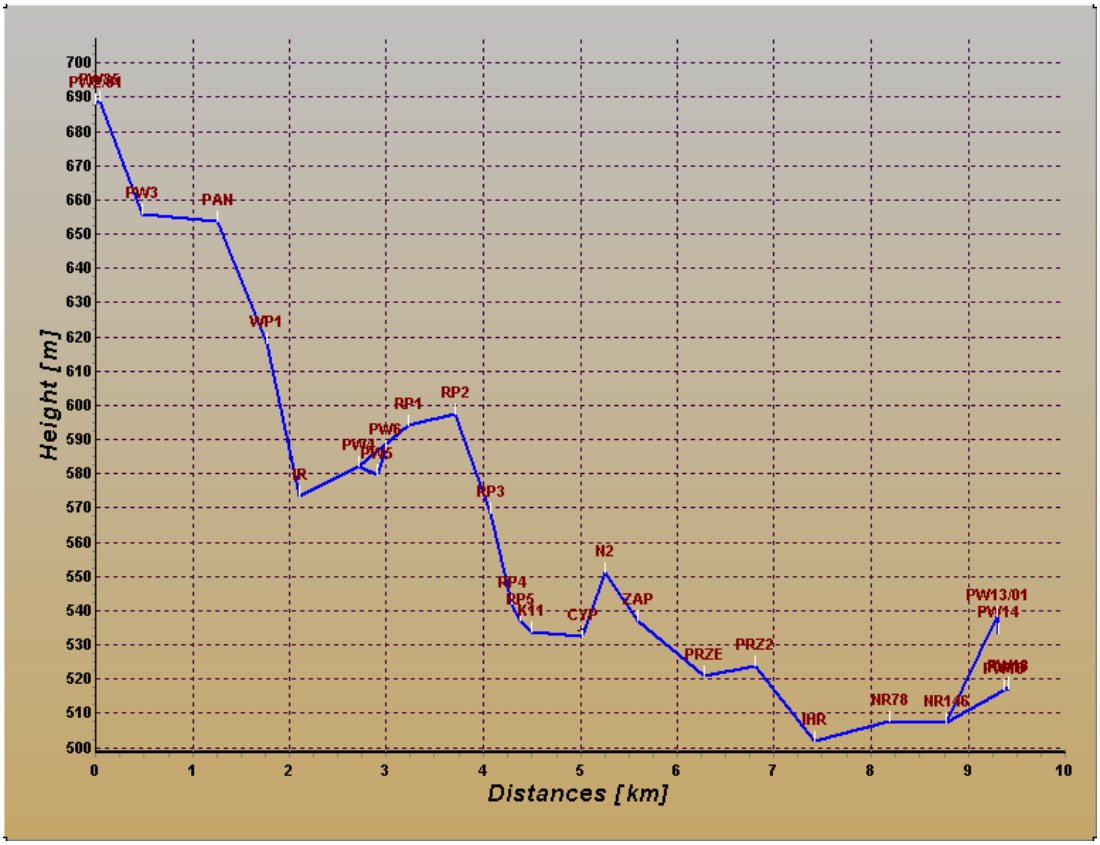

Fig. 2 Vertical profile of the control-line; significant differences in elevations can be seen; they caused terrestrial precise leveling very heavy

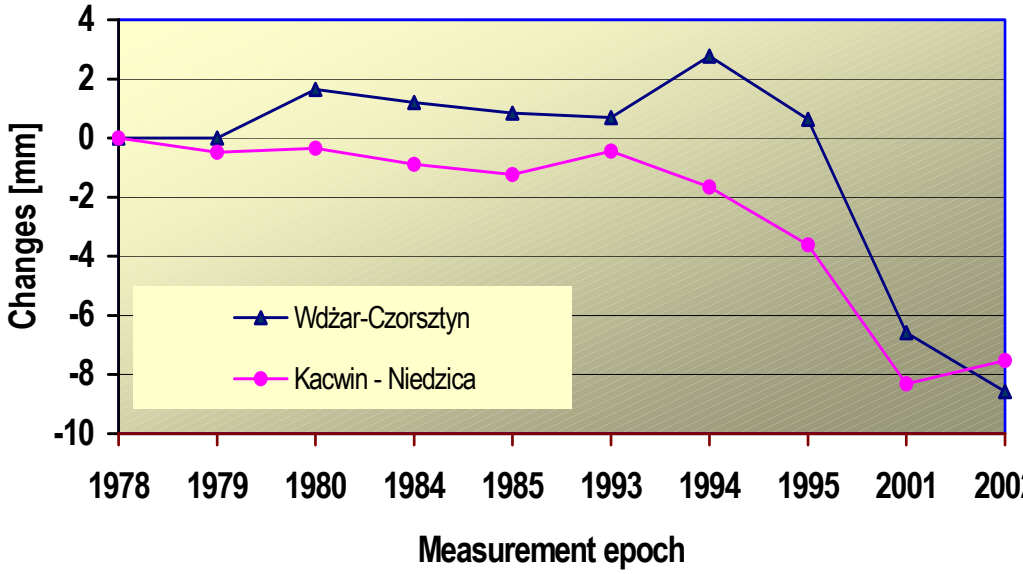

Fig. 3 Vertical changes since 1978 are presented; in the period of 1994-2001 heights decreasing of the Pieniny Klippen Belt is evident

Fig. 4 The gravity control-network

1. has the water loading of the reservoir changed the mobility of the area,
2. has the water penetration in lime-stones contributed the stress and the movement distribution ?

The goal of the studies was to compare the results of new geodetic observations with the old ones (those of nineties of last century) and searching for more reliable geodynamic conclusions.

The research-team expected to develop a set of rational recommendations concerning frequency of repeated measurements at the Czorsztyn geodynamic test-field.

Studies were to aimed at the results of such level of certainty that will eliminate the risk connected with exploitation of the dam and water reservoir as far as geodynamic premises concern.

SCOPE OF THE STUDIES

The status of the control networks was examined at the beginning of the field-works in the autumn 2000. The dam construction, but mainly the artificial lake creation has changed definitely course of some testing-lines. A certain lines have found themselves under water of the lake, some were destroyed in the course of construction works. It was find necessary to adopt the test-field as such to the new terrain circumstances. Run of the control lines, consistent with that one before artificial lake creation, has been restored as exactly as possible.

The following studies and measurements have been executed:

1. The shallow seismic refraction-sounding and the electric resistance profiling have been repeated.
2. The precise leveling line (leveling network) has been measured twice (2001, 2002) applying precise-code-leveling instruments. The horizontal network has been measured for three-times (2001, 2002, 2003).
3. Gravity measurements have been executed in relation to the distant reference stations. Gravity gradients have been measured in a direct neighborhood of the water dam.

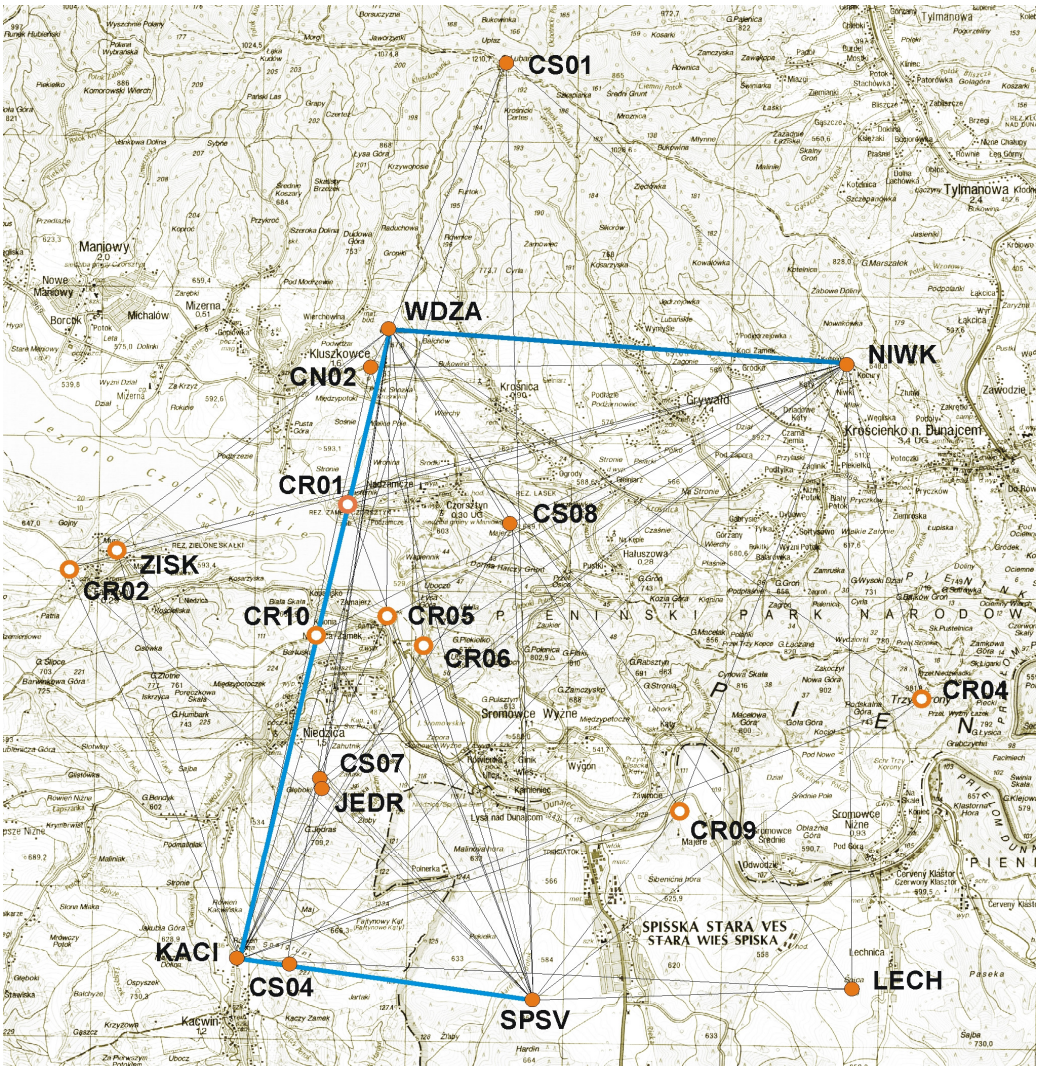

Fig. 5 The sketch of horizontal control-network; pair of stations situated at the Magura Nape (WDZA, NIWK) and three at the Podhale Flysh (KACI, CS04, SPSV) are destined as reference; parts of the line WDZA-CR01-CR10-KACI are controlling dynamic horizontal behavior of the area

The satellite GPS measurements have been expanded over adjacent areas of the Slovak part of the Pieniny and Tatra Mountains to provide wider geodynamic context

4. Vertical network of the test-field has been connected to the Polish national vertical control for the sake of forward studies.

The studies were executed by the staff of the Institute of Geodesy and Geodetic Astronomy, Warsaw University of Technology. The group of students of the Faculty of Geodesy and Cartography took part in the field-works. Several students prepared their diploma-theses using results of the studies. On the Slovak side of the border, GPS measuring campaigns were organized and coordinated by the staff of the Technical University in Bratislava the staff of the Slovak Geodetic Office.

PRECISE LEVELING CONTROL-LINE AND VERTICAL MOVEMENTS

Precise leveling control-line is running from the Magura nape in North, crossing the Pieniny Klippen Belt reaches the Podhale Flysh in South. Total length of the line reaches 10 km. Leveling measurements were executed applying precise code levels Zeiss DiNi12.

Part of the old leveling line was flooded by the water of the Czorsztyn Lake. This part of the line was replaced by the trigonometric leveling done simultaneously and reciprocally. Instant changes of refraction was restricted applying multi-series measurements. Exchange of observers on both measuring stations is to eliminate personal observing errors.

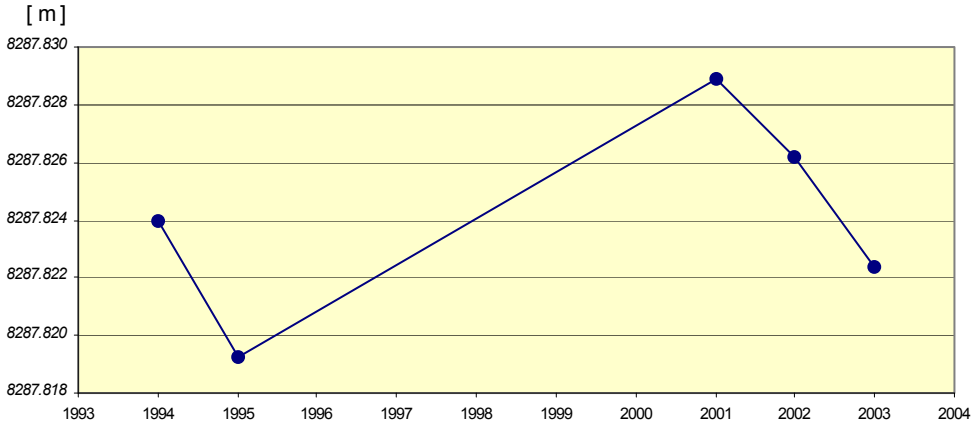

Fig. 6 Horizontal distance changes of Magura nape and Podhale Flysh

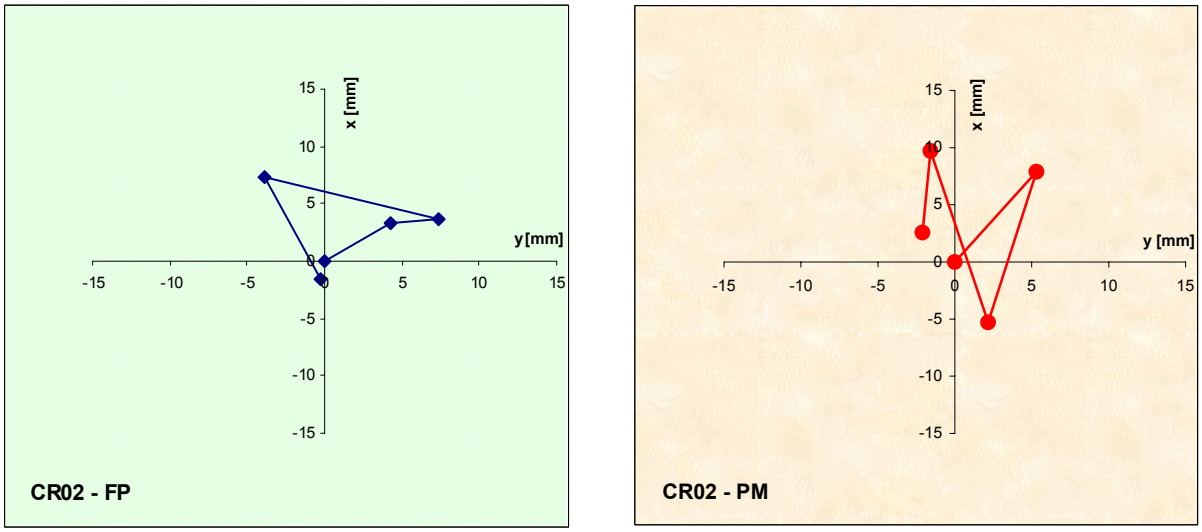

Fig. 7 Exemplary charts of changes of horizontal coordinates

Significant changes of height-differences were proved. The chart displays vertical changes of the Pieniny Klippen Belt relating Magura nape (Wdzar Mt. – Czorsztyn Castle) and Podhale Flysh (Kacwin – Niedzica Castle).

GRAVITY CONTROL-NETWORK

The gravity control-network consists of 8 stations: 4 reference stations and 4 control stations. The network is illustrated at the sketch.

In the time interval of six years (1995 – 2002) significant increase of the gravity at the control point Niedzica reaching 0.1 mGal was observed.

HORIZONTAL CONTROL-NETWORK

Horizontal control-network was established in 1978. In 1993 the network was adopted to GPS satellite observations. In the period of 2001 – 2003 measurements at 10 reference stations and at 8 control stations were performed.

Results of satellite GPS measurements have not proved evident horizontal motions between the Magura nape and Podhale Flysh – the tectonic units adjacent the Pieniny Klippen Belt from North and South. Generally a tendency of approaching each other can be observed excluding the period of 1995 – 2001 when the water reservoir was filled up and the structures become more distant.

The control stations within the Pieniny Klippen Belt demonstrated different behavior proving oscillatory (roaming) changes of coordinates in the range of ±10 mm. Such a magnitude does not authorize to be definitely interpreted as a motion of the station.

SEISMIC SHALLOW REFRACTION-SOUNDING

Changes in the seismic wave velocities are highly interesting: increasing in the region of the northern contact and decreasing in the southern contact comparing with those of 1988. Such a

behavior can be explained by the increase and decrease of the stresses in the basement resulting probably from the water loading of the artificial lake. Horizontal movements between the control points monitored by satellite GPS measurements have demonstrated generally shortening at the northern contact of the Pieniny Klippen Belt and differentiated extension trend at the southern contact. Such a behavior corresponds with mentioned above distribution of seismic wave velocities.

Figures 8 and 9 show the results of electric resistance-profiling and seismic shallow refraction-sounding; In both figures:

(a) part is for charts of electric resistance,

(b) map of isoom,

(c) geophysical section, with the seismic waves velocities,

(d) tectonic reconnaissance.

To compare the old (1980) and new (2001) geophysical study results full, dot, red and green lines should be properly considered:

- *full-lines* – measurements of 2001,
- *dot-lines* – measurements of 1980,
- *red-lines* – measurements of 2001,
- *green-lines* – measurements of 1980.

GENERAL CONCLUSION

The results of geodynamic studies have proved recent activity of the area considerable enough to take it into account in the process of forecasting safety of the dam in Niedzica and the Czorsztyn Lake. For the same reason the studies should be repeated no later then after five years (for detailed results see Czarnecki, 2004).

The Institute of Geodesy and Geodetic Astronomy has decided to continue once-a-year GPS measurements on selected stations of the testing-field basing on its own statutory founds.

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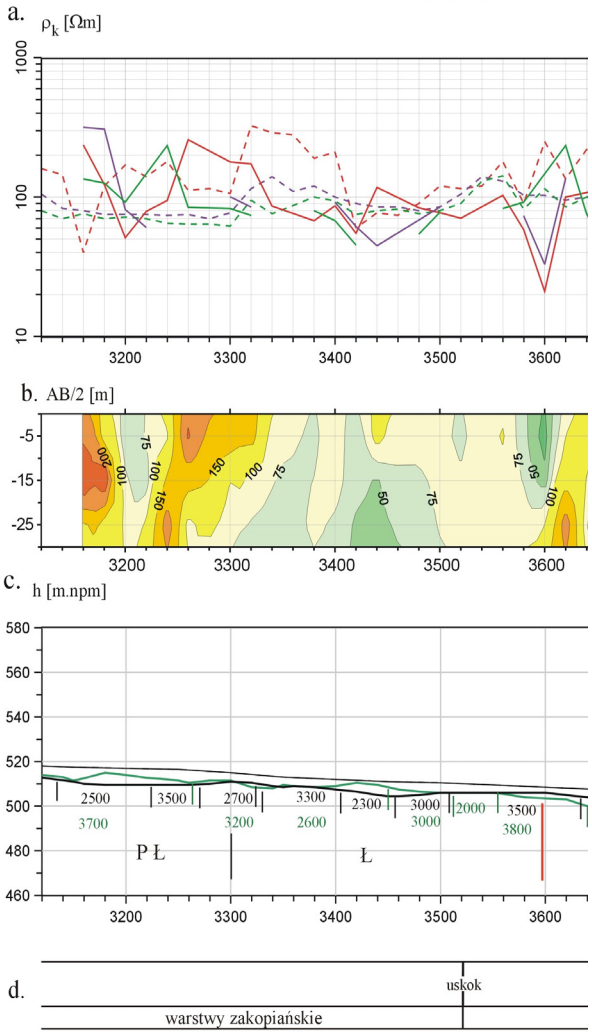

Fig. 8 The Northern contact of the PKB and Magura Nape

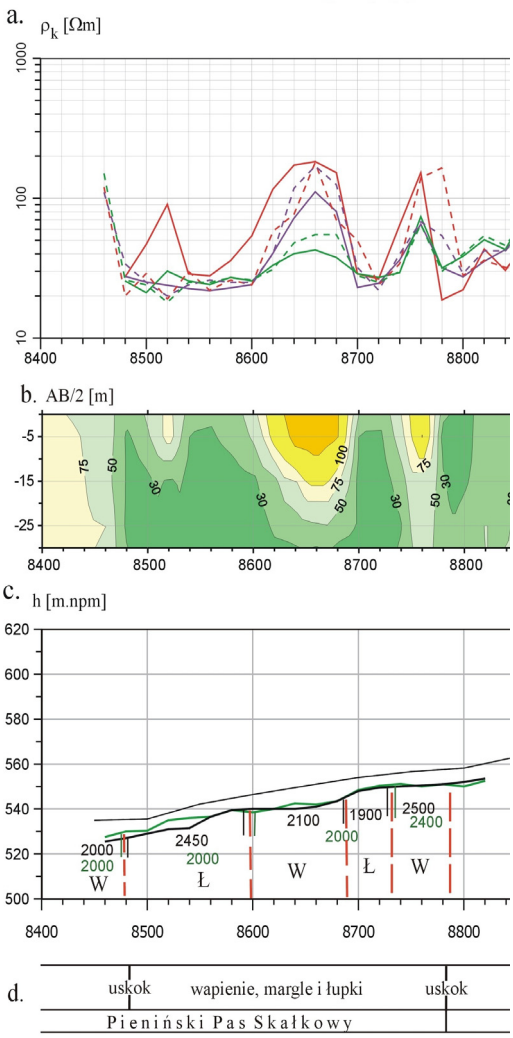

Fig. 9 The Southern contact of the PKB and Podhale Flysh