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3D MONITORING OF THE SELECTED ACTIVE TECTONIC STRUCTURES IN POLAND, ITALY AND GREECE

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ABSTRACT
The paper presents the results of geodynamic research in the frame of the project COST 625 relating to active tectonic structures' monitoring on the selected areas in Poland, Italy and Greece. Research was realised using a self-developed control and measurement system. The results of researches for period 2000-2006 indicate slight movements of observation points in the Sudety Mts. reaching several millimetres. However, the results confirm recent mobility of tectonic structures of this area. Research realised in the Mediterranean Region objects – Gargano, Norcia (Italy) and Kaparelli (Greece) – indicate movements of observation points reaching over a dozen millimetres, particularly on the Gargano area. Continuation of cyclic control measurements on these objects is fully justified.

KEYWORDS: active tectonics, geodetic monitoring system, local GPS network, crack gauge observation

1. INTRODUCTION

The monitoring of active tectonic structures in the frame of the project COST 625, on the Polish research areas, was begun in 2000 year. At the beginning two new research areas in the Polish Sudeten was organised: Dobromierz area in the Sudetic Marginal Fault zone and Janowice area on the Mid-Sudetic Fault. Geodynamic areas set up earlier in SW Poland, like Snieznik Massif area (set up in 1992), Szczeliniec Wlk. (1993) area and GEOSUD research network (1996), were also included into the studies within the COST 625 project.

Within the frames of international cooperation with the research groups from Italy and Greece local GPS surveys were organised and performed on three research areas in these countries: Gargano GPS Network on the Mattinata Fault (Gargano Peninsula, Italy), Norcia Network in Norcia Tectonic Basin (Central Apennines, Italy) and Kaparelli Network on the Kaparelli Fault Zone (Gulf of Corinth, Greece).

This paper presents: conception of control and measurement system, general organisational principles of the researches and summary of the main results describing the Polish group achievements.

2. MONITORING SYSTEM

The self-developed concept of a four-segment monitoring system (Table 1) was used in organisation of the studies (Cacoń et al., 2004b).

Table 1 Characteristics of the control and measurement system.

	Segment I	Segment II	Segment III	Segment IV
Observations, instruments	GPS and precise levelling	precise levelling, total station	crack-gauge, extensometer, inclinometer,	gravimeter
Frequency of observations	1-2 years	3-6 months	1 month	1-2 years
Accuracy of displacement measurements	± (0.1-3.0) mm	± (0.5-2.0) mm	± (0.01-0.1) mm ± (0.01-0.1) mm/m	(10-15) μGal

The following measuring techniques were used in the research surveys within the COST project:

- GPS technique (segment I) – yearly observations,
- Geodetic technique (segment II) – observations twice a year,
- TM-71 crack-gauge measurements – monthly observations.
- Relative gravimetric measurements – yearly observations,

Full four segment observations was implemented on the "Dobromierz" testing area. "Snieznik Massif", "Szczeliniec" and GEOSUD research networks include GPS, TM-71 and gravimetric measurements. "Janowice" network is observed only by terrestrial geodetic and relative extensometric techniques. According to the COST 625 theme only geometric surveys are presented in this paper. Gravimetric measurements used in the segment IV of the system are not included as a non geometric technique.

3. ORGANISATION OF THE RESEARCHES IN THE POLISH AREAS

During years 2000 and 2001 two geodynamic areas were established in the Sudety Mts. (Fig. 1) in tectonically active regions:

- "Dobromierz" on the Sudetic Marginal Fault, within the geological structure shown on the profile (Fig. 2) and in a direct contact with the water dam (Fig. 4),
- "Janowice" on the Mid-Sudetic Fault, in the geological structure shown on the profile (Fig. 3, Fig. 5),

Monitoring sites in all Polish research areas were set up as concrete blocks with heads for forced centring of measuring instruments (Fig. 6). All three geometric segments of the monitoring system was installed in the "Dobromierz" area (Figs. 7, 8 and 9). In the "Janowice" area only geodetic (segment II) and relative extensometric (segment III) measurements are realized. Monitoring networks and locations of TM-71 on those research areas are shown in Figures 10 and 11.

In 2003, two additional sites on whose researches started prior to 2000, were included in the COST 625 research programme:

- "Snieznik" local network (established in 1992) – (Fig. 12),
- "GEOSUD" regional network (measured since 1996) – (Fig. 1).

As well as annually repeated GPS surveys, observations preformed monthly with TM-71 crack gauges installed in the mentioned research areas were included into the project COST 625:

- "Bear Cave" (in the "Snieznik" research area) – 2 TM-71 instruments (Fig. 13),
- "Szczeliniec" (in the "Stolowe Mts.") - 3 TM-71 instruments (Fig. 14),
- "Złoty Stok" (in the "Gertruda" adit in an abandoned gold mine on the Sudetic Marginal Fault) - 2 TM-71 instruments (Fig. 15),

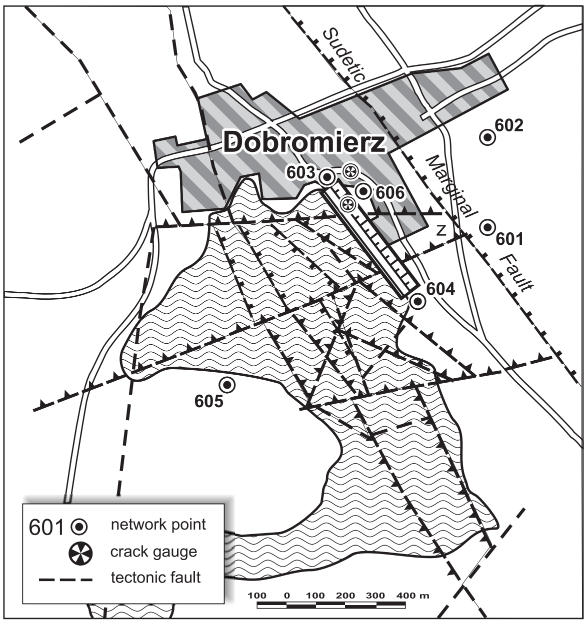

Fig. 10 Dobromierz network (Cacoń et al., 2003a).

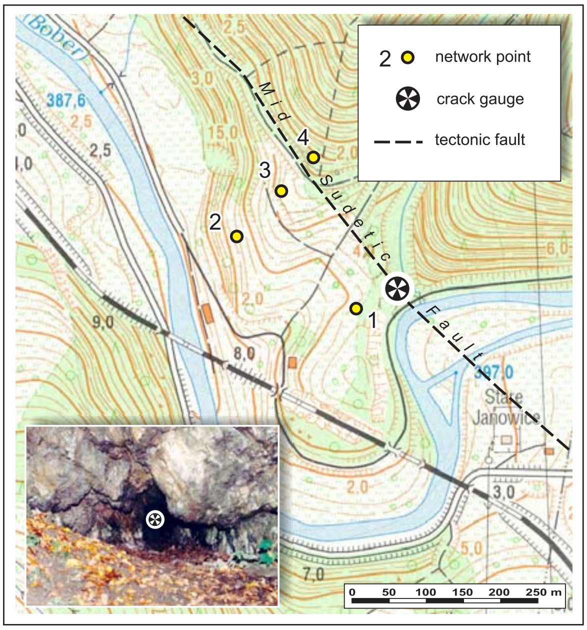

Fig. 11 Janowice research network.

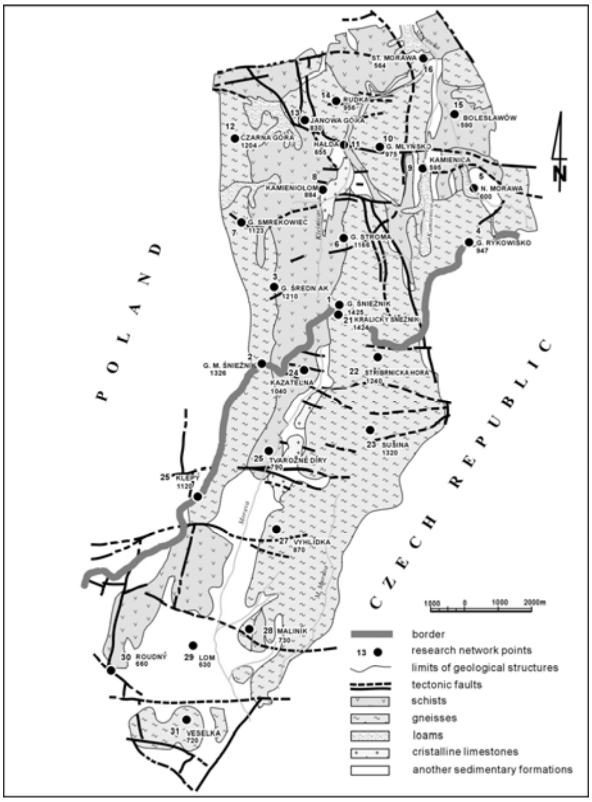

Fig. 12 Snieznik local network.

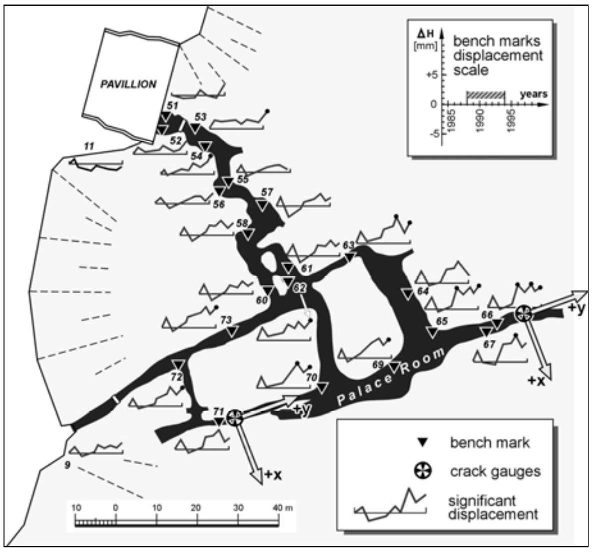

Fig. 13 Localisation of crack gauges and benchmarks in Bear Cave in Snieznik Massif research area.

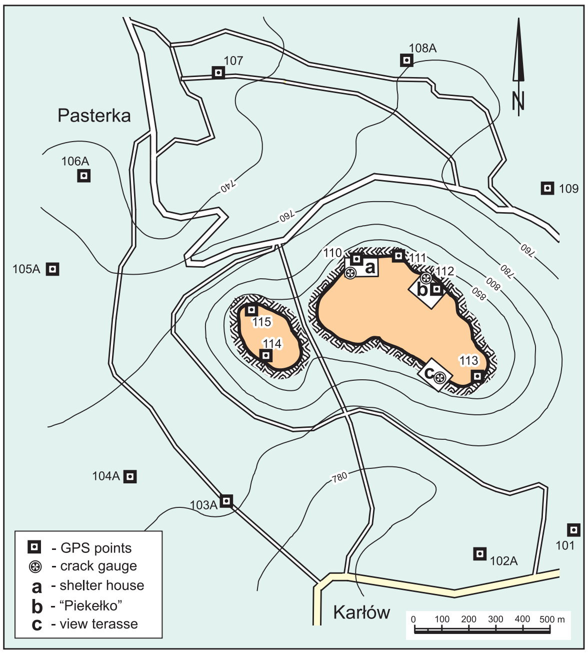

Fig. 14 Szczeliniec (Stołowe Mts.) research area (Cacoń et al., 2003b; Mąkolski et al., 2005).

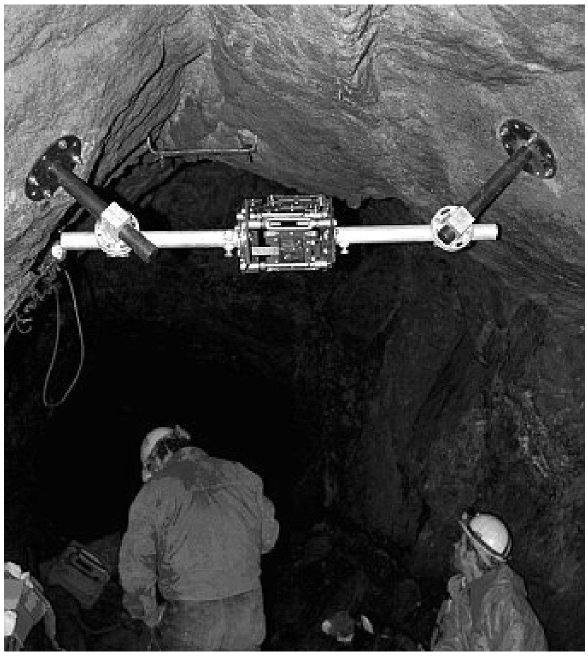

Fig. 15 Crack gauge in the "Gertruda" adit.

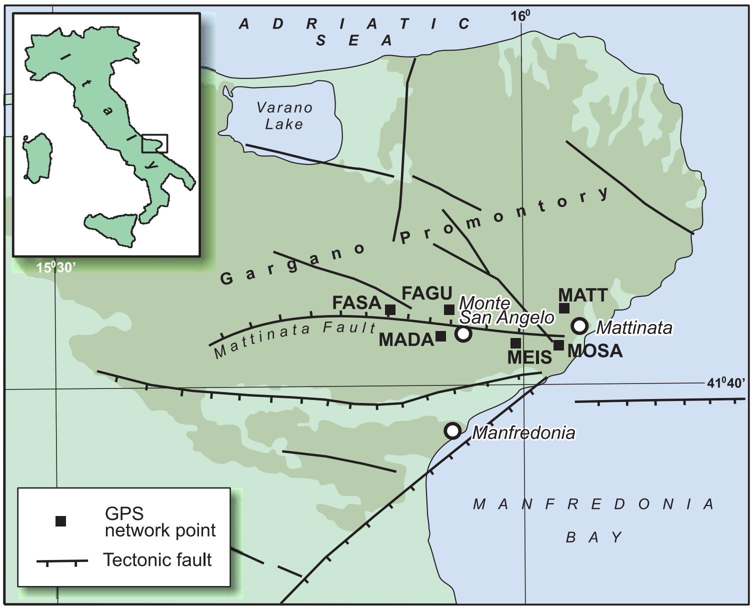

Fig. 16 Gargano geodynamic research area.

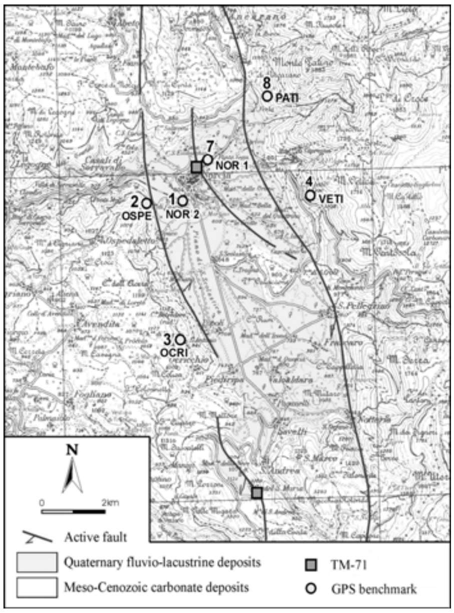

Fig. 17 Norcia research area.

4. RESEARCH COOPERATION ON THE SITES IN ITALY AND GREECE

Within bilateral scientific cooperation with the Italian partners (Prof. G. Cello, Dr. E. Tondi from University of Camerino and Dr. L. Piccardi from Institute of Geosciences and Earth Resources, Section of Florence) two geodynamic research GPS networks were established in Italy: "Gargano" Network in July 2002 (Fig. 16) and "Norcia" Network in November 2004 (Fig. 17).

In the Gargano promontory, which is one of the sectors of the Apulian foreland in southern Italy, the Mattinata Fault System represent the most important tectonic and seismogenic features (Borre et al, 2003, Tondi et al., 2005). The Norcia seismic area, located in the axial zones of the central Apennines, represent the intramontane basin and is affected by several faults of Late-Quaternary age (post 700 ky) which cut through, or reactivate, previous thrust-related features (Borre et al., 2003).

Similar research area was established on Kaparelli fault in the eastern part of the Gulf of Corinth, with cooperation of the Greek partners (Dr. G. Drakatos and Dr. A. Ganas from National Observatory of Athens) in November 2003 (Fig. 18).

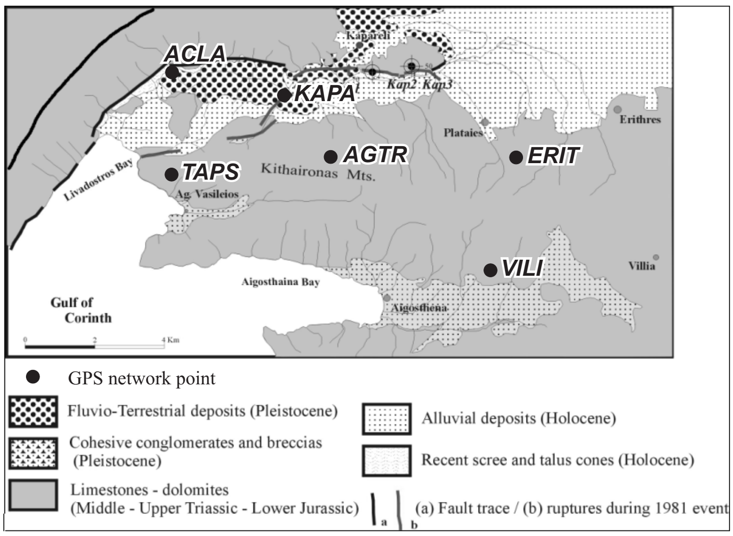

Fig. 18 Kaparelli geodynamic research area.

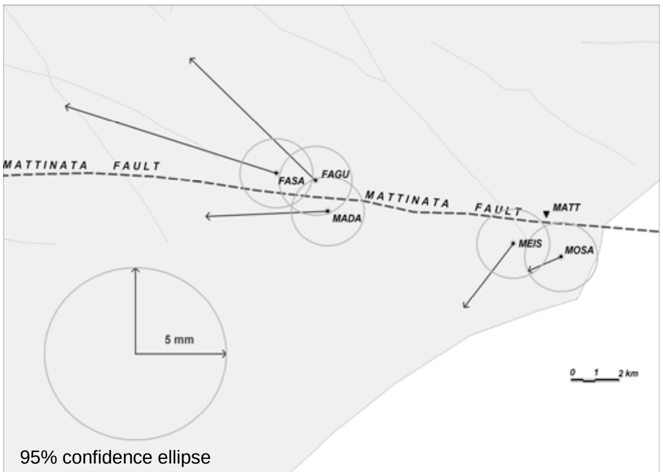

Fig. 19 Horizontal total displacement vectors of Gargano network sites.

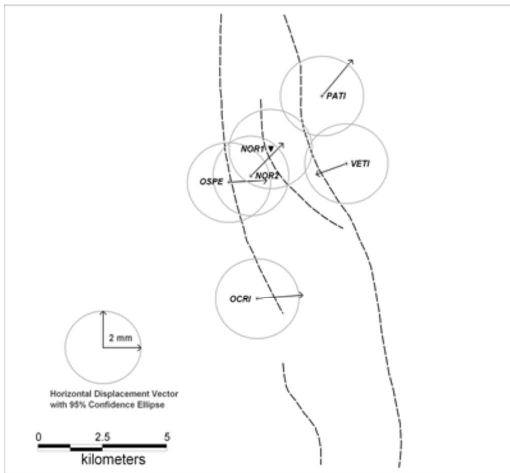

Fig. 20 Horizontal displacement vectors of Norcia network sites.

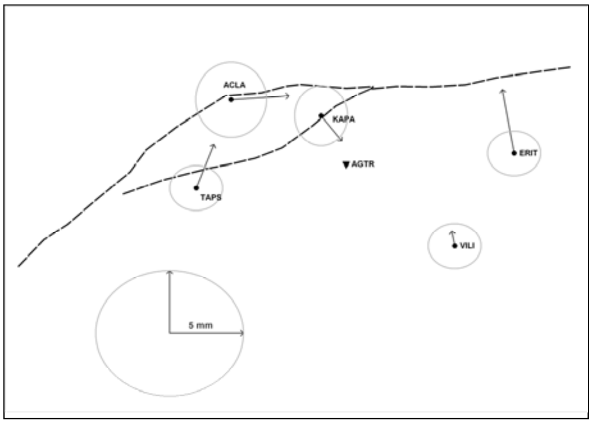

Fig. 21 Total horizontal displacement vectors of "Kaparelli" network sites.

The eastern Gulf of Corinth contains several active fault segments that accommodate N-S extensional strain. In 1981 three large earthquakes ruptured faults onshore including the south-dipping Kaparelli fault. Earthquake ruptures resulted in metric-scale ground displacements which were well mapped and supply an excellent dataset for fault slip directions and strain patterns. In addition, recent geological data showed that the Kaparelli area forms the boundary between fast-slipping normal faults in Corinth-Perachora regions and slow-slipping faults in Viotia, Attica (Drakatos et al., 2005).

The GPS sites in the network established in Italy and Greece were set up as a metal rod with heads for forced centring of measuring instruments (Cacoń et al., 2005a).

The yearly epoch GPS campaigns have been realized in the networks located in Italy and Greece by the research team from the Institute of Geodesy and Geoinformatics (Wroclaw University of Environmental and Life Sciences). The GPS observations were processed in the ITRF2000 frame (each daily session separately) connected to the IGS Italian Permanent Station Mattera (MATE).

The accuracy of determined coordinates representing un-weighted RMS values of coordinate residuals taken from each year (comparison of coordinates from each session with respect to the combined solution in mm) was obtained on the level of 2 mm for horizontal components and 5 mm for vertical component.

The total horizontal movement vectors (displacements) of Gargano Network sites for the period: October 2002 – July 2006, in the local reference frame, with site MATT as a stable reference point, is shown in Figure 19.

Horizontal movement vectors (displacements) of Norcia Network sites for the period: May 2005 – May 2006, in the local reference frame, with site NOR1 as a reference point, is shown in Figure 20.

Preliminary horizontal displacement vectors of "Kaparelli" network sites (with their 95% confidence ellipses) for the period: May 2004 – May 2006, in the local reference frame, with site AGTR as a reference point, are presented in Figure 21.

The presented results have only preliminary character, only long observation cycles (5–6 years) create proper foundations for interdisciplinary interpretations of their results and prediction of changes.

5. RESULTS OF THE MEASUREMENTS ON THE POLISH SITES

The results of geodynamic researches on the Polish (as well as the Italian and the Greek) objects were presented in numerous publications (see: Cacoń

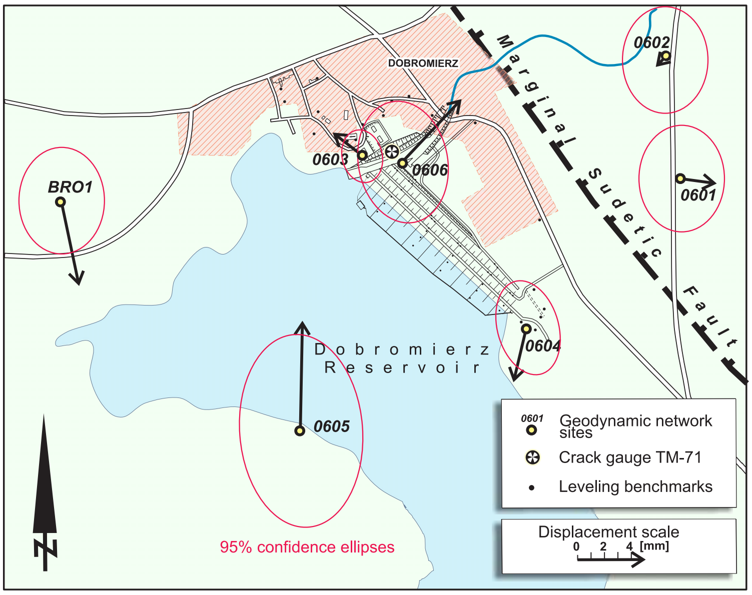

Fig. 22 Dobromierz – results of geodynamic researches in 2001-2005 period.

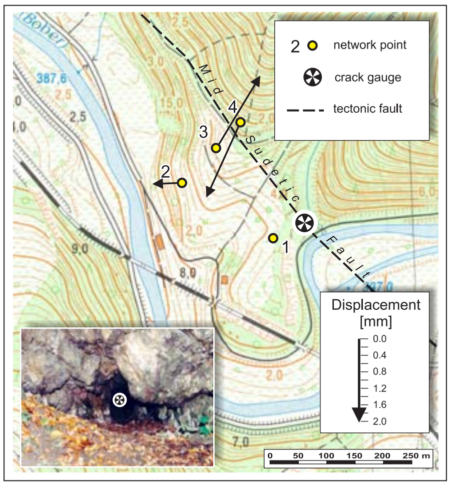

Fig. 23 Janowice – results of geodynamic researches in 2001-2005 period.

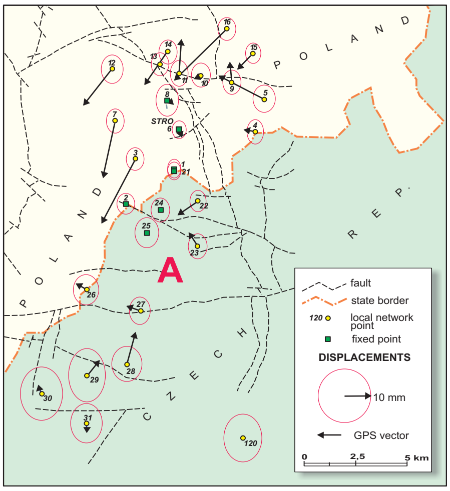

Fig. 24 Snieznik – horizontal displacements: results from 1993-2004 period (Cacoń et al., 2004c).

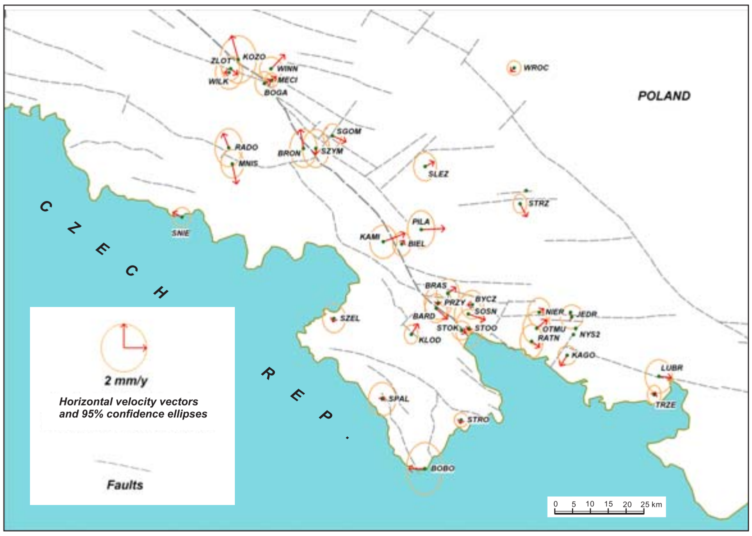

Fig. 25 GEOSUD – horizontal velocity vectors with 95% confidence ellipses in 1996-2005 period (Bosy et al., 2006).

et al., 2005a). The graphical representation of the results of the repeated GPS surveys is shown on the figures below. These concern the following areas: “Dobromierz” (Fig. 22), “Janowice” (Fig. 23), “Snieznik” (Fig. 24), “GEOSUD” (Fig. 25). Detailed deformation analysis of the Polish Sudetes and Fore-Sudetic Block is published in the paper (Cacoń et al., 2005b).

The results of studies performed on several objects in the Sudety Mts. indicate local movements of individual sites. There is no visible large scale tendency. This is particularly true of relative observations with TM-71 crack gauge. The cyclic GPS surveys, one or two orders less accurate than TM-71 observations, in most cases are contained within the limits of accuracies of the calculated vectors. Nevertheless in several cases confirm instability of geological structures in the areas of main tectonic faults in the Sudety Mts. and the Fore-Sudetic Block.

The results of TM-71 observations made on the monitored research areas in Sudeten are presented in the form of graphs of total displacements along the axis of the instrument: x, y and z (Figs. 26-31).

Results of the TM-71 observations analyses was presented in details in the paper Kontny et al (2005). Very slow relative movements (below 0.1 mm/year) are detectable at most sites in the Sudeten. Only results from Dobromierz site show horizontal movements above 2 mm/year, which is probably a movement of a particular rock-block in the given situation. As for the instruments located on the surface one-year periodicity has been found dominant, and follows seasonal temperature variations. Longer periodicity was also detectable (e.g. ca 12 years). No such a periodicity was detected for gauges located underground, in more stable environment (cave, mine adit etc.). The „echoes" of strong, far away earthquakes are probably observable in the TM-71 data time series in episodic displacements. The effects of local seismic events are not clearly noticeable.

6. SUMMARY

Application of a self-developed concept of a control and measurement system for 3-dimensional monitoring of active tectonic structures has demonstrated its effectiveness in unbiased recording of these structures' movements.

The system was implemented in the Polish Sudety Mts. in the early 90s of the 20th Century. Measurements in four segments of this system are used in research works. The results presented in this study, covering 3 segments (gravimetric observations not included), indicate movements of observation points reaching several millimetres. However, most of these values fall into the 95% probability error ellipse.

Experiences acquired with the system during research works in the Sudety Mts. have been successfully used in organising research networks on three objects in the Mediterranean Sea Basin: Gargano, Norcia in Italy and Kaparelli in Greece. Among other things less invasive, for natural environment, technique of observation points' foundation has been applied. The Polish team (authors of this study) have undertaken satellite GPS measurements constituting segment I of the system. The third measurement segment (TM-71 crack-gauge relative observations) is carried out by the Czech (Košťák, J. Stemberk) and Slovakian (L. Petro) team. The results, presented in this study, despite relatively short period of observations, show substantial movements of research points on these objects. This, particularly is true of the Gargano area, where movements of observation points reaching over a dozen millimetres were registered in the 2002-2006 period. These changes may be a sign of a possible earthquake. Observations on the remaining two objects have been shorter, nevertheless also show tendency to movements of research points.

Geological and geophysical premises, as well as GPS observations to date, substantiate usefulness for continuation of cyclic control measurements on these objects.

ACKNOWLEDGEMENTS

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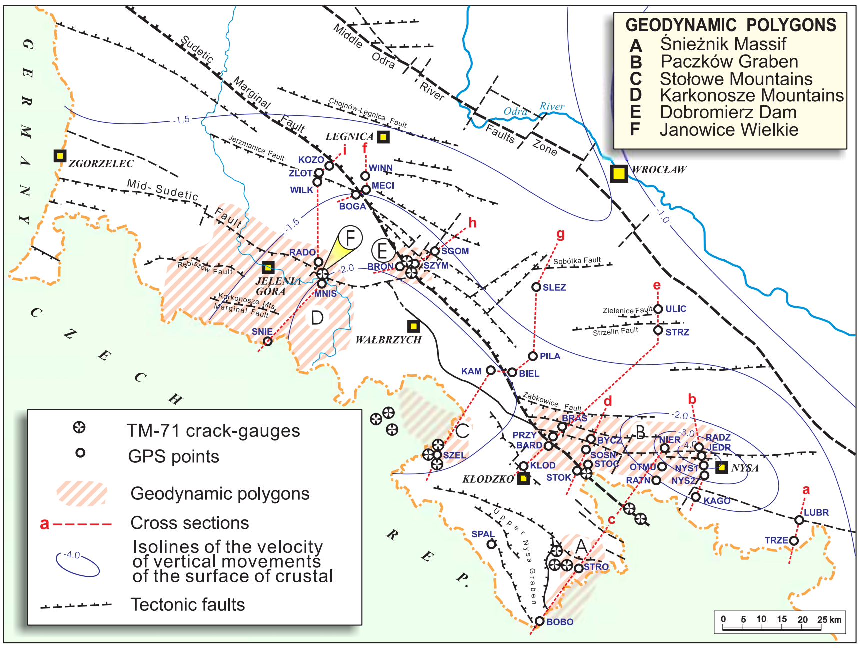

Fig. 1 Sudety Mts. geodynamic areas and “GEOSUD” network (Cacoń et al., 2004a).

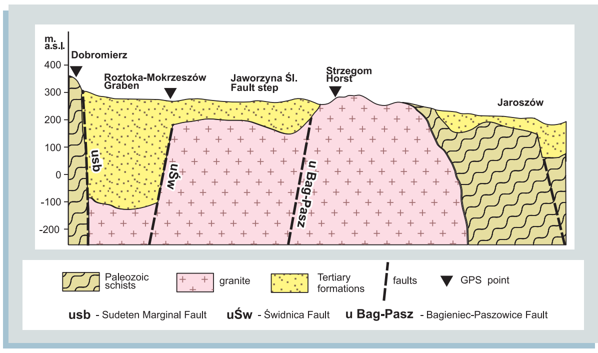

Fig. 2 Dobromierz geological profile.

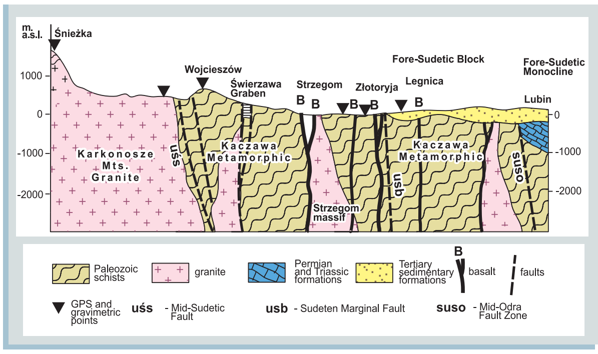

Fig. 3 Janowice profile.

Fig. 4 Dobromierz dam.

Fig. 5 Janowice site observation pillar.

Fig. 6 GPS point.

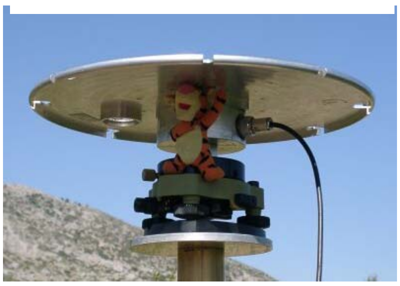

Fig. 7 GPS Antenna.

Fig. 8 Total station.

Fig. 9 Crack gauge.

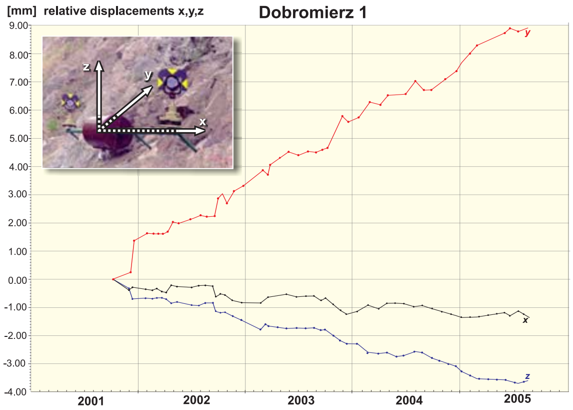

Fig. 26 Dobromierz – results of TM-71.

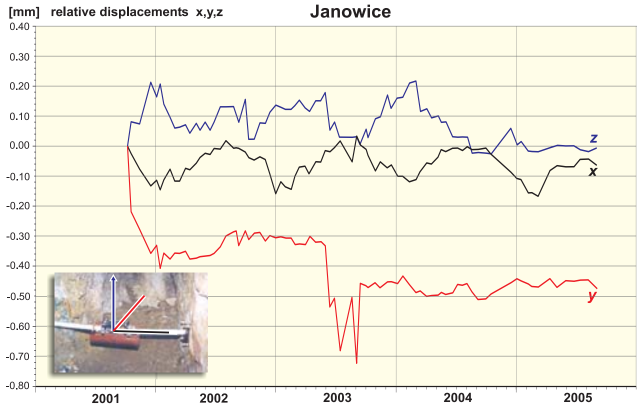

Fig. 27 Janowice – results of TM-71.

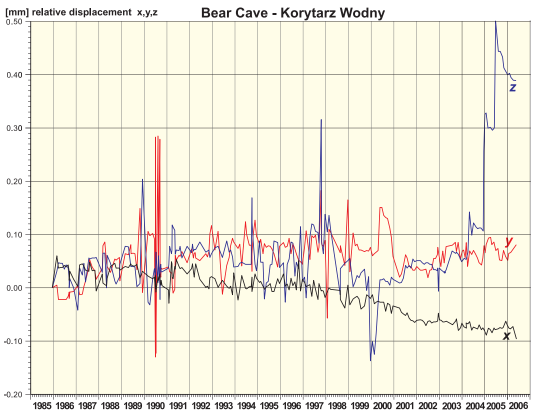

Fig. 28 Bear Cave, „Korytarz Wodny" – results of TM-71.

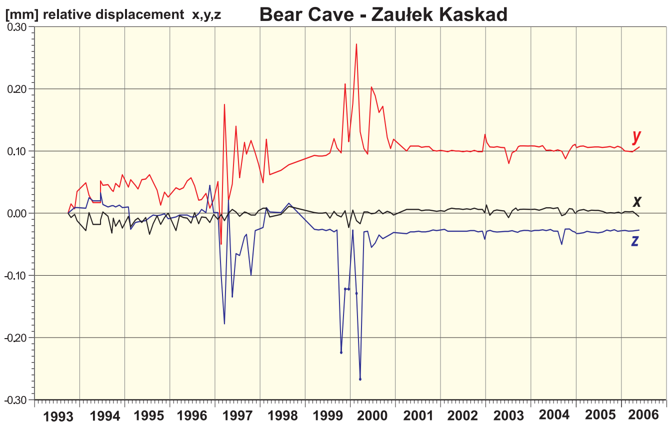

Fig. 29 Bear Cave, „Załek Kaskad" – results of TM-71 observations.

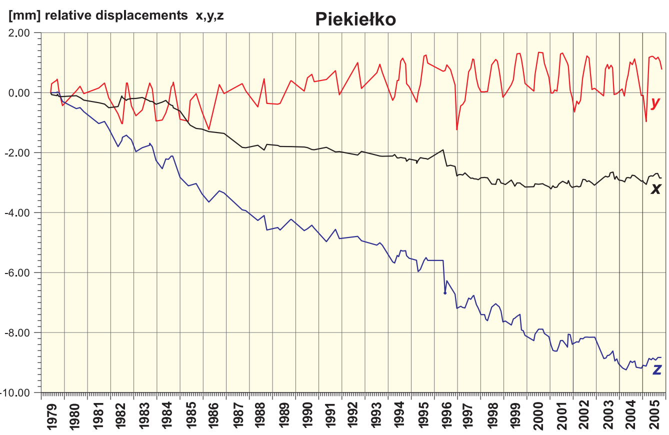

Fig. 30 Szczeliniec, „Piekiełko" – results of TM-71.

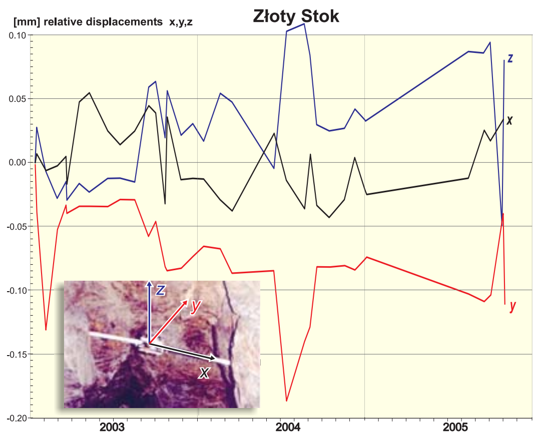

Fig. 31 Złoty Stok, „Gertruda" adit – results of TM-71.