Acta Geodyn. Geomater., Vol. 4, No. 1 (145), 39-51, 2007

3D MONITORING OF ACTIVE FAULTS AND SLOPE MOVEMENTS IN THREE BULGARIAN SITES INCLUDED IN COST 625 PROJECT

Nikolai DOBREV * and Elka AVRAMOVA-TACHEVA

Geological Institute, Bulgarian Academy of Sciences, 1113 Sofia, Bulgaria
**Corresponding author's e-mail*: ndd@geology.bas.bg

(*Received* December 2006, *accepted* February 2007)

ABSTRACT
The present paper shows the results of 3D monitoring with the use of extensometers TM71 performed in Bulgaria in the framework of COST Action 625. This research was performed in selected areas: Simitli graben that is the most seismoactive area in Bulgaria; Madara plateau – rock scarp with historical monument affected by rock toppling; East Rhodopes area – a possibly active fault zone and a large landslide. The most impressive results were established at Simitli graben area with the rate of 2.73 mm/year sinistral movement of Krupnik Fault. Local earthquakes located at NE part of the graben usually influence the movements along this fault. An acceleration of the left lateral movements during calm periods has been established, and respectively, the movements stop (or going in opposite direction) during seismic activity. At Madara site, the results from the 15 years monitoring show subsidence of rock slices by 0.9 mm per year and similar rate movement of the slices to South direction. Influence from Izmit earthquake, Vrancea earthquakes and local ones have been established. The monitoring of the fault at General Geshevo Village, East Rhodopean area started in 2003. The first results show mainly gravitational movements – subsidence of NE block 1.5 mm/year.

KEYWORDS: fault, slope movement, extensometer, 3D monitoring

INTRODUCTION

Determining recent activity of faults and the dynamics of various types of slope movements by geological-tectonical and geomorphological signs is not sufficient for practical decisions, for more global investigations of their interrelations with some other geodynamical processes, as well as for realistic hazard prognoses. Only exact measurements could provide the necessary quantitative data.

The instrumental monitoring in Bulgaria with use of 3D extensometers and geodetic surveying has been performed on active faults and the related slope deformations since 1982-1983. Recently GPS measurements were introduced, too. The research with the use of 3D extensometers was performed for monitoring of active faults and slope deformations in selected areas in Bulgaria (Simitli graben, Madara, General Geshevo Village - East Rhodopes; see Fig. 1).

SIMITLI GRABEN

The Simitli graben (70 km^2) is situated at the crossing point of two significant fault zones called Struma (local directions 150-170°) and Krupnik-Gradevo (40-80°). A longer part of the graben is formed along the Krupnik-Gradevo fault zone. It is crossed by the Struma fault zone, which marks the contemporary bed of Struma River. Farther to the south, the Struma River enters into the Kresna Gorge.

The Krupnik-Gradevo fault zone is represented by two marginal faults called Krupnik and Gradevo, dipping 60-80° toward each to other. The southern border of the graben is defined by the Krupnik fault, which orientation is changeable - about 80-90° near the village of Krupnik and 20-40° at 2 km eastward from Struma River (Figs. 2, 3). To the West, the Krupnik fault zone can be followed on Macedonian territory.

The Struma fault zone is a long and wide tectonic structure. It is characterized as a complicated fault system built by parallel fault lines with a direction of 160-180° (Zagorcev, 1992, and others). On the territory of Bulgaria it is composed of several groups of smaller fault zones.

The Simitli graben originated during the Upper Miocene over Praecambrian metamorphites and Palaeozoic granites. Neogene slightly lithified sediments, which fill the graben, exceed 1500 m in its central parts. The total amplitude of vertical tectonic movements along the Krupnik fault in the Pliocene-Quaternary period is about 3400 m (Vrablyanski and Milev, 1973; Vrablyanski, 1974).

The research area represents the epicentral zone of one of the strongest Balkan and European earthquakes – on 4th April 1904, 10:02 and 10:25 GMT, with magnitudes 7.1 and second one 7.8, respectively (Kárník, 1968; Christoskov and Grigorova, 1968; Shebalin et al., 1974). In spite of insufficiency of historical data, we have information for other two strong earthquakes around or in this region on 4th September 896 and 6th December 1866 (Watzof, 1902; Shebalin et al., eds, 1974).

Fig. 1 Location of recent 3D monitoring sites in Bulgaria.

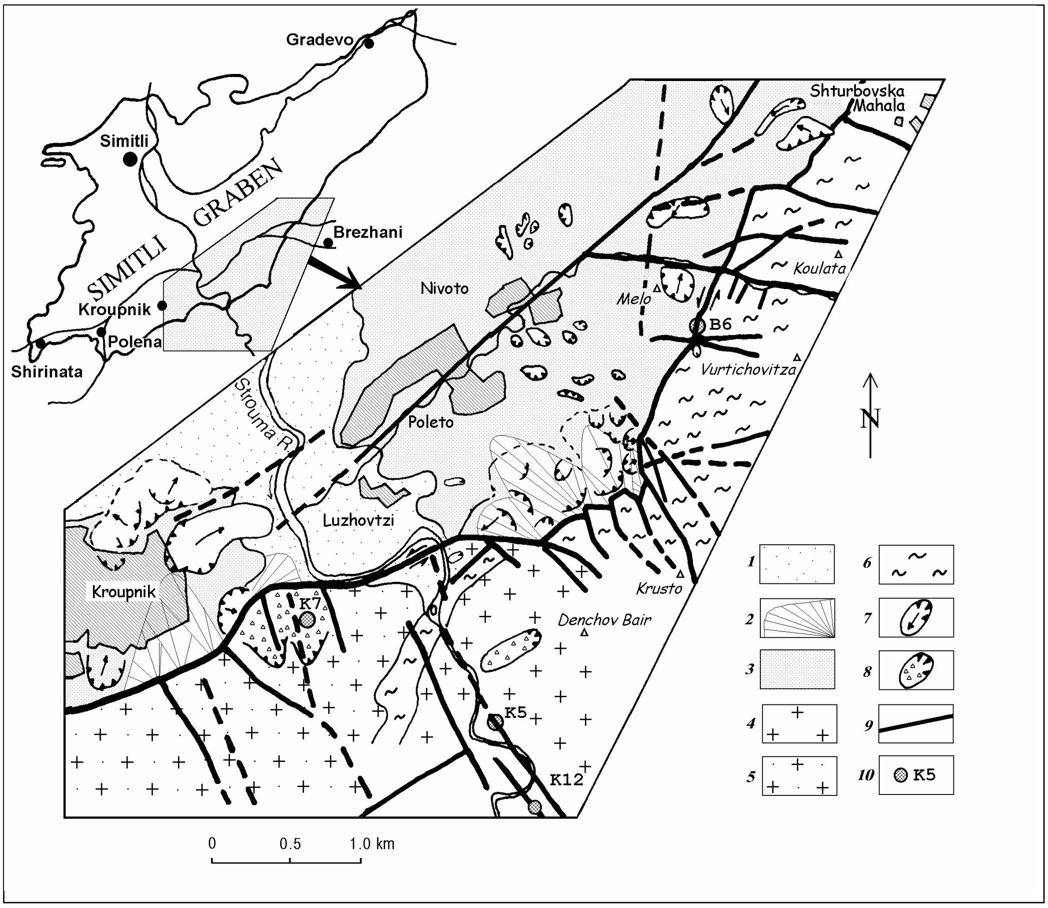

Fig. 2 Geological-tectonical map of Simitli Graben.
Legend: 1 - Quaternary: alluvium; 2 – Debris fans; 3 - Neogene: sandstones, conglomerates, clays, coal; 4 - Upper Cretaceous granites; 5 - Palaeozoic granites; 6 - Praecambrian: amphibolites, gneisses, marbles; 7 – landslide; 8 – slope deformation in rocks; 9 - fault; 10 - Monitoring point No.

Table 1 Orientation of the spatial axes of monitoring points in SW Bulgaria (after Avramova-Tacheva et al., 1984; Košták and Avramova-Tacheva, 1988; Dobrev et al., 2003).

Monitoring point No.	+X horizontal zone widening	+Y horizontal shear movement along the fault (fissure) direction	+Z vertical movement	Local fault direction
K5	SW block to 225°	SW block to 135°	subsidence of the SW block	150°
B6	Neogene basin to 290°	Neogene basin to 200°	subsidence of the Neogene basin	20-40°
K7	The northern block to 350°	The northern block to 260°	subsidence of the northern block	260°
K12	SW block to 240°	SW block to 150°	reverse movements (or subsidence of the SW block)	150°

Fig. 4 View of monitoring point 6. The left lateral displacement is obvious.

The seismic activity continues up to present. Nowadays, the Simitli area is the most seismically active one in Bulgaria (Ranguelov et al., 2001). The most part of these earthquakes are connected with the Krupnik Fault – located in the part between its crossing point with the transversal Predela Fault and the Bulgarian-Macedonian border. Nowadays, the study is performed through bilateral projects between Geological Institute of the Bulgarian Academy of Sciences and the Institute of Rock Structure and Mechanics, Prague, and Universities of Florence and Camerino, Italy.

MONITORING POINTS

The aim of the monitoring research in this area is to understand the recent movements along the main structures that are connected with the 1904 Krupnik earthquake. The monitoring is provided by 3D extensometers TM71 and recently, by GPS measurements (Dobrev et al., 2005).

The first monitoring points were arranged in 1982-1983. Avramova-Tacheva et al. (1984), Košťák and Avramova-Tacheva (1988) and Dobrev and Košťák (2000) have already described the present situation of the monitoring points in detail. GPS measurements began few years ago.

The first gauge (so called K5, No. 5 in Bulgaria) is installed in a single tectonic structure connected with the Struma fault zone which is oriented N-S (Table 1; Košťák and Avramova-Tacheva, 1988). At this locality, the fault represents a zone 2.5 m wide filled by broken and crushed granite material. This fault can be traced on to South where it is evident.

The next monitoring point (No. 6, B6 or Brezhani 6) was arranged at the Krupnik fault (Fig. 4). The measuring system bridges the contact between the Praecambrian amphibolites and the Neogene coarse-grained sediments. A special trench exposes the contact of fault zone, which width is 3.4 m at that point (Avramova-Tacheva et al., 1984; Avramova-Tacheva and Košťák, 1995).

Monitoring point K7 (No.7 or Kroupnik 7) is built in a fissure located on the right side of the Strouma River, 700 m SE from the village of Kroupnik. This part of the flanked frame was strongly affected during the seismic events in 1904. As a result, a remarkable seismogravitational slope deformation appeared. A semi-circular scarp is apparent on the slope face as well as eight clearly visible steps, which are separated by fissures about 1 m wide. A TM71 extensometer was installed in one of these fissures to detect slope (and possibly tectonical) movements and operated till the beginning of 1994.

The last point K12 (No.12) for 3D monitoring was installed in November 2003. The selected fault is an element of Struma Fault zone and it is located in Kresna Gorge. The site was chosen after detailed selection among five suitable places, and after discussion between Bulgarian (S. Shanov, N. Dobrev

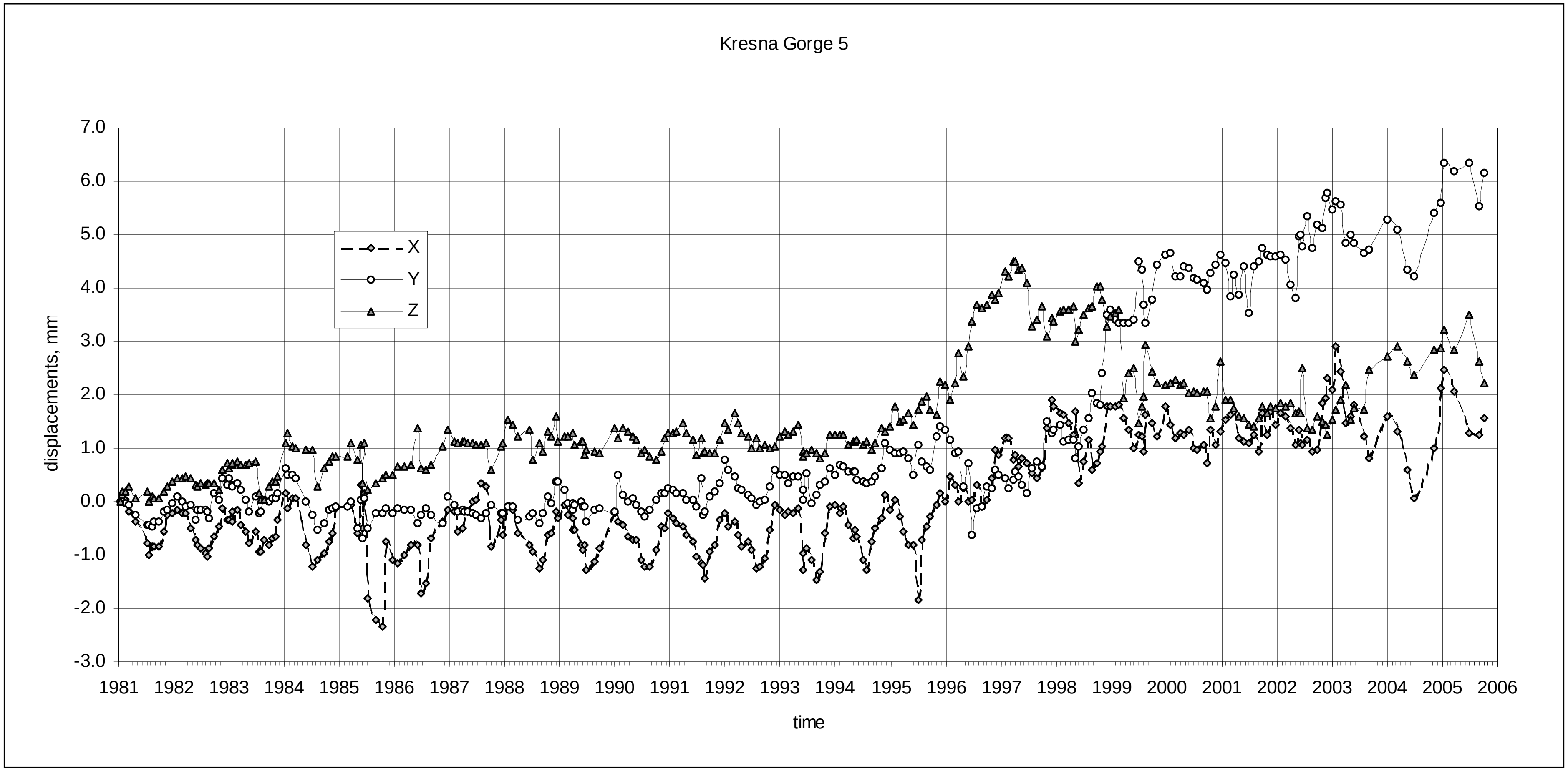

Fig. 5 Tectonic movements found at point no. 5 – Kresna Gorge.

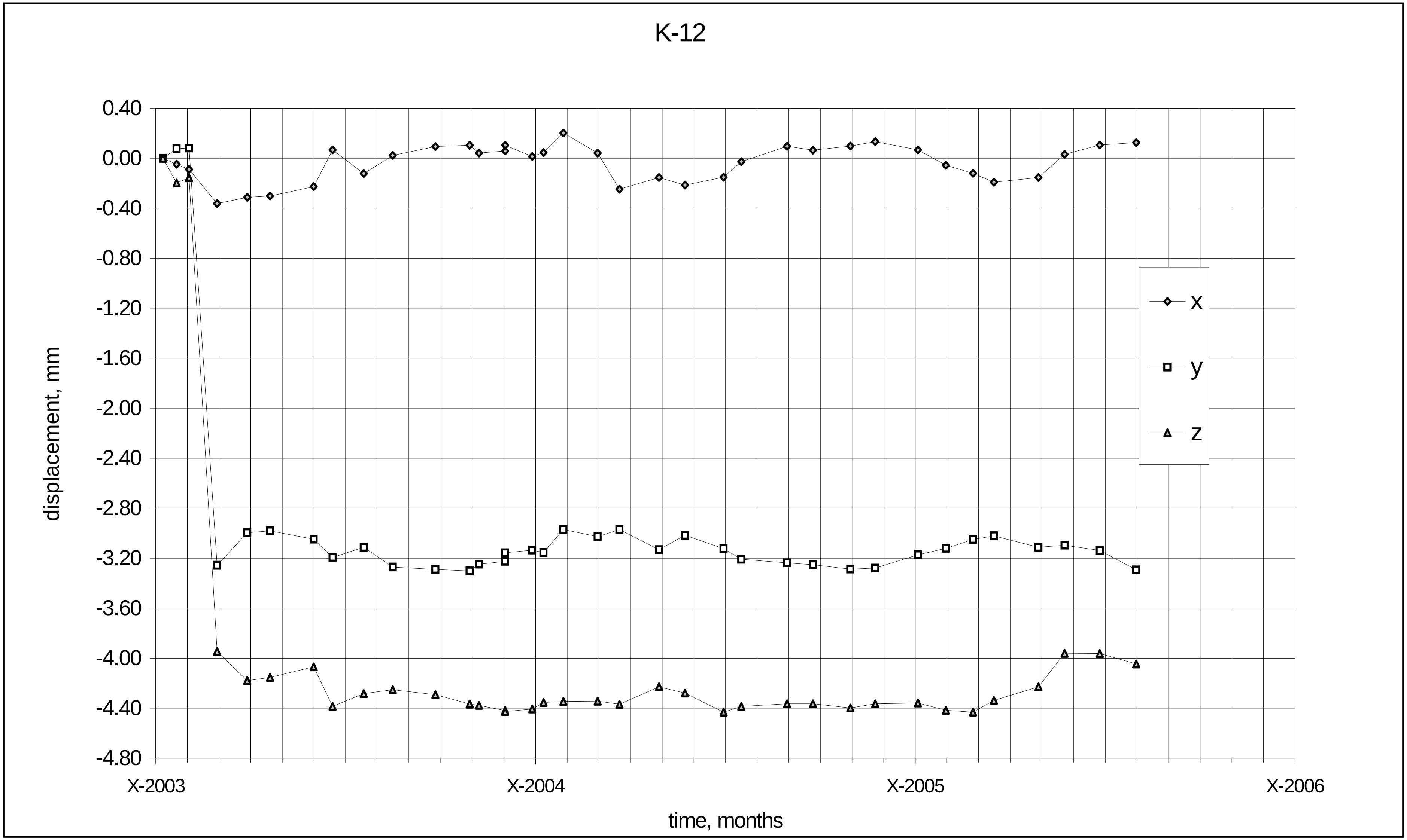

Fig. 6 Tectonic movements found at point no. 12 – Kresna Gorge.

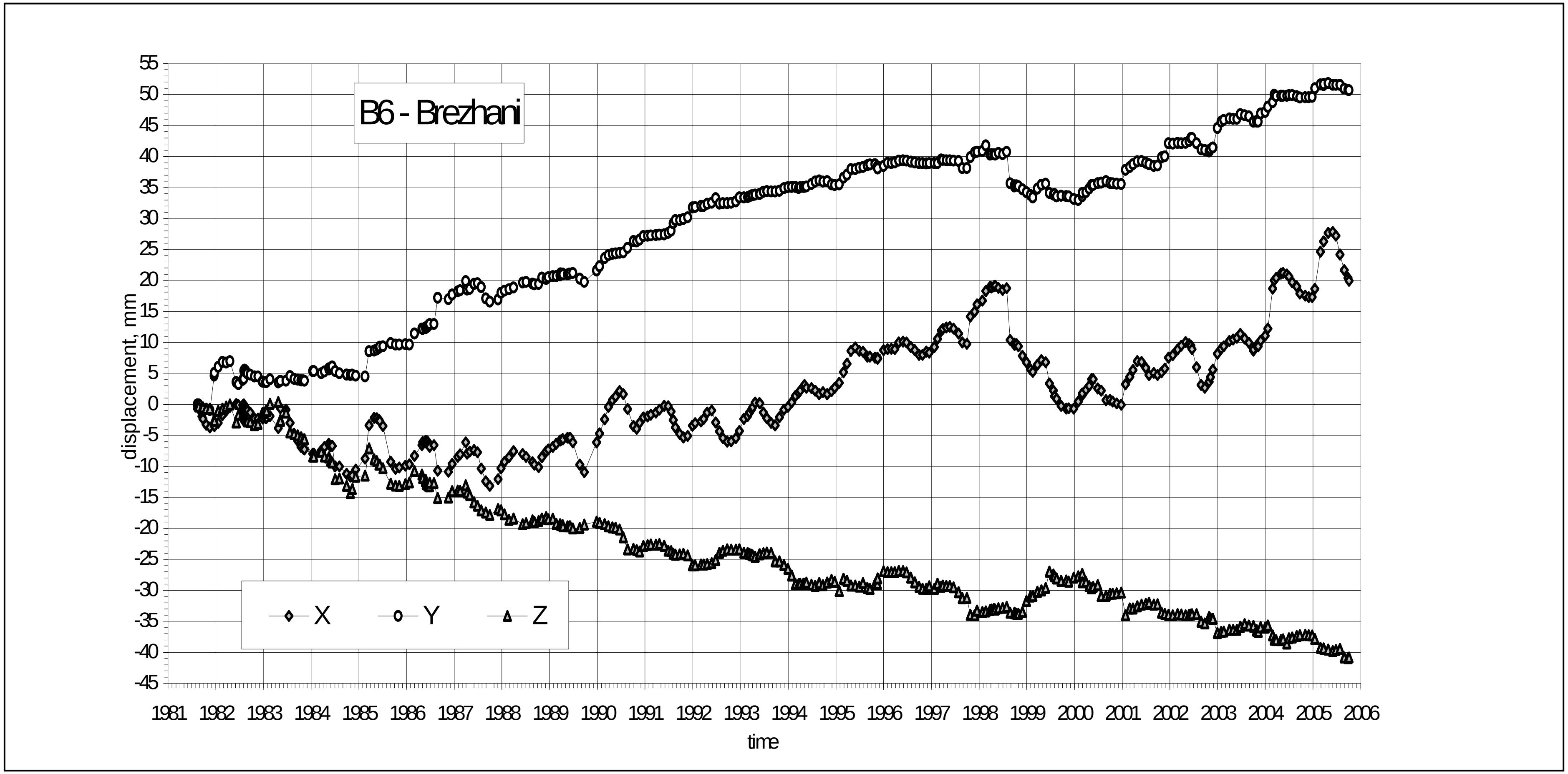

Fig. 7 Tectonic movements found at point no. 6 – Brezhani.

Table 2 Rates of vector movements calculated for monitoring points in SW Bulgaria (Dobrev et al., 2005, in print).

Point	period	rate, mm/year	azimuth	block
6	23.07.2001-26.07.2004	4.53	238°	W, Neogene basin
5	23.07.2001-26.07.2004	0.51	165°	SW block
12	29.12.2003-29.12.2004	0.55	142°	SW block

and E. Avramova) and Czech scientists (B. Kostak, F. Hartvich and P. Stepancikova).

OBTAINED RESULTS

The analysis of data from the monitoring points installed on Struma fault system (no. 5 and no. 12) shows left-lateral movements. The earthquakes rarely influence point No. 5. The rates are variable for different periods (Table 2; Figs. 5, 6). For example, the period 2003-2004 is characteristic with a slip with a rate of 0,5 mm/y for the two points. However, the results calculated from 30 measurements at point No.12 within period November 2003 – September 2005 show decreasing of the rates of movements - the normal component is 0.17 mm/y. A sharp displacement was found that resulted from a local earthquake swarm in Simitli-Predela area between 8th and 13th December 2003.

The last monitoring point (No. 6) observes the Krupnik fault near Brezhani Village. The left-lateral slip rate is calculated as 2.73 mm/y; the rate of reverse movements is 0.63 mm/y. The established extension of about 2.8 mm/y is a result mainly of temperature impact of the rock massif (Fig. 7). Local earthquakes located NE from this monitoring point usually influence the movements along this fault. We established acceleration of the left lateral movements during calm periods, and respectively, the movements stop (or going in opposite direction) during seismic activity in NE part of this point, i.e. at Predela-Gradevo area. An effect of stronger earthquake in south, southwest and southeast direction (in Central Greece, Turkey and Aegean Sea) with focal depth more than 20 km was found (Shanov and Dobrev, 1997).

GPS measurements confirm the extension of the graben in N-S direction. The rate is estimated between 4 and 6 mm/y (Dobrev et al., 2005).

MADARA PLATEAU

Madara is a historical and archaeological reserve located about 10 km E of the town of Shumen, NE Bulgaria. The reserve extends over NW marginal zone of the Madara Plateau. Here, on an area of 2 km^2, ruins of a Thracian sanctuary, Roman villa rustica, temples and chapels as well as a medieval Bulgarian fort etc. have been uncovered. An outstanding place should be given to a rock wall bas-relief dated to 8th century, and called Madara Horseman listed among protected monuments in the World Heritage List of UNESCO. The bas-relief represents a scene of a horseman, who is said to be Bulgarian khan Tervel (701-717) on his horse, piercing a lion with a spear and followed by a dog (Fig. 8). The monument is cut to a rock wall at a height of 23 m above the terrain including cut inscriptions is 7.2 m wide, and 6.5 m high.

Fig. 8 A general view of Madara Horseman bas-relief.

The rock massif bearing the bas-relief is destabilised. Several characteristic rock blocks in the form of rock slices of different profiles, up to 80 or 120 m high have developed here. The state as it is comes from all different conditions and factors like geology, fissuring, physical and deformational parameters, lithology, tectonic activity, erosional processes, climatic conditions, seismicity, human activity, etc. Stability of the block with the bas-relief establishes the main problem. To solve it, there is a call for research into failure mechanism of the wall as well as of the block behind it, and of interrelations between rock blocks from the edge of the plateau above the monument to the bottom.

The rock massif consists of two complexes: the upper one comprises limy-sandy sediments of Upper Cretaceous - Cenomanian age; the lower one is marly of the Lower Cretaceous - Hauterivian age. The second lower complex is marly, and consists of grey-bluish layered marlstones, creeping if heavily loaded.

The rock wall is almost vertical built by limy-sandy complex. Downwards the slope covers marlstones by debris slope deposits sloping from 10 to 20° (Fig. 9).

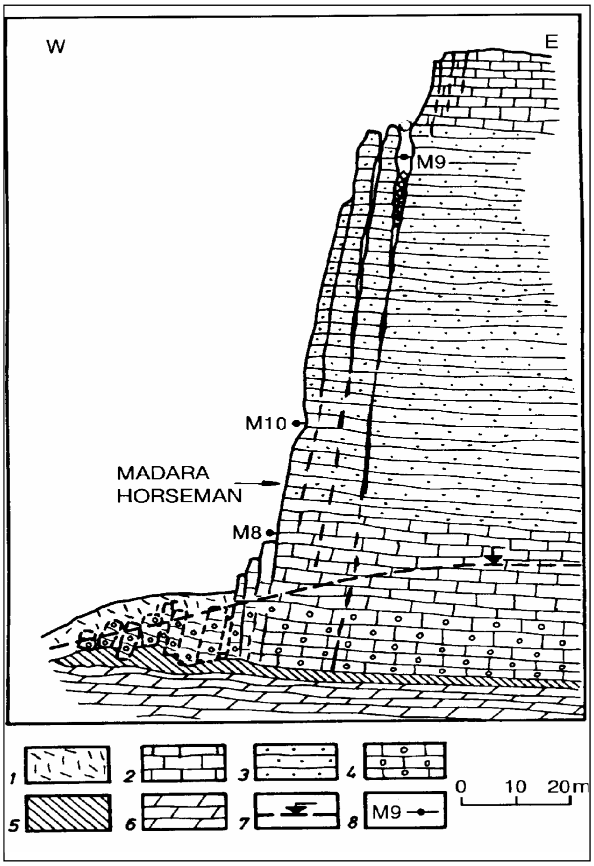

Fig. 9 Engineering Geological profile through the Madara plateau (acc. Frangov et al., 1992; Kostak et al., 1998): 1 – Deluvium; 2 – Sandy limestones; 3 – Calcareous sandstones; 4 – Conglomeratic limestones; 5 – Clay; 6 – Marls; 7 – Ground watertable; 8 – Monitoring point.

The Madara Horseman crosses a section that developed six slices, separated from the plateau. First three of them can be found now as very low steps in the lowest section of the wall being relics of old frontal blocks. The bas-relief is carried by the fourth rock slice, which is followed by other ones. Formation of two or three new slices about 3 m wide can be detected behind the furthermost edge of the plateau by traces of cracks.

The first attempt to explain formation of such a structure had been made by Venkov and Kossev (1974), who concluded that the reason is in high deformability of the marly bedrock due to water percolation, as well as in gravitational extension of the massif.

The region suffers by seismic effects coming from outside. This may be exemplified by the Vrancea earthquakes (Romania) - May 30 and 31, 1990, M=6.8 and 5.7, respectively. The closest epicentral areas are situated near to the town of Provadia (25 km SE Madara), at Shabla-Kaliakra area (110 km ENE Madara), and Gorna Oryahovitza-Strazhitsa area (75-100 km W Madara) and Izmit Earthquake (in Turkey, about 200 km SSE Madara, 17th August 1999) which manifested strong earthquakes after 1900.

Local earthquakes with epicentres outside the area of Madara Village can be localised to several active tectonic faults, e.g. Novi Pazar and Sub-Balkan Faults. Local earthquakes are in majority here.

Extensometers TM-71 applied to many rock stability projects successfully (Košťák, 1991) were installed here. First gauge signed M8 applied to a dipping rock discontinuity on the main wall projecting directly from the bottom to the bas-relief, a second gauge signed M9, was set between two major blocks in the marginal zone above the main wall. The two gauges have operated since 1990. A third gauge signed M10 was set to an open crack in the main wall right above the bas-relief, being in operation from 1993. Thus, direct information about deformational crack effects proceeding in time is obtained. The gauge M8 is well accessible from the ground, the other two, M9 and M10, are accessible by mountaineering.

DESCRIPTION OF RESULTS

The results from the 15 years monitoring show subsidence of rock slices by 0.9 mm per year and similar rate movement of the slices to South direction. The curve of displacements has a sinusoidal course, but it is often disrupted by sharp displacements. Some of these displacements are of seismic impact (Košťák et al., 1998). Its position in territory gives way to effects alternating with moderate seismic activity from local earthquake foyers, but with relatively often influence of the strong intermediate-depth Vrancea earthquakes and more rare influence of the strong shallow Marmara earthquakes. The result is shown on Fig. 10. The large deformations were recorded after the strong Izmit earthquake (M=7.4) at point M9 (just below the plateau's edge). Small-size displacements were established after shallow earthquakes from Provadia source zone (about 20 km E Madara).

The monitoring of that site is provided by financial support from Ministries of Culture of Bulgaria and Science and Technology. The study is included in the bilateral project with IRSM, Prague.

EAST RHODOPES

The research area is situated to the ENE of the town of Zlatograd, near the Bulgarian-Greek boundary. It is characterized by a complex tectonics and diverse geological structures. Two main geological units build the studied area: Praecambrian metamorphites and Palaeogene volcanic-terrigenous rocks (Boyanov and Mavrudchiev, 1961; Goranov, 1960; and others).

The Vacha Formation represents the oldest rocks of this region. The rocks are well represented in the Zlatograd and its surrounding. They take place to the West of the landslide's territory. This formation includes metamorphites, mainly gneisses, gneiss-schists, schists, quarzites, marble and amphibolites.

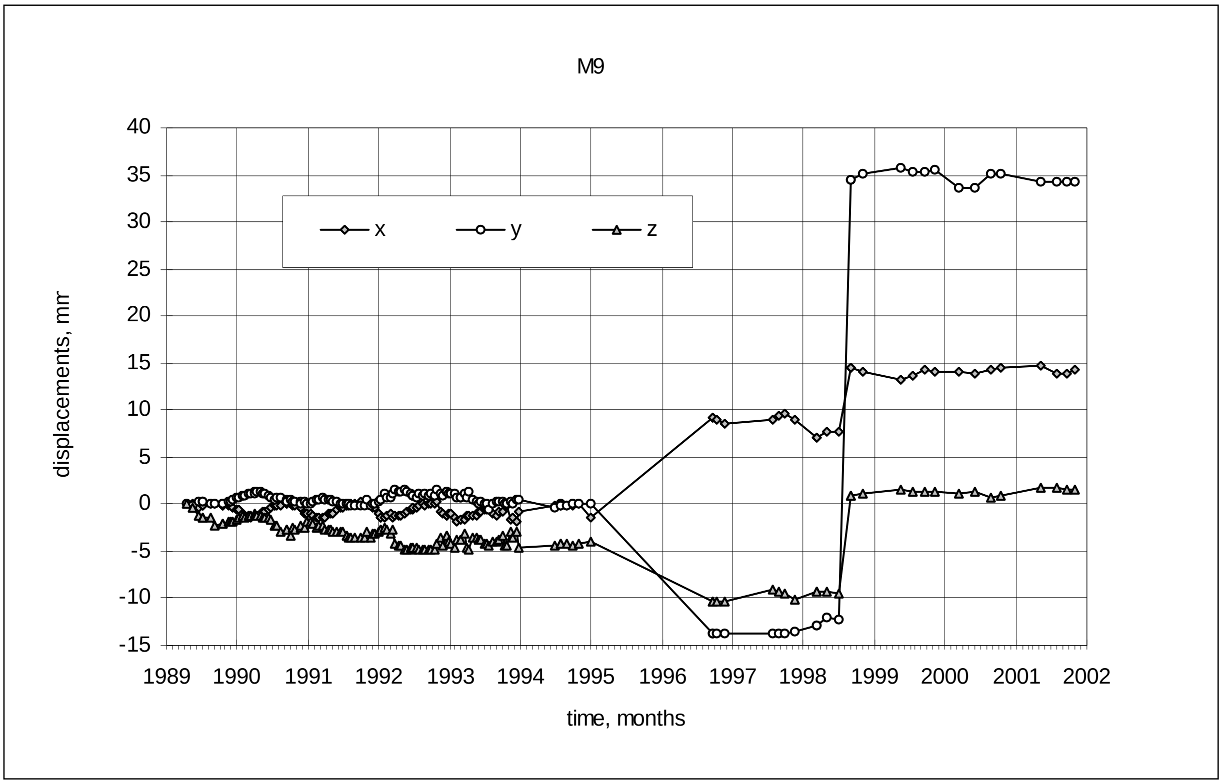

Fig. 10 Displacements found at point no.9 (M9) – Madara.

The Paleogene (Upper Eocene and Oligocene) volcanic rocks and terrigeneous sediments lay over a block of fragmented Precambrian rock complex. The faulting and the block fragmentation occur in the investigated territory. Several graben-like depressions are formed. Specific conditions define the development of several rock formations. Well-distributed Oligocene rocks include following formations: Formation of first acidic volcanism (tuffaceous sandstone, slightly to strongly calcareous sandstone and sandy limestone); Formation of second acidic volcanism (tuffs); Djebel Formation (sandstone, sands, aleurites and clays). The studied area takes place to the South of the superimposed Upper Thracian Depression and the NE Rhodope one.

The two faults are developed in the locality of the studied landslide. Then, Dobromirtsi faults pass near the top of the landslide and just at his toe. Several other faults with NW-SE, N-S and E-W directions are with local importance.

The Shiroka Laka fault (NW-SE) takes place near the N periphery of the General Geshevo landslide. The fault forms the NE border of the landslide and is developed also inside the landslide - in the Paleogene tuffs of the main landslide scarp. The slickensides on the fault plane indicate oblique sinistral movements. The directions in the striation are in coordination with the position of the open fractures. Such fractures cut the road outside of the landslide as well. The normal component of the movement is predominant. The subsidence takes place in the northern blocks. The pitches of the strokes are of value about 70-80º. The fault is revealed between the road and the main scarp – with a length of the outcrop about 50 m. The maximal height of the fault plane outcrop is approximately 10 m. The fault follows a direction of 300º behind the scarp. Along this fault plane, some fractures could be followed approximately 20 m behind the main scarp. The faults with E-W direction are also observed in the investigated landslide territory (Fig. 11).

MONITORING AND INSTRUMENTATION

Repeated geological mapping of the landslide was carried out after the activation of the sliding processes. All the mapped points were recorded by GPS and marked on a topographic base in scale M 1: 5 000. A benchmark network was developed for the monitoring of the landslide processes, its initial positioning and measurement being made by high GPS accuracy. Two boreholes were drilled near the main landslide caving with a depth of 115 and 125 m. The vertical electric sounding was performed in points of the landslide body in order to establish the geological structure into depth.

The choice of the new monitoring site was made after a detail selection among a few suitable sites. The new site is located about 30 m NW direction from the main scarp. The monitoring of the recent movements along the active faults is accomplished in a very small

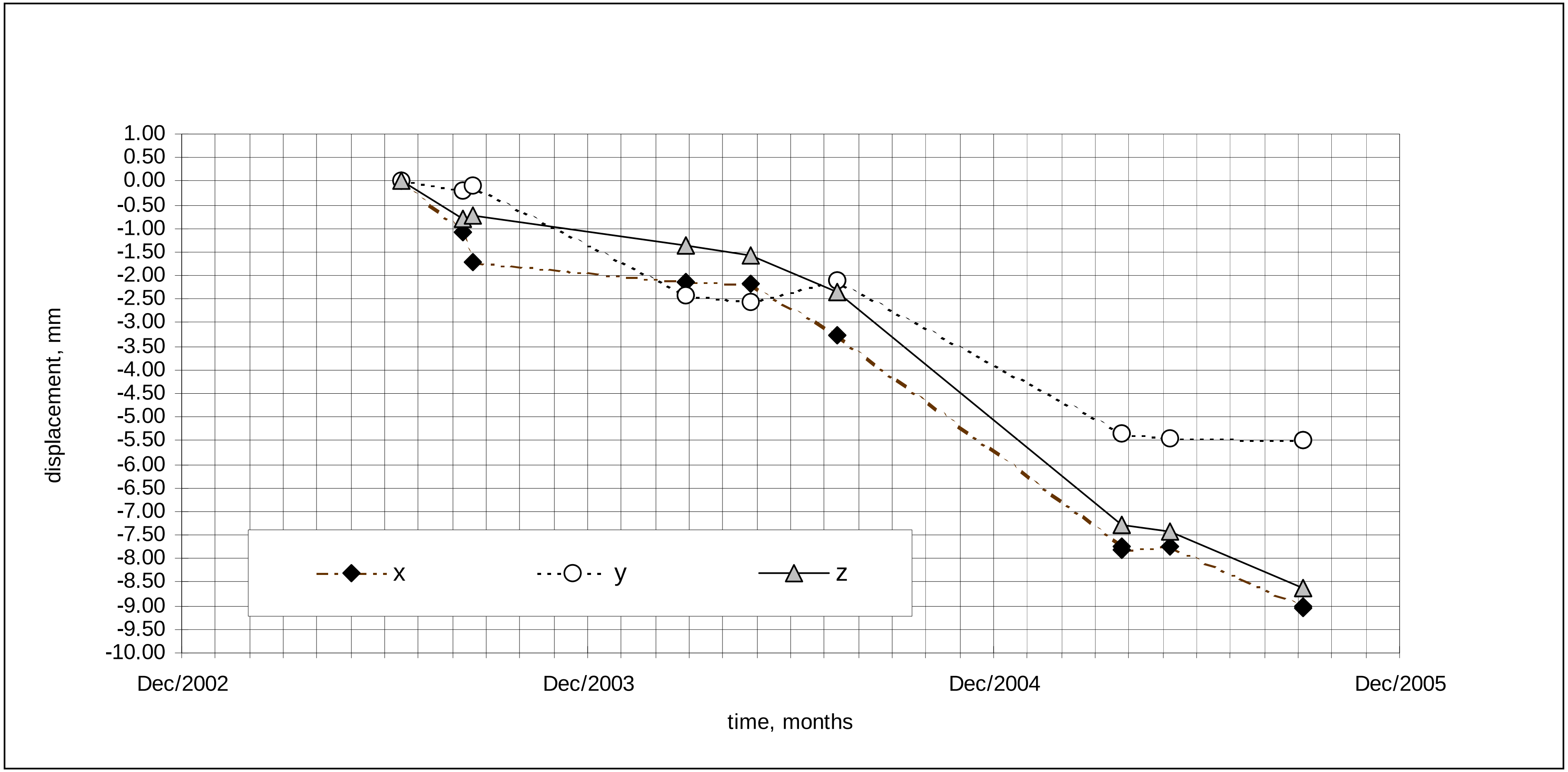

Fig. 12 Displacements recorded at point no.11 – General Geshevo.

trench. The trench lays in soft and suitable for digging tuffs. The tuff zone is 0.8-1.2 m wide.

The measurements are provided by extensometer TM71. Each device consists two planar indicators, which presence ensures the registration of the displacements of three spatial directions – X (opening or compressing of the fault zone), Y (strike-slip movement) and Z (vertical movement). The device is installed on steel holders made of thick tubes and cemented to drill holes. The holders bridge the walls of the fracture (fault) with the gauge. The accuracy of the devices is 0.01 mm. Local fault elements are: azimuth N112º, dip 50º NE.

The first results from the fault monitoring are shown in Fig. 12. The rates of the fault movements at the monitored site are preliminary till now. Generally, they could be characterized with: movements along X-axis – extension of the fault zone; movements along Y-axis – left (predominantly) and right lateral movements; movements along Z-axis – subsidence of NE block 1.5 mm/year.

CONCLUSION

In general, our monitoring points located in SW Bulgaria show apparent activities, especially at the point no. 6 (Brezhani). Here, the general movement is left-lateral - 2.73 mm/y, with changeable periods of opening and compression of the fault zone. The established extension is about 2.8 mm/y caused mainly by temperature impact upon the rock massif. A low rate of reverse movements is also established – 0.63 mm/y. The seismicity of local earthquakes with epicentres NE from the monitoring point usually induce the movements along this fault with acceleration of the left lateral movements during calm periods, and respectively, stopping of movements (or going in opposite direction) during seismic activity in NE part of this point.

The other two sites installed to observe Struma Fault (no.5 and no.12) show one order lower rates of sinistral movements. A sharp displacement was detected after a local earthquake swarm in Simitli-Predela area between 8th and 13th December 2003.

The results obtained by long-term monitoring at Madara sites show subsidence of rock slices by 0.9 mm per year and similar rate movement of the slices in south direction. Large deformations were recorded after the strong Izmit earthquake at point M9, as well as small-size displacements after shallow earthquakes from Provadia source zone.

Preliminary results of the new site arranged at East Rhodope area show gravitational movements most likely, i.e. extension of the monitored zone, right strike-slip and subsidence of the NE block within 1.5 mm/year.

The prolonged 3D monitoring in Bulgaria in the framework of COST Action 625 contributed to solve important practical as well as scientific problems. At the same time the effectiveness of teamwork in COST 625 project as well as many years of cooperation between the geological Institute of BAS and IRSM, Prague in this field shows the importance of mutual investigations on such an international base for clarifying and solving significant regional and global scientific and practical problems.

ACKNOWLEDGEMENTS

We express our gratitude to leaders of COST 625 project Dr. B. Kostak, Dr. L. Piccardi and Dr. J. Stemberk for their assistance in our work as well as to all colleagues that participated in both way in organizing and keeping up the monitoring. The financial support was provided by National science fund, Ministry of Education and Technologies of Bulgaria, as well as from the Ministry of Culture for Madara Horseman monument.

REFERENCES

Avramova-Tacheva, E.B. and Košťák, B.: 1995, Local three-dimensional extensiometric measurements for the determination of displacements in the Krupnik fault zone, Bulgaria. Acta Montana IRSM ASCR, Ser. A, No.8 (97), 87-98.

Avramova-Tacheva, E., Vrablyanski, B. and Košták, B.: 1984, An attempt to detect recent movements along seismogenic faults. Review of the Bulgarian Geological Society, vol. XLV, part 3, 276-288, (in Bulgarian).

Boyanov, I. and Mavrudchiev, B.: 1961, Paleogene volcanism in East Rhodope Mts. Ann. Sofia Univ., Biol.-Geol.-Geogr. fac., 2-Geology, 54, 113-158, (in Bulgarian).

Christoskov, L. and Grigorova, E.: 1968, Energetic and space-time characteristics of the destructive earthquakes in Bulgaria after 1900. Bull. Geophys. Inst., BAS, 12, 79-105, (in Bulgarian).

Dobrev, N., Georgiev, I. and Kostak, B.: 2005, Extensometric and GPS monitoring of recent tectonic movements in the Simitli graben, SW Bulgaria, Geodesy, BAS, 17, 98-107.

Dobrev, N., Glavcheva, R., Frangov, G. and.Shanov, S.: 2003, Observation of fault movements in SW Bulgaria and the impact of the local seismicity. Rep. National Conf. On Preventive Works Earthquakes And Landslides, Sofia, 10 Dec. 2004, 75-87.

Dobrev, N., Varbanov, R., Matova, M., Frangov, G., Drakatos, G. and Kostak, B.: 2004, First steps for monitoring on possibly active fault zone in East Rhodopes, Bulgaria. Acta geodynamica et geomaterialia, Ac. SCi. Cz. Rep., Prague, Vol.2, No.1(137), 7-12.

Dobrev, N.D. and Kostak, B.: 2000, Monitoring tectonic movements in the Simitli Graben, SW Bulgaria. Engineering Geology, Elsevier, 57 (3-4), 179-192.

Frangov, G., Ivanov, P., Dobrev, N. and Iliev. I.: 1992, Stability problems of the rock monument "Madara horseman". In: Proc. of the 7th Int.

Congr. on Deterioration and Conserv. of Stone, Lisboa, Portugal, 1425-1435.
Goranov, A.: 1960, Litology of Paleogene sediments in part of East Rhodope Mts. Works on Geology of Bulgaria, Ser. Geochim., 1, 259-310, (in Bulgarian).
Karnik, V.: 1968, Seismicity of the European area. Publ. Academia Praha, part 1, 116-122.
Košťák, B. and Avramova-Taceva, E.: 1988, A method for contemporary displacement measurement on a tectonic fault. Journal of Geodynamics 10, 115-125.
Košták, B.: 1991, Combined indicator using moire technique. Proc. 3rd Int. Symp. Field Measurements in Geomechanics, Oslo, 53-60.
Kostak, B., Dobrev, N., Zika, P. and Ivanov. P.: 1998, Joint monitoring on a rock face bearing an historical bas-relief. Quarterly Journal of Engineering Geology, London 30(1), 37-46.
Matova, M., Dobrev, N. and Košták B.: 2001, Certain extensometric data for the influence of the 1999-2000 Turkish earthquakes to Bulgaria. Fourth Turkish-German Joint Geodetic Days, Berlin, April 2001, vol. II, 769-776.
Ranguelov, B., Rizhikova, S. and Toteva. T.: 2001, The Earthquake (M 7.8) Source Zone (South-West Bulgaria). Full Catalogue And Macroseismic Maps. Prof. Marin Drinov Academic Publishing House, Sofia, 279.
Shanov, S.B. and Dobrev, N.D.: 1997, Impact of the seismic processes on the movements along the Kroupnik fault zone (SW Bulgaria). Comptes rendus de l'Academie bulgare des Sciences, 6, 95-98.
Shebalin, N., Karnik, V. and Hadzievski, D.: 1974, Catalogue of earthquakes. UNDP/UNESCO survey seismicity of the Balkan region, Printing Office of the University Cyril and Methodius, Skopje.
Varbanov, R. and Frangov, G.: 2002, Large active landslide in East Rhodopes – Bulgaria. Jub. Sci. Session for Acad. Strashimir Dimitrov, GI – BAS, poster report.
Vrablyanski, B.: 1974, Neotectonic investigations in the Simitli graben and its frame. Bull. Geol. Inst. of Bulg. Acad. of Sci., Ser. Geotect. 23, 195-220, (in Bulgarian).
Vrablyanski, B. and Milev, G.: 1973, Neotectonic features of the Struma fault zone. Acta Montana, Praha, series A, No. 4(90), 111-132.
Watzof, S.: 1902, Tremblements de terre en Bulgarie observés pendant le XIX-ème siècle. Institut météorologique central, Sofia, Imprimerie de l'Etat. 96, (in Bulgarian, Summary in French).
Zagorchev, I., 1992: Neotectonic development of the Struma (Kraistid) Lineament, southwest Bulgaria and northern Greece. Geological Magazine, 129, 2, 197-222.

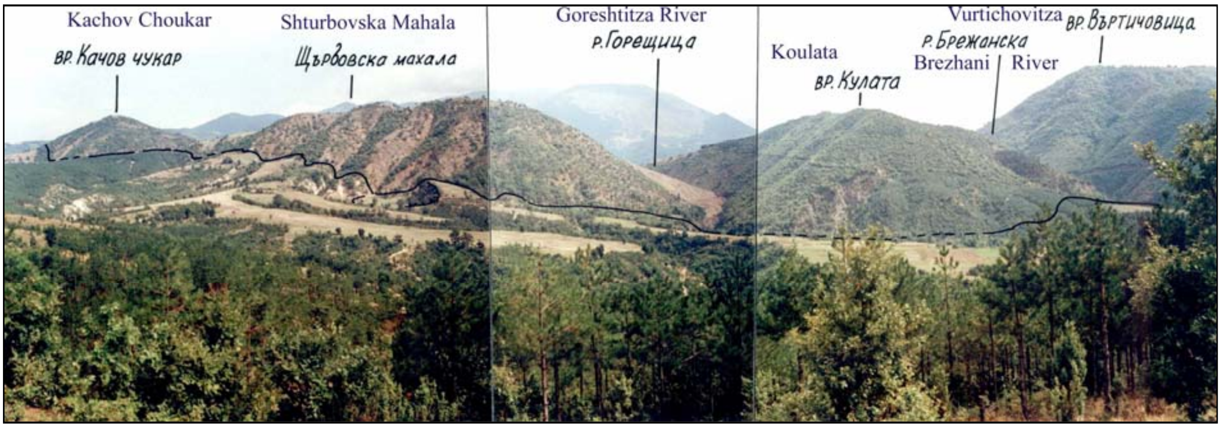

Fig. 3 The Krupnik fault on the left side of Strouma River.

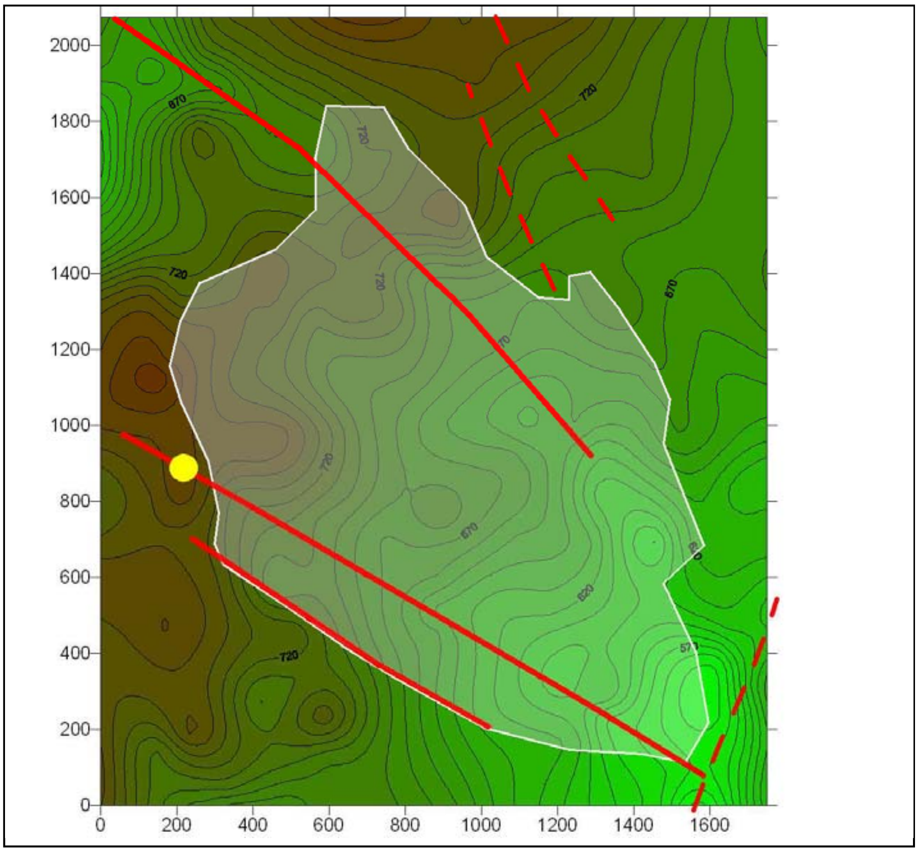

Fig. 11 Geomorphology map of the General Geshevo landslide. The borders of the landslide are shown by yellow contours; the new faults and the Dobromirtzi fault are shown by red lines; the monitoring site is shown by yellow circle.