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GEODYNAMIC EFFECTS DETECTED IN THE STOLOWE GÓRY MOUNTAINS INVESTIGATED ORIGINALLY FOR GRAVITATIONAL MASS MOVEMENTS

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ABSTRACT

Rock block forms of the Szczeliniec Wielki (919 m a.s.l.) in the border area of the Stolowe Mountains massif originated due to various exogenous and endogenous processes. The processes had started in the Upper Cretaceous, culminated in Late Tertiary, and continue till the present day with much lower intensity. Such processes were indicated by historical earthquakes and different tectonic events in the Sudeten Mountains and adjacent areas. Results of geodetic geodynamic studies are presented.

Several sectors of the Sudeten Mountains which include the Table Hills - Stolowe Mountains, show horizontal and vertical movements. Results of periodic precise levelling in three geodetic micro-networks established on the Szczeliniec Wielki: "Przy Schronisku", "Piekielko" and "Tarasy Poludniowe / Schody" are presented. Investigations have been augmented with TM-71 crack gauging in rock blocks. These studies started in 1972 increasing gradually effectiveness of monitoring. Levelling changes, as well as displacements resulting from 3D monthly records of three TM-71 crack gauges have been confronted with recent investigations into tectonic micro-deformations along the Sudeten Fault in the Bohemian Massif. It is suggested that aseismic geotectonic processes participated in the deformations found in investigated networks.

KEYWORDS: geodynamics, recent crust movements, tectonic processes, rock block displacements, national park, table hills, geodetic networks, precise levelling, gravity measurements, crack gauging,

1. INTRODUCTION

The Stolowe Góry Mts. in central Europe, appear as a marginal section of Sudeten Fault zone bordering Bohemian Massif from Polish flat plains in NE. Here, Mt Szczeliniec Wielki (919 a.s.l.) represents the peak with the highest strata outcrops of thick-bedded Upper Cretaceous sandstones which display high walls and giant blocks separated by deep fissures. For its unique rock forms the area has been protected since 1993 as a Polish National Park „Góry Stolowe – Stolowe Góry Mountains".

Contemporaneous orographic picture of the Stolowe Góry Mountains is attributed to endogenous and exogenous processes that started in the Upper Cretaceous and intensified in the late Tertiary. The processes continue with much lesser intensity until present time. Earthquakes in the Sudeten and adjacent areas, indicated by the results of works by Karnik et al. (1984), Schenk et al. (1989, 1991), give evidence of such processes. Results of geodetic and gravimetric studies in the central part of the Stolowe Góry Mountains (Cacoń et al., 2010) and the Stolowe Góry Mountains National Park (Cacoń et al., 2011a, 2011b) confirm it as well.

Studies of gravitational mass movements on the Szczeliniec Wielki have been carried out since the 70'ties of the 20th Century. Periodic geodetic measurements (precise levelling, Total Station), in different time cycles, were enhanced with precise observations of relative movements between rock blocks with the use of TM-71 crack gauges (Košťák, 2001, 2006). Results of these studies in various periods have been published by Košťák and Cacoń (1976), Košťák and Cacoń (1988), Stemberk et al. (1994), Mąkolski et al. (2005) and Cacoń et al. (2008).

Complex origination of rock blocks movements on the Szczeliniec Wielki have been interpreted by a number of researches, among others: Pašek and Pulinowa (1976), Pašek and Košťák (1977), Ter-Stepanian (1976). Instability of rock blocks has been explained by plasticity of marl bedrock, thermal changes in the winter-summer period, as well as by the process of scouring. These interpretations are based mainly on data of qualitative character. Observations with geodetic instruments carried out since 1972 and observations with TM-71 crack gauges carried out since 1974 provide quantitative data for interpretations of rock blocks movements. This concerns mainly data obtained with crack gauging in monthly frequency and accuracy of 0.05 mm.

In this work special attention is paid to anomalous rock block displacements and tilts recorded in the period of the last 15 years (1996–2011). The special reason for it is evident. Geodynamic studies revealed important aseismic movements in central Europe during this period. Data which originally concerned the zone of Sudeten Fault (Czech-Polish border line, Stemberk et al., 2010) were verified even for Krušné Hory Mts. Fault zone (Bohemia-Saxony border line, Košťák et al., 2011), and evidenced even on West Carpathian territory of Slovakia (Petro et al., 2011). The main movement observed as a pressure pulse, occurred in summer 2003 and started a period of increased geodynamics which could be followed till 2007. Following the pulse significant movement anomalies occurred by the end of 2004. Globally, it appeared as the time of the catastrophic tectonic and seismic evens along the Sunda trench near Sumatra. The process along the trench was enormously intensive and continued several years.

Geodynamic anomalies were traced on a relatively large territory covering Bohemian Massif and West Carpathians of Slovakia where only limited number of internal and low seismic events could interfere and such interference could be local only. Thus, the 2003/7 anomalies were found worth of special investigation even in the case of the Szczeliniec Wielki lying in the territory of the earlier studies. The object investigated originally for gravitation movements could have been affected by the incriminated geodynamics with impact to stability.

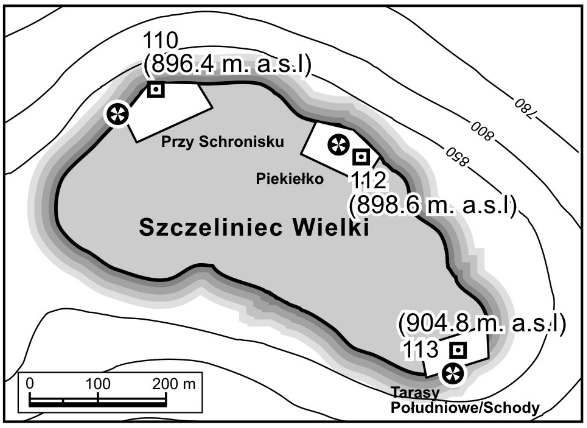


Fig. 1 Fragment of local spatial network covering the upper part of the Szczeliniec Wielki and Szczeliniec Maly massifs.

2. METHODS

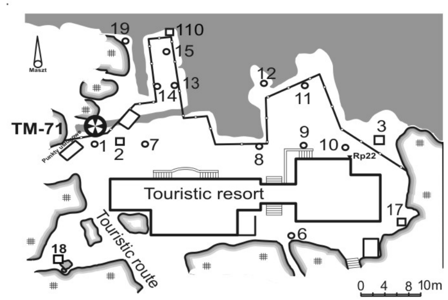
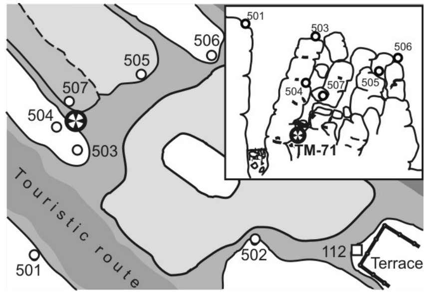
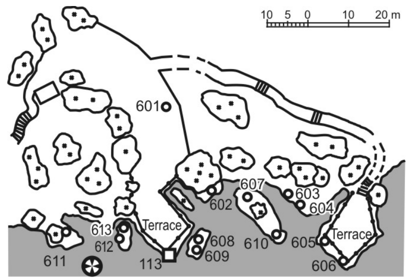
Measurements of mass movements of rock blocks on the Szczeliniec Wielki are carried out with geodetic methods (precise levelling, Total Station) and TM-71 crack gauges. These measurements belong to segments II and III of the control and measurement system published recently (Cacoń, 2004; Cacoń and Kontny, 1993). In the meantime, periodic GPS and gravimetric measurements are carried out on several points (110, 112, 113) of the local spatial network (Fig. 1) covering the Szczeliniec Wielki, and constitute segments I and IV of the control and measurement system. It is with reference to these points that periodic geodetic measurements in the three local micro-networks located on rock blocks has been realised. All the points in these networks are equipped with metal bolts in rock blocks. Relative observations of displacements between rock blocks carried out with three TM-71 crack gauges have been integrated into the analysis of the geodetic measurements.

Crack gauging carried out in rock fissures not deep under the terrain, which is the case of Szczeliniec Wielki, suffers with temperature variations. Instrumental effects are eliminated generally. However, effects upon rock are complex since boulder dimensions, rock structure and water percolation play role in the massif and cannot be described precisely. Such effects follow climatic cycles as a rule showing certain regularity. 3D gauging show usually advantage of important reduction of the unwanted effects in shear components (y) and (z), as well as in rotations while fissure dilatation (x) is more affected. This is to see reasons for leaving graphs without improper corrections. Reader will then find some sinusoidal variations of periodical climatic origin in our results. We can resign to (x) if seriously affected, or produce a useful plot to show the real time course in the graph. Anomalies to be investigated are generally considerably dissimilar to climatic effects and well identifiable.

General characteristics of the three study areas on the Szczeliniec Wielki have been given in Table 1.

Periodic geodetic measurements were carried out repeatedly in September under analogical atmospheric conditions of fall, first annually, then in uneven intervals of several years. Usually, we accepted observation of an external anomaly that could change ground conditions in the massif as a signal to start a measurement campaign in the particular year. Such an anomaly could be atmospheric conditions like extreme rainfalls and snowfalls, large temperature amplitudes found in the winter-summer periods, as well as possible earthquakes in close or distant surroundings of the Table Mountains. Additionally, levelling measurements between points (110, 112 and 113) of the micro-networks (“Przy Schronisku”, “Piekielko” and “Tarasy Południowe / Schody”) have been carried out on several occasions. In that it was the point 113 which has been determined on the basis of satellite GPS measurements within the frames of the regional geodynamic network GEOSUD research (Cacoń, 2004) as a stable reference point (Fig. 1). The point has been assigned the SZEL acronym. On the

Table 1 Characteristics concerning research measurements on Mt Szczeliniec Wielki.

<table>
<tr><td colspan="2" rowspan="3">Specification</td><td colspan="3">Name of research micro-network</td></tr>
<tr><td>Przy Schronisku</td><td>Piekielko</td><td>Tarasy Poludniowe / Schody</td></tr>
<tr><td colspan="3">Geodetic measurements</td></tr>
<tr><td colspan="2">Scheme of the research network</td><td>
</td><td>
</td><td>
</td></tr>
<tr><td colspan="2">Start of measurements</td><td>1972</td><td>1982</td><td>2008</td></tr>
<tr><td colspan="2">Number of measurement epochs</td><td>16</td><td>14</td><td>4</td></tr>
<tr><td rowspan="2">Accuracy of displacement determination</td><td>horizontal Δ(x, y)</td><td colspan="3">±(1.0–2.0) mm</td></tr>
<tr><td>vertical ΔH</td><td colspan="3">± 0.3 mm</td></tr>
<tr><td colspan="5">TM-71 crack-gauge measurements</td></tr>
<tr><td colspan="2">Start of measurements</td><td>1974</td><td>1979</td><td>1998</td></tr>
<tr><td colspan="2">Frequency of observations</td><td colspan="3">1 observation per month</td></tr>
<tr><td colspan="2">Accuracy of relative displacements determinations</td><td>± 0.1 mm</td><td></td><td></td></tr>
<tr><td colspan="5">Levelling (precise) measurements linking local micro-networks</td></tr>
<tr><td colspan="2">Start of measurements</td><td colspan="3">1974</td></tr>
<tr><td colspan="2">Number of measurement epochs</td><td colspan="3">13</td></tr>
<tr><td colspan="2">Accuracy of height determination change</td><td colspan="3">± 0.3 mm</td></tr>
</table>

points 110, 112 and 113 gravimetric measurements have been carried out several times.

TM-71 crack gauge observations have been regular in monthly intervals since the gauge installations unless extreme winter conditions prevented access.

3. OBSERVATIONS

3.1. GEODETIC OBSERVATIONS

3.1.1. "PRZY SCHRONISKU" GEODETIC MICRO-NETWORK

The measurements (precise levelling, total station) of the network in the shelter house area have the longest history (1972–2010). Horizontal and vertical displacements of points in various periods have been presented in the cited publications. In Figure 2 vectors of vertical displacements for the entire 38-year period (1972–2010) are shown.

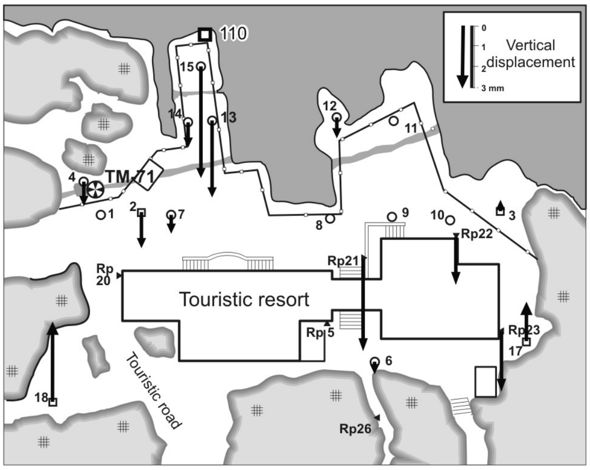
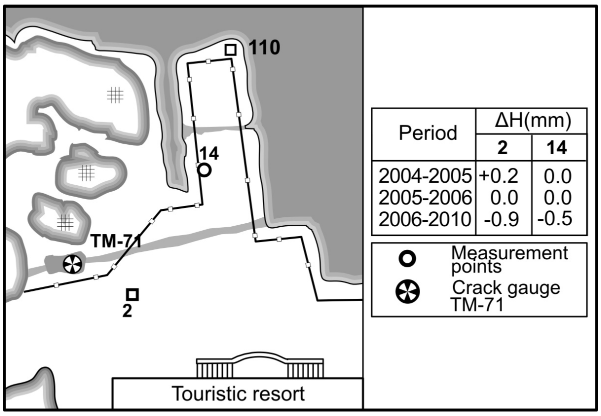


Fig. 2 Vertical displacements of the points of the „Przy Schronisku" micro-network in the 1972–2010 period.



Period	ΔH(mm)	
	2	14
2004-2005	+0.2	0.0
2005-2006	0.0	0.0
2006-2010	-0.9	-0.5

Fig. 3 Height changes of points 2 and 14 „Przy Schronisku" in the 2004–2010 period.

For the two points in the closest neighbourhood of the TM-71 crack gauge, on which levelling measurements could be carried out, change of height in 2004–2005, 2005–2006 and 2006–2010 intervals have been determined (Fig. 3). Quantitative vertical displacements concern points 2 and 14 that are located on two adjacent rock blocks, between which TM-71 crack gauge has been placed.

Recorded height changes in the first two periods are within the limits of their accuracy determination. Nonetheless, these have been given because of the trends, which developed into opposite vertical directions. In the third one, four year long period, the significant displacement show subsidence of -0.5 mm on point 14 and subsidence of -0.9 mm on point 2.

3.1.2. "PIEKIELKO" GEODETIC MICRO-NETWORK

Measurements in this network have been carried out since the year of 1982. Velocities of the horizontal movements of points in the 1982–2010 period are within limits of 0.68 and 1.43 mm per year in the down-slope direction. Vertical movements of the same points have reached the values between 0.30 and 0.87 mm per year (Fig. 4).

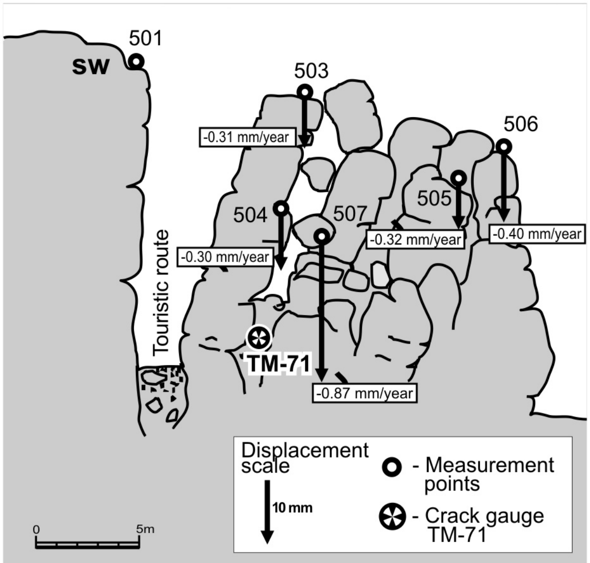
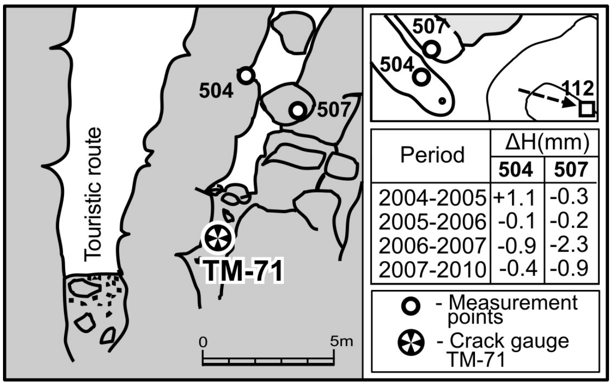


Fig. 4 Subsidence and vertical movements of points in the „Piekielko" micro-network in the period 1982–2010.



Period	ΔH(mm)	
	504	507
2004-2005	+1.1	-0.3
2005-2006	-0.1	-0.2
2006-2007	-0.9	-2.3
2007-2010	-0.4	-0.9

Fig. 5 Height changes of points 504 and 507 in the „Piekielko" in the 2004–2010 period.

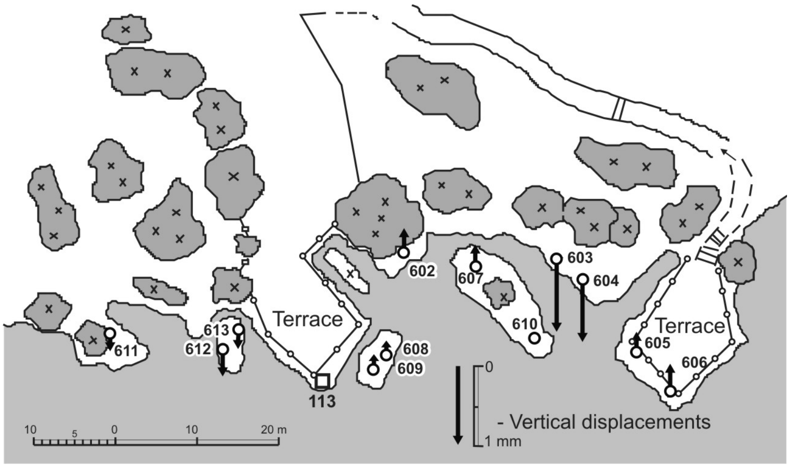
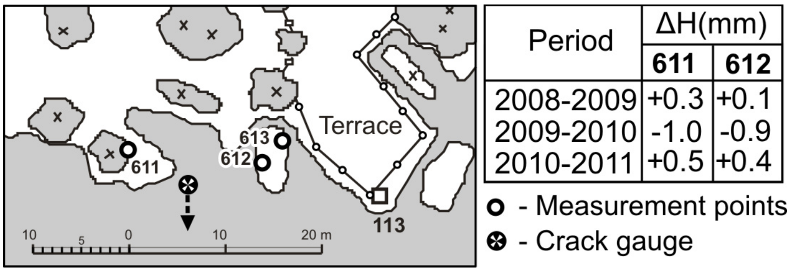


Fig. 6 Vertical displacements of points in the „Tarasy Poludniowe / Schody” micro-network in the 2008–2010 period.



Period	ΔH(mm) 611	ΔH(mm) 612
2008-2009	+0.3	+0.1
2009-2010	-1.0	-0.9
2010-2011	+0.5	+0.4

Fig. 7 Height changes of points 611, 612, 613 in the 2008–2011 period in the „Tarasy Poludniowe / Schody”.

These results in a wider approach have been included in the papers by Cacoń et al (2011a, b). In Figure 5 vertical displacements of points 504 and 507 located on two adjacent rock blocks near the TM-71 crack gauge have been shown. These changes represent intervals of periods between years 2004, 2005, 2006, 2007 and 2010. In the first period (2004–2005) the rock block with point 504 has been elevated by +1.1 mm, whereas the point 507 subsided by -0.3 mm. In the following periods subsidence within (0.1–2.3) mm has been recorded for both these points.

3.1.3. „TARASY POŁUDNIOWE / SCHODY“ GEODETIC MICRO-NETWORK

This network has been set up in the year of 2008 and the measurements have been carried out annually until 2011. Displacements of points, both horizontal, as well as vertical in particular yearly intervals show oscillatory character. The vectors of height changes for the entire period (2008–2011) have been pictured in Figure 6. For the points 611, 612 (Fig. 12) located approximately 18 m above the TM-71 crack gauge quantitative data have been compiled characterizing their vertical displacements (Fig. 7) between measurements in years 2008–2009–2010–2011. These displacements on points 611 oscillate (+0.3; -1.0; -0.5). Similar vertical changes have been recorded on the point 612 (0.0; -0.9; +0.4) mm.

3.1.4. LEVELLING LINE CONNECTING THE RESEARCH SITES OF MICRO-NETWORKS

In the 1974–2010 period 13 measurement cycles of precise levelling have been carried out between points 113–112 and 113–110. This precise levelling produced reference positions for the micro-networks: “Przy Schronisku” (110), “Piekielko” (112), and “Tarasy Południowe/Schody” (113). The results of these measurements have been shown in Figure 8.

The changes of height differences between points 113 and 112 are within the 0 to -4.0 mm limits and between points 113 and 110 between 0 to -4.3 mm limits. The changes on points 112 and 110 in relation to point 113 in the 2004–2005–2006 period represent movements and are of particular interest for interpretations.

Changes of gravity correspond well to the changes of height differences between points 113 and 110 as well as 113 and 112. They have reached:

$\Delta g\ (113–110) = +3.6\ \mu Gal/y$,

$\Delta g\ (113–112) = +1.5\ \mu Gal/y$.

Period	CHΔH(mm)	
	113-112	113-110
1974-1975	-3.2	-2.3
1975-1976	+1.1	+1.9
1976-1977	0.0	+0.6
1977-1978	-0.1	0.1
1978-1979	-0.3	0.0
1979-1988	+0.1	-0.1
1988-1991	+0.4	+0.4
1991-2004	+2.0	+0.6
2004-2005	-1.8	-1.0
2005-2006	-1.8	-0.1
2006-2010	-0.3	-0.8
2010-2011	-0.1	-3.4

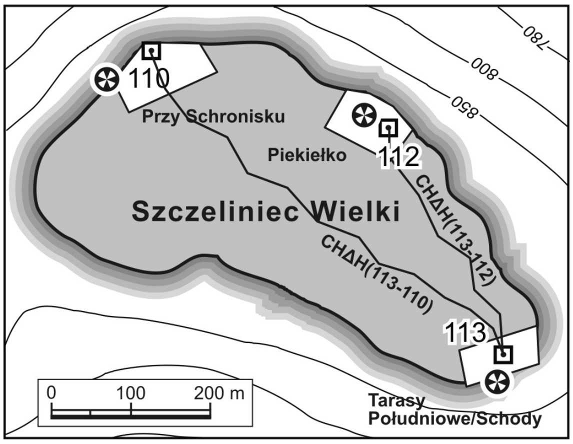


Fig. 8 Changes of height differences (CHΔH) between points 113–112 and 113–110 in the 1974–2010 period.

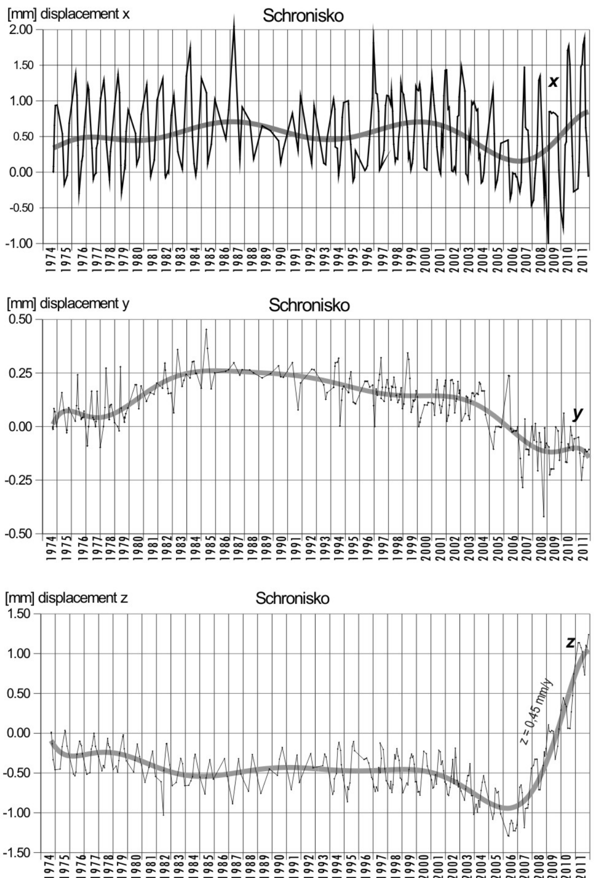


Fig. 9 Displacements x, y, z (1974–2011) between two edge rock blocks at the Schronisko platform of Mt Szczeliniec Wielki. Record by TM71 crack gauging.

3.2. CRACK GAUGE OBSERVATIONS

3.2.1. SCHRONISKO SITE

Questions regarding stability of a tourist lodge „Schronisko“called forth crack gauging in the platform surrounding the lodge. The gauge was installed 1974 between two edge blocks of the platform margin (Fig. 3). The site is located just under the platform on which the geodetic micro-network “Przy Schronisku” was established. Observations 38 years long involved 3D relative movements between the fissure walls: component x – opening of the fissure; component y – horizontal shear in the fissure, which represents movements into the valley; component z – vertical shear showing subsidence. Since October 2006 instrumentation has been completed with special grids for angular deviation detection. Thus, monitoring of rotation γ_{xz} in vertical plane (xz), as well as γ_{xy} in the horizontal plane (xy) is also available.

Observed displacements x, y, z are displayed in Figure 9. The data were discussed recently by Cacoń et al. (2011a, b). As seen from the graphs, for a long time the fissure suffered mostly with temperature dilatations in its width (x) within 2 mm of variation. Horizontal movements (y) were low and mostly reversible within 0.5 mm. Similarly, vertical displacements (z) varied within 0.5 mm. Therefore, as for the question of platform stability when such minor oscillations in position neglected, the answer was clear and simple, as well as practically important: stability. However, this was valid until 2002 only, when situation became changing. The reality of the recent change is supported by data about angular deviations available from the last years of measurements (Fig. 10). A definite linear crack bulging in γ_{xz} develops. It is evidently progressive without any tendency to reverse. This is an indication of instability after years which did not have shown any progressive change. The situation calls for a more detailed interpretation.

3.2.2. PIEKIELKO SITE

The monitoring started as early as in 1979. The gauge was installed right behind the NE outer block wall of the wide gulch known as Piekielko in which

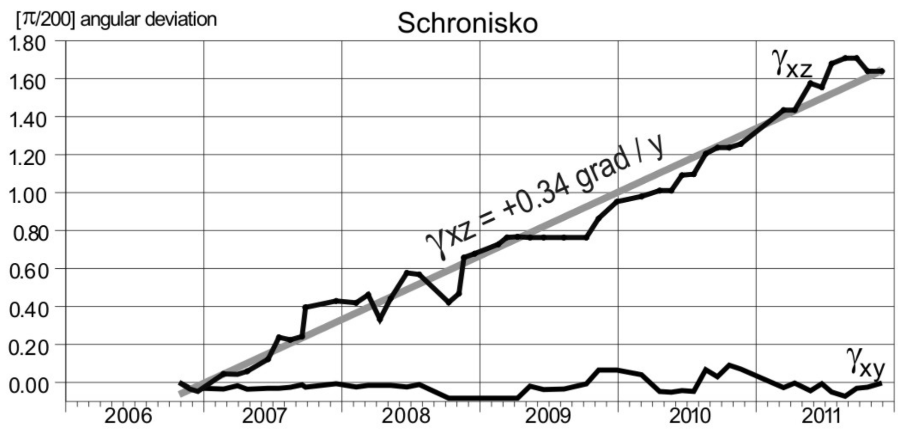


Fig. 10 Angular deviations γ_{xy} ; γ_{xz} (2006–2011) recorded in the edge fissure of the Schronisko.

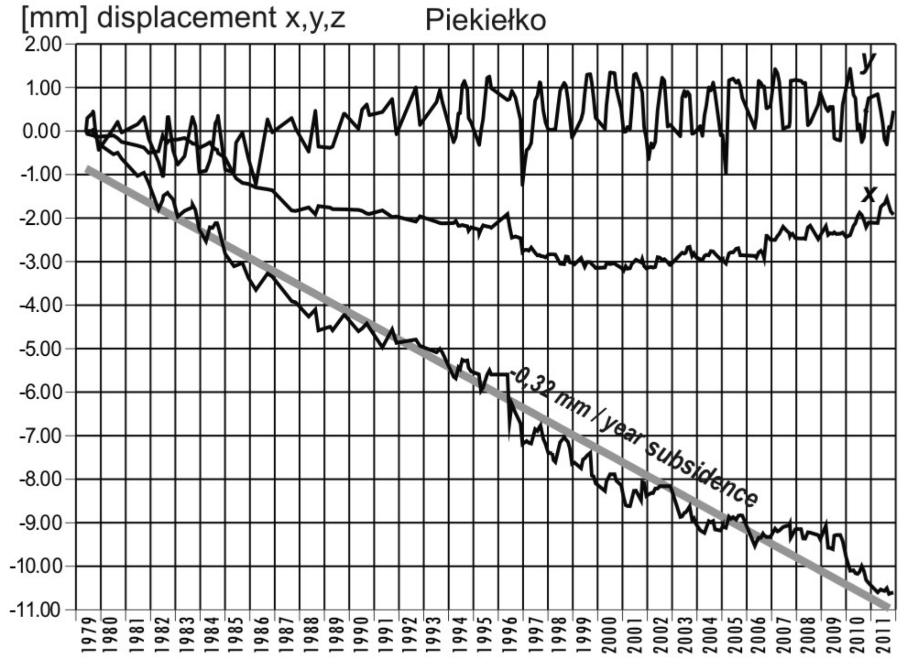


Fig. 11 Displacements x, y, z (1979–2011) recorded by TM71 crack gauging between two flanks of a fissure located in the block field of Piekielko close to the gulch where the central tourist path passes. A significant instability with progressive subsidence in (z) vertical coordinate has been evidenced by crack gauging.

a tourist path in the Szczeliniec top zone is located (Fig. 4). The path is in a deep fissure which separates the giant block field gently sloping down to NE towards the valley. The observation has been kept running in spite of difficult winter conditions which did not allow always access to the fissure when completely under a cover of snow and ice. The record covered 32 years until now.

Observed displacements x, y, z are displayed in Figure 11 and have been discussed by Cacoń et al. (2011a, b). Important slope instability has been evidenced here. Data concerning 3D coordinates x, y, z show a permanent process of slope movement with subsidence (z) as a main factor. The block field NE of the Piekielko gulch slips slowly down into the valley towards the Pośna Creek. The site in the fissure evidenced a total vertical movement of 10.5 mm in the last 32 years.

3.2.3. SCHODY SITE

The site "Schody" (under "Tarasy Południowe") is located in the NW section of the central part of

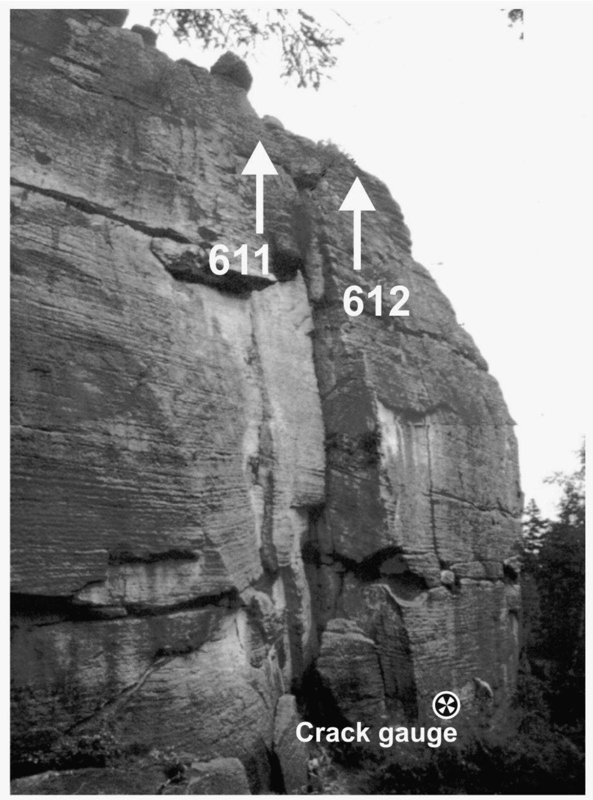


Fig. 12 A high marginal sandstone wall of the central Szczeliniec Wielki peak section.

Szczeliniec Wielki where an 18 m high vertical edge wall cuts down the top zone of the massif. The situation can be well observed in the situation (Fig. 8). The gauge was installed on a vertical crack zone which cuts vertically the magnificent wall. It is located right at the bottom of this solid wall as seen in photo of Figure 12. Foundation of this huge sandstone block is evidently overloaded. The place is crucial regarding safety of a tourist path below where slope is full of fallen blocks. Here is the most dangerous section of the Szczeliniec tourist paths. Gauging in this place represents rock monitoring in an extreme situation where results will reflect sensitively rock stress/strain variations rather than displacements.

The monitoring started in 1998 both in space x, y, z coordinates and rotations γ_{xy} , γ_{xz}. Fourteen years of observation is available now for interpretation. Results of the crack gauging were given by Cacoń et al. (2011b). As expected, results show generally different nature than fissure displacement data from other sites and show scatter of movements, i.e. stress variations appropriate to high internal load in the rock blocks. Observed scatter of movements in space x, y, z coordinates is difficult for detailed interpretation. However, in this case, angular deviations γ_{xy} , γ_{xz} are more informative. The graph in Figure 13 shows wall instability displayed as wall bulging and reflected in constant tilt trend on the vertical crack zone as shown in horizontal coordinate γ_{xy} .

The instability can be characterized as secondary creep in rock. A detailed inspection of the graph

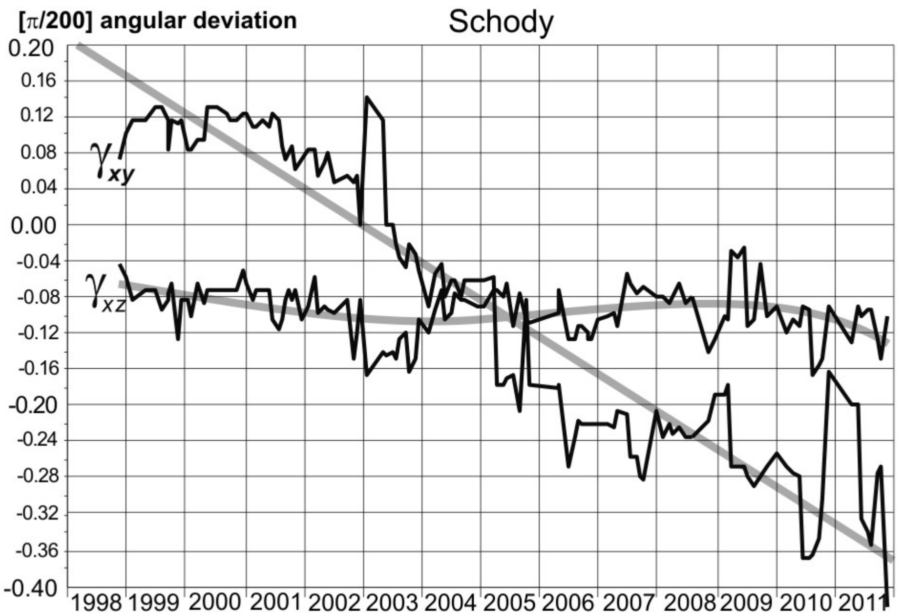


Fig. 13 Angular deviations γ_{xy} ; γ_{xz} (1998–2011) recorded by TM71 crack gauging of the split found centrally in the rock wall above Schody path.

Table 2 Geodynamics reflected in recent monitoring results

Symbol	Tectonic process	Period	Area	Reference
A	North Anatolian Fault Activity	1997 - 1999	Turkey	Košťák et al., 2007
P	Pressure pulse and increased activity induced	2003 - 2007	Central Europe and Mediterranean	Stemberk et al., 2010; Košťák et al., 2011 Petro et al., 2011
S	Sunda trench increased dynamics	2004 - 2007	Eurasian and Indian-Australian plates contact	Košťák et al., 2011 Petro et al., 2011
G	tectonic unrest	2009	Aegean Sea, Bulgaria, E Slovakia, Mt Szczeliniec W.	Shanov, 1993 Dobrev and Košťák, 2000 Petro et al., 2011
T	Pulse recurrence ?	2010 – 2012 ?	Central Europe and Mediterranean	current indications ?

Symbols used to localize particular tectonic reactions in the measurement data of Figs 16 – 23

shows also significant scatter in angular data. The scatter could be hardly interpreted from field mechanical rock conditions. It reflects rather internal geodynamics from the depth of the massif.

4. GEODYNAMICAL ANALYSIS

Geodynamical analysis deals mainly with anomalies. In this crack gauging is advantageous as frequency of measurements is generally higher than with geodetic methods and short time anomalies can be identified more easily. However, data are relative and refer to cracks and fissures. Displacements of objects are due to interpretation. Contrary to gauging, geodetic data reflect displacements better, and relativity is bound to reference points supposed to be stable. Combination of the two methods may increase therefore the weight of the results.

4.1. DATA OF CRACK GAUGING

It was a recent research using crack gauging of tectonic faults in Bohemian Massif which discovered a period of increased geodynamics (2003–2007). It started after detection of a tectonic pressure pulse on the basis of specific movement anomalies. During the period a series of characteristic events occurred and became determined. The pulse was indicated first on the Sudeten Fault (Stemberk et al., 2010). Later, supplementary investigations verified it in Rheingraben (Germany) and Mediterranean (Italy, Greece). It appeared in 2003 and was not of a local character only. It was notably on the Krušné Hory Fault, where the pulse and the tectonic process that followed have been evidenced with the use of a number of geophysical methods (Košťák et al., 2011). Analysis of crack gauging data like that in Slovakia confirmed presence of the pulse on the Slovak territory showing thus an extensive function of this phenomenon even on objects not directly set on tectonic faults (Petro et al., 2011). Szczeliniec Wielki is known as a rock complex showing factual gravitational instability. Let us see its detailed deformations confronted with geodynamic events determined recently and reported in the above publications.

To simplify the graphical exposition, the graphs are supplemented with symbols when useful, to show disposition of the processes documented in the earlier research and relate results with the earlier data sources. The symbols and particular data are given in Table 2.

4.1.1. SCHRONISKO - SUBSIDENCE

Detailed analysis of the deformation graphs in the period of the last 15 years (Figs. 14, 15) displays new development. The development shows close affinity to the process of increased geodynamics reported recently. The process which followed an aseismic geodynamic pressure pulse was demonstrated by a number of deformation effects along the Sudeten Fault zone by Stemberk et al. (2010). Schronisko platform instability started along with the pulse. Later, it passed into a subsidence well defined by monitored micro – displacements in coordinates (x) and (z). Thus, present platform instability can be attributed to tectonic movements detected generally at the Sudeten Fault zone.

Figure 16 refers to horizontal shear component (y). Generally, it shows a similar course like (x) and (z) but combined with frequent anomalies in detail. These anomalies are distributed in accord with geodynamic phases recorded recently (Table 2). The component oriented horizontally, is more sensitive to different outer deformation signals.

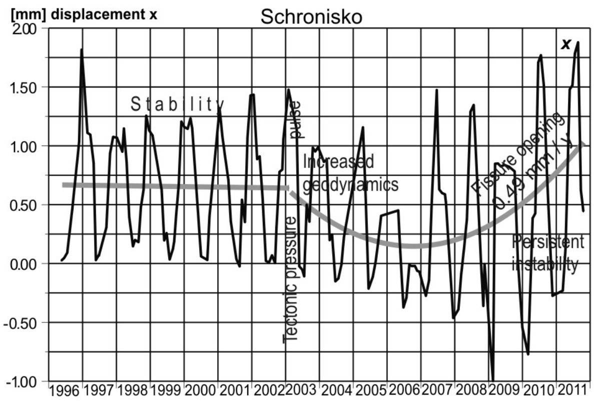


Fig. 14 Detailed course of displacements in coordinate (x) recorded at Schronisko site (1996–2011). A process of permanent fissure opening – instability is detected.

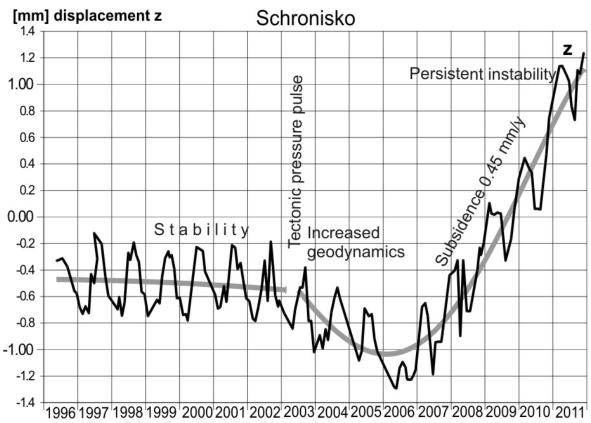


Fig. 15 Detailed course of displacements in coordinate (z) recorded at Schronisko site (1996–2011). A permanent process of subsidence takes place at present.

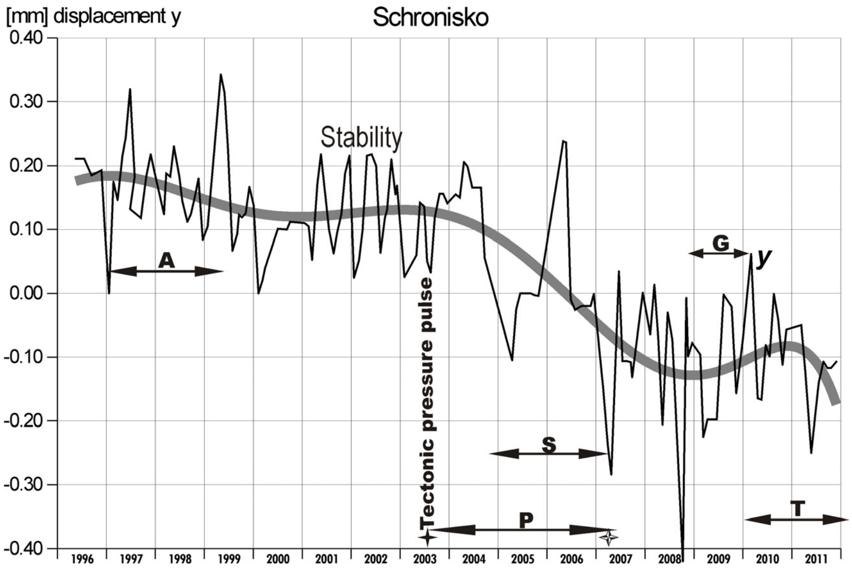


Fig. 16 Detailed course of displacements in coordinate (y) recorded at Schronisko site (1996–2011). The coordinate represents shear movements in the fissure oriented horizontally out of the marginal wall of the massif to open space. Such a movement is critical and sensitive to changes deep in the massif.

4.1.2. SCHODY WALL - BULGING ANOMALIES

High pressures in the overloaded wall at the Schody site (Fig. 12) are very characteristic and make it sensitive to micro-rotations or tilts. Thus, contrary to the original approach when our attention had been drawn to stability problems and so the progressive trend of bulging was investigated (Fig. 8) we can go to investigate preferentially frequent anomalies in tilts which well express individual geodynamic events in the course of bulging (Fig. 17). Here, an unusual similarity between outstanding rotation anomalies of 2003 and 2010/11 can be well noticed. It suggests a repetition in the pulse process. Besides, we find significant affinity with the disposition of a number of tectonic events found earlier (Table 2).

4.1.3. PEKIELKO – EXTREME TILT ANOMALY

A detailed graph of micro-rotations γ_{xz} at the Piekielko site (Fig. 18) is surprising. Observed gradual acceleration from 1983 to 2004 caused by slope mass movements in the block field in the NE slope section of Mt Szczeliniec reversed almost abruptly by the end of 2004 when positive rotation changed to negative. Established reversed trend did

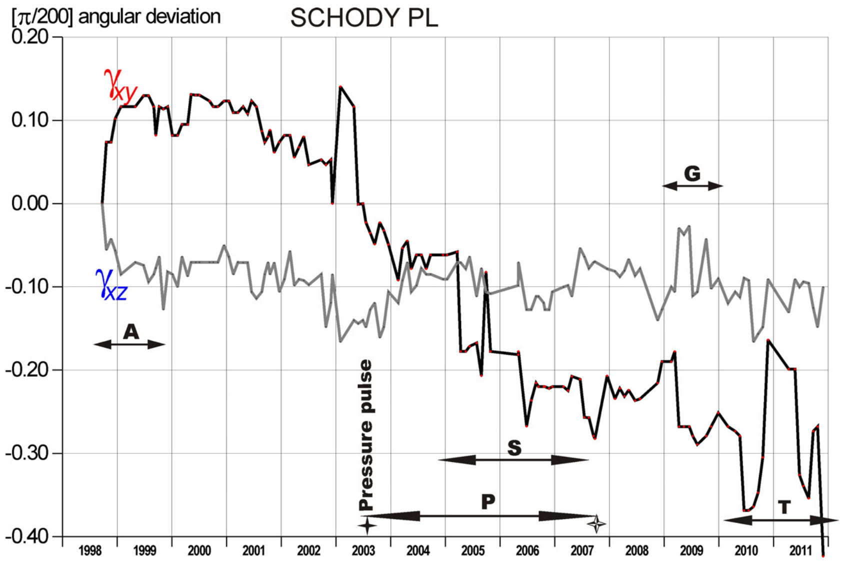


Fig. 17 Detailed course of angular deviations γ_{xy} ; γ_{xz} recorded at the Schody site (1998–2011). Geodynamic events are observed as anomalies in the course of creep.

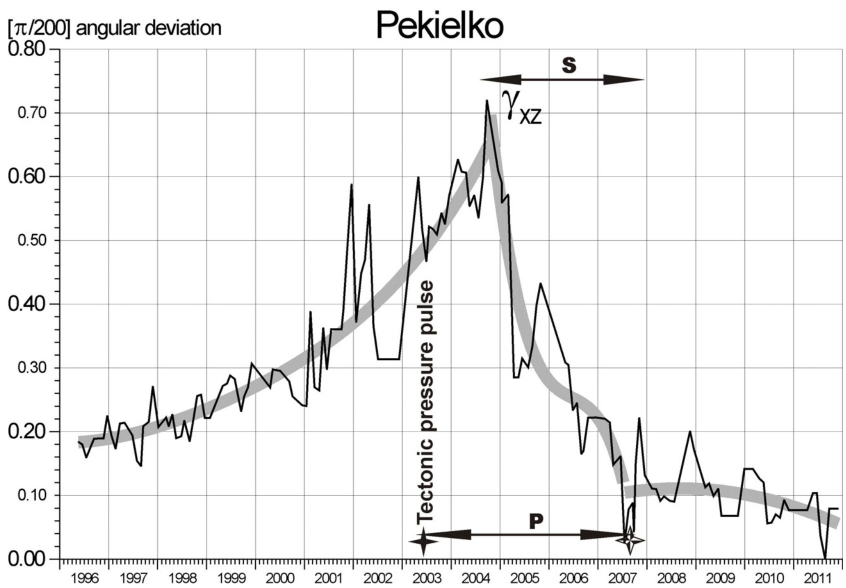


Fig. 18 Detailed course of angular deviation γ_{xz} recorded at the Piekielko site (1996–2011).

not change until 2007 when another turn to stabilization was observed. Geodynamic disposition given in Table 2 is evident.

The change could be investigated in detail following steps in observation records. The last positive rotation due to slope movements occurred between 25 Aug 2004 and 23 Oct 2004, when the peak was registered. The first negative rotation was recorded on 16 Dec 2004, which started negative series. Now, Sumatra earthquake of 26 Dec 2004 appeared on the Sunda trench. However, it appeared only after the peak and full 10 days later than our evidence of negative trend in rotation. Accordingly, the change in rotation appeared well earlier than any seismic wave suspect to produce the reaction. The effect was therefore aseismic and must be understood as a result of a deep geodynamic process rather than any seismic wave reaction of the earthquake. Nevertheless, coincidence with the Sunda trench tectonic activity and the pulse process is evident also and should not be overlooked. In any case, one should stress the aseismic nature of the effect at the Pekielko site.

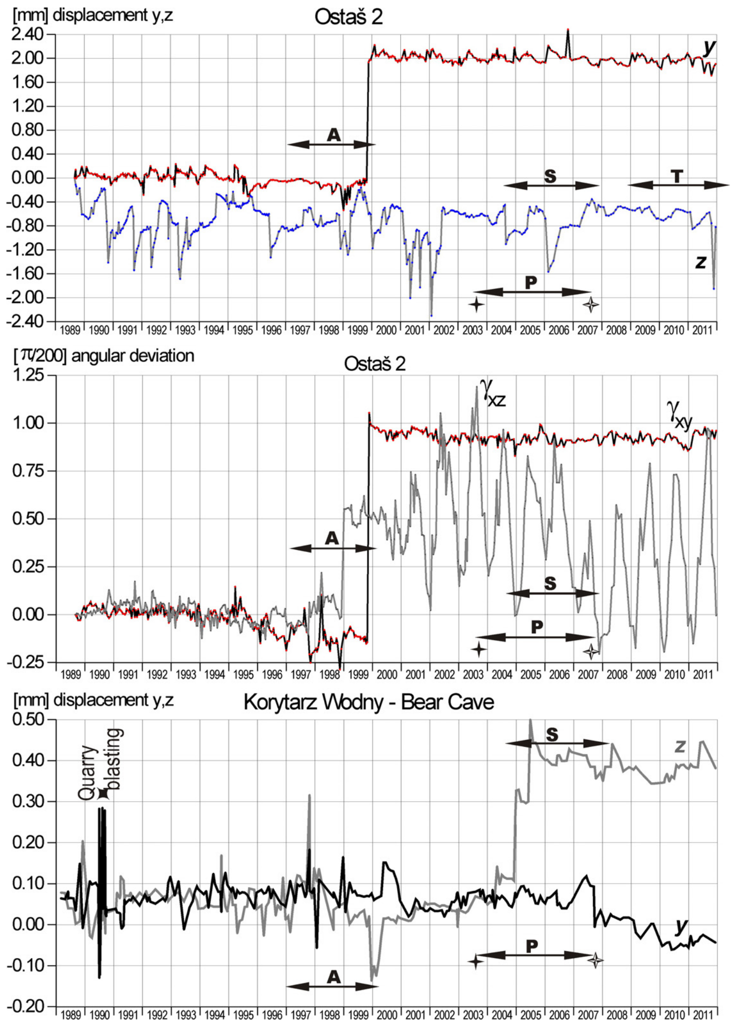


Fig. 19 Detailed course of displacements (y), (z) from Ostaš Hill, site 2 and Bear Cave, site Korytarz Wodny, supplemented with angular deviations γ_{xy} ; γ_{xz} from Ostaš (1989–2011).

Contrary to rotation, Pekielko displacements (Fig. 11) did not reflect the process. One can see therefore, that mass slope deformation of the Piekielko block field reduce the site sensitivity to possible geodynamic events. A geodynamic reaction is lost on the background of slope movements. Sensitivity is lower at this site than in case of the Schody site or even that of the Schronisko site where stresses are generally high. Nonetheless, Pekielko graph in γ_{xz} reflects some basic events of the increased geodynamic period.

4.1.4. OSTAŠ HILL AND BEAR CAVE – IRREVERSIBLE MOVEMENTS

Supplementary examples may be given to show sensitivity of different rock objects in the area to known geodynamic events. In that Mt Szczeliniec is not an insulated formation. Events like those evidenced in rock blocks of Szczeliniec Wielki were found widely in central Europe. This is particularly valid with objects set directly on tectonic faults. However, even geological formations not directly set on tectonic faults were found sensitive. One example is just Mt Szczeliniec. Other examples may be given from the wider zone of Sudeten Fault, and searched not for geodynamics originally but for possible mass movements.

The first object is Ostaš Hill near the Czech town of Police n. M., another point of the Table Hills located on the Czech side of the boundaries. The second to be given is Bear Cave under Mt Snieźnik (Fig. 19). The graphs show remarkable reactions to documented geodynamic processes (Table 2). One can observe analogy in geodynamic reactions with that of Mt Szczeliniec.

4.2. GEODETIC DATA

The results of periodic geodetic studies of rock block displacements on the three sites of the Szczeliniec Wielki provide quantitative data that can

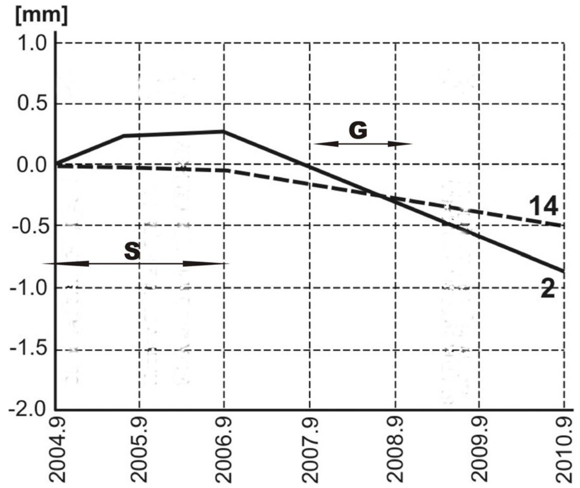


Fig. 20 Height changes of points 2 and 14 ("Przy Schronisku") compared with disposition of Table 2.

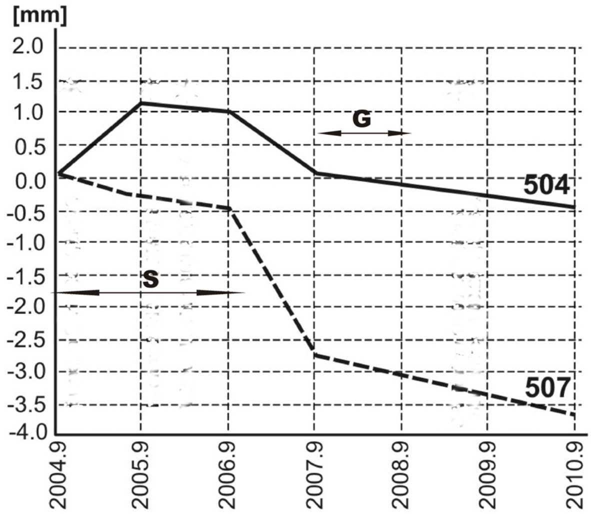


Fig. 21 Height changes of points 504 and 507 ("Piekielko") compared with disposition of Table 2.

be interpreted as geodynamic. Lower frequency of these measurements than TM-71 crack gauge observations makes interpretation of the geodetic results more difficult. The accuracy of geodetic measurements, lower by an order, in comparison to relative observations with crack gauges (Table 1) is also a significant factor for interpretation. Nonetheless, an attempt has been made to analyse changes in point heights (determined more accurately than horizontal changes) found in several measurement cycles. The incriminated cycles were: 2004–2010 in case of the "Przy Schronisku" and the "Piekielko" micro-networks, and 2008–2011 for the "Tarasy Poludniowe / Schody" micro-network. These periods have been selected after analysis of results, which indicated that the greatest relative displacements of rock blocks have been recorded in incriminated periods of increased anomalies recorded with gauging. Also, points in the micro-networks have been selected at places located close to the crack gauges for the analysis.

4.2.1. "PRZY SCHRONISKU" NETWORK

The results of height changes in the points 2 and 14 (Fig. 3) have been compared with the disposition of Table 2 periods.

The displacements of the SW rock block with point 2 read +0.2 mm between measurements in September of 2004 and 2005, i.e. occurred during a known tectonic process (**S -** Table 2**)**. Between September 2005 and September 2006 the rock block was stable while between September 2006 and September 2010 it subsided by -0.9 mm. It could be suggested that this movement was influenced by a process of tectonic unrest (**G** – Table 2).

On the point 14, located on the NE rock block, between September 2004 – September 2006 no significant changes have been registered and between September 2006 – September 2010 its subsidence reached -0.5 mm only.

4.2.2. "PIEKIELKO" NETWORK

In the "Piekielko" network the analysis concerned points 504 and 507 (Fig. 21) located on neighbouring rock blocks, between which, 6 m below, TM-71 crack gauge has been installed. On the point 504, in the September 2004 – September 2005 period, an uplift of +1.1 mm was registered. It could be linked with the tectonic period **S** (Table 2). The next period,

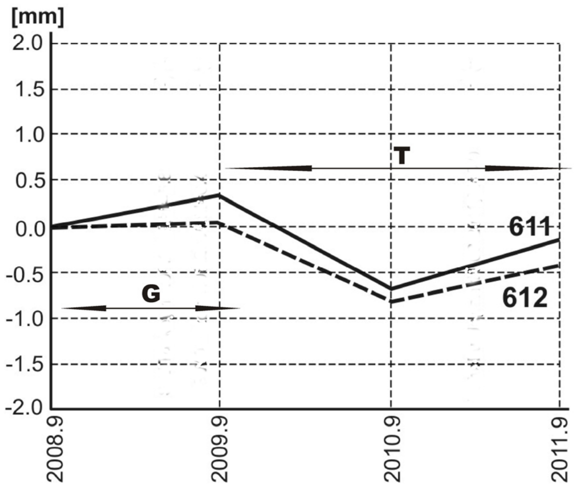


Fig. 22 Height changes of points 611 and 612 („Tarasy Poludniowe / Schody") compared with disposition of Table 2

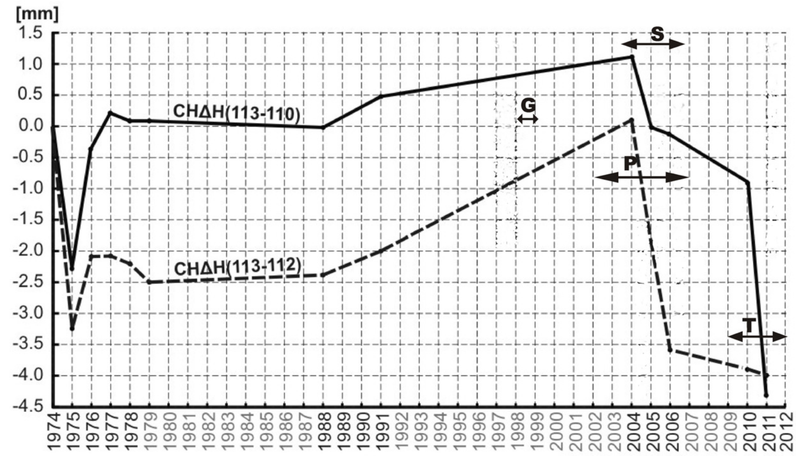


Fig. 23 Changes of height for levelling lines between points 113–112 and 113–110. Results compared with disposition of Table 2. (For line locations see Fig. 8).

September 2005 – September 2006 could be regarded again as stable. Next, the total subsidence of this point (-1.3 mm) between September 2006 – September 2010 could be connected with **G** (Table 2).

Changes of heights on point 507, particularly in the September 2006 – September 2010 period, show significant subsidence of -3.2 mm. The course follows the same trends as 504 and the interpretation will be analogous. Generally, analogical results with those of “Przy Schronisku” were obtained.

4.2.3. “TARASY POLUDNIOWE / SCHODY” NETWORK

Displacements of some selected points in the “Tarasy Poludniowe / Schody” network for periods: September 2008 – September 2009, September 2009 – September 2010, September 2010 – September 2011, were obtained.

Changes found on points 611, 612 in the particular periods (Fig. 22) were compared with the disposition of tectonic periods of Table 2. Movements in September 2008 – September 2009 are parallel and within the same range (0.7 and 0.9 mm). As such they can be regarded to follow **G** period. In the next period September 2010 – September 2011 points 611, 612 have been uplifted by 1.3 and 1.5 mm, which could have been related to geodynamics connected with increased geodynamic activity **T**.

4.2.4. THE LEVELLING LINES CONNECTING THE RESEARCH SITES

Changes of height during the period 1974–2011 in levelling lines between points 113 and 110, as well as between 113 and 112 are presented in Figure 23 and compared with the geodynamic disposition set in previous research (Table 2). The change in height found between points 113 and 112 which amounted to -3.6 mm in September 2004 and September 2006 periods is particularly characteristic. It is interpreted with regard to the Sunda trench tectonics. It may be stated that this change has caused permanent subsidence of point 112 in relation to point 113.

This above result assigned to **S** has found analogy in **T** period where a similar process could be repeated. Subsequent vertical movements between the points in the years 2010 and 2011 produced identical values -3.9 mm (2010) and -4.0 mm (2011). Besides, movements of the points 112 and 110 reaching up to -4.3 mm regarding the reference point 113 during 2005–2011 period (Fig. 23) indicate permanent subsidence in the massif.

The changes have not shown greater influence on the permanent displacements of rock blocks within the three networks. However, relative change of heights between points 112 and 113 indicates permanent subsidence of the point 112 together with the “Piekielko” area.

5. CONCLUSIONS

Geodetic data found changes in heights of selected points in the three micro-networks of the Szczeliniec Wielki. The analysis has verified displacements within the periods of increased dynamics 2003/7. The effects verified activation of geodynamics in the massif during that particular period, as well as later on. The same conclusion can be drawn from crack gauging in the massif.

Detailed investigations into stability of this important geological object evidenced gravitational deformations. Additionally, presented investigations in the National Park „Stolowe Góry Mountains“ have recognized recent geodynamic effects including permanent subsidence which has been of an aseismic origin. Data obtained from long-term rock movement monitoring on Mt Szczeliniec Wielki bear evidence that the massif is not inert to deep geodynamic processes.

The aseismic phenomenon of a pressure pulse detected in the Bohemian Massif as well as elsewhere in Europe in 2003 (Stemberk et al. 2010; Košťák et al. 2011) has been confirmed in the Polish National Park „Góry Stolowe – Stolowe Góry Mountains", Mt Szczeliniec Wielki.

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