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LOCAL THREE–DIMENSIONAL EXTENSIOMETRIC MEASUREMENTS FOR THE DETERMINATION OF DISPLACEMENTS IN THE KRUPNIK FAULT ZONE, BULGARIA

Elka AVRAMOVA-TACHEVA[1)] and Blahoslav KOŠŤÁK[2)]

[1)]Laboratory of Geotechnics of the
Bulgarian Academy of Science, Sofia

[2)]Institute of Rock Structure and Mechanics,
Academy of Sciences of the Czech Republic, Prague

Abstract. Registration of displacements along two deep faults in SW Bulgaria evidenced a dynamic activation of the faults, which react to seismic activity by creep, as well as by fast slips.

Key Words: extensiometric measurements, Krupnik fault

1. Introduction

The existence of recent landforms and slope deformations in the N part of the Kresna gorge and the adjacent grounds indicates the recent mobility of the region. Undoubtedly, it is connected with the formation of complex tectonic knot due to intersecting of two big deep faults: the Struma and the Krupnik ones. It is also classified as the most active seismotectonic knot in SW Bulgaria [Matova, Rizhikova 1980]. Most of the slope deformations impress with their size and features, which are conditioned by their tectonic and seismotectonic predetermination. In the N parts of the Kresna gorge, cut deep into the granitoids, creep deformations and rockfalls prevail, while in the range of the Krupnik fault several types of landslides are displayed [Avramova-Tacheva et al. 1984].

2. Registrating Stations and Appliances

To demonstrate the recent activity of the two faults and slope deformations connected with them, local investigations of the displacements on and inside them were organized as an element of the general geodynamic research of the region. Another aim of these local investigations is to search for a connection between the quantities and directions of the displacements and seismic events of near earthquake focuses, as well as for prognostic signs of powerful earthquakes.

The mechano-optical apparatus TM-71 [Košťák 1969], constructed in the Institute of Geology and Geotechnics of the Czechoslovak Academy of Sciences, gives a good possibility for permanent measurements of slow spatial movements. This is an extensiometer which registrates displacements along the three axes X, Y, Z with an accuracy of 10^{-5} m by means of moiré effects arising from the superposition of two nets directly connected with the moving objects – in this case with the opposite sides of a fault zone or fracture [Košťák 1977]. The registration of displacements may be accomplished automatically by an appropriate program or individually – visually or by means of photography. The temperature to make corrections due to dilatation of the measuring bridge and possibly to calculate the temperature deformations of the rock massif, is also registered simultaneously [Gasharov, Avramova-Tacheva 1976]. The advantage of the utilized apparatus in comparison with other extensiometric systems is in its simplicity and long term stability under different ambient influences. Three registering stations were built and function in the intersection area between the Struma and the Krupnik faults (Fig. 1 – graphic materials after [Avramova-Tacheva et al., 1984 and Rybář et al. 1986] are used).

The first registering station (TM–5) is situated on the left valley slope of the Struma River, whose valley follows the Struma fault zone. It registers movements along a tectonic zone with an orientation of 150°, belonging to a bundle of subparallels to the main fault zones, morphologically very clearly expressed along a considerable distance in the gorge. It has been operating since the beginning of 1982. The second registering station (TM–6) shows movements along the Krupnik fault, on the N end of the Struma gorge. The measuring system overbridges the contact between the Proterozoic amphibolites and the Tertiary coarse-grained sediments filling up the Simitli graben. The contact fault zone of a width of 3.4 m at that point is exposed by a trench in which the measuring appliances are assembled [Avramova-Tacheva et al. 1984]. The station has been functioning since the middle of 1982. The third registering station (TM–7) was also built in the range of the fault zone of the main fault line of the Krupnik fault, but immediately to the W of the Struma River. There, on the S boundary slope of the Simitli graben, a series of deep fractures parallel to the slope are traced, which are connected also with the display of slope movements. The measurement appliances are mounted in one of these fractures. It is supposed that they register tectonic, seismotechnic and gravitational displacements along a fracture connected to the main fault. The station has been operating since the end of 1983.

The three registering stations described above enable registration and investigation of local movements along the two deep faults, as well as of dangerous gravitational deformations due to one of them – the Krupnik fault. The stations are at two principally different situations – a fault or fracture in hard rocks and a contact between the hard and incompetent environment (Fig. 2). Local conditions require that, along with the measurements and the interpretation of their results, a series of geological and geomorphological details must be recognized.

The orientation and the interpretation of the registered displacements at the three stations are given in Table 1.

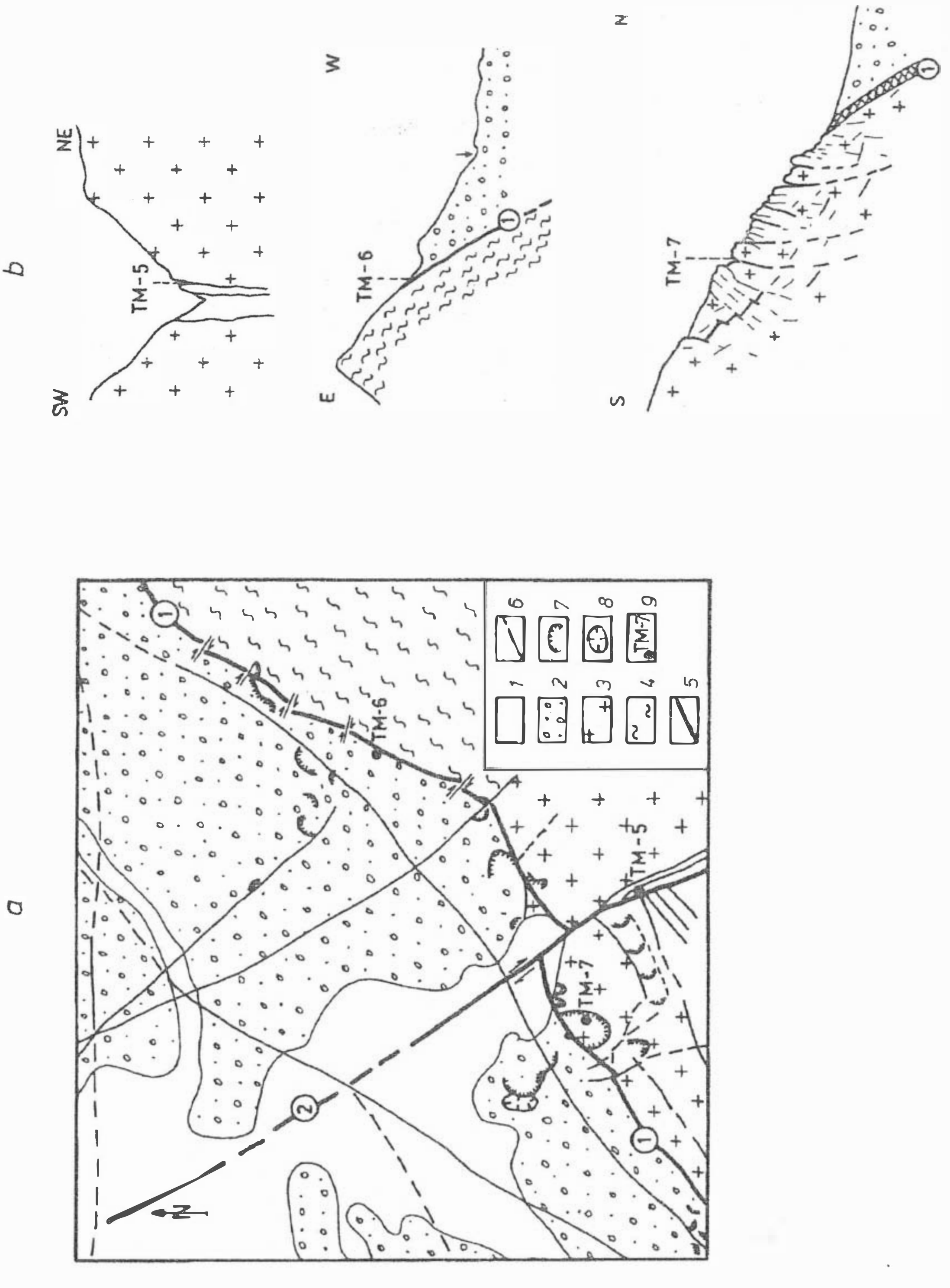

FIG. 1. Position of the local registering stations – situational (a) and geological (b) profiles. Explanations: 1 – Quaternary alluvial deposits; 2 – coarse-grained Pliocene deposits in the Simitli graben; 3 – S Bulgarian granites; 4 – Proterozoic amphibolites; 5 – main faults (1. the Krupnik fault, 2. the Struma fault); 6 – proved and supposed faults of lower order; 7 – slope deformations: rockfalls, landslides, deep creeping, etc.; 8 – accumulation of an ancien rockfall; 9 – registering station.

TABLE 1.

Regis-tering station	Orientation and interpretation of the displacement +X Horizontal expansion of the zone (fracture)	+Y Horizontal slip in the zone (fracture)	+Z Vertical slip in the zone (fracture)
TM–5	225°	the lower SW block to the SE – 135°	the lower SW block downwards
TM–6	290°	the Tertiary basin to the SSW – 220°	the Tertiary basin downwards
TM–7	350°	the lower N block to the W – 260°	the lower N block downwards

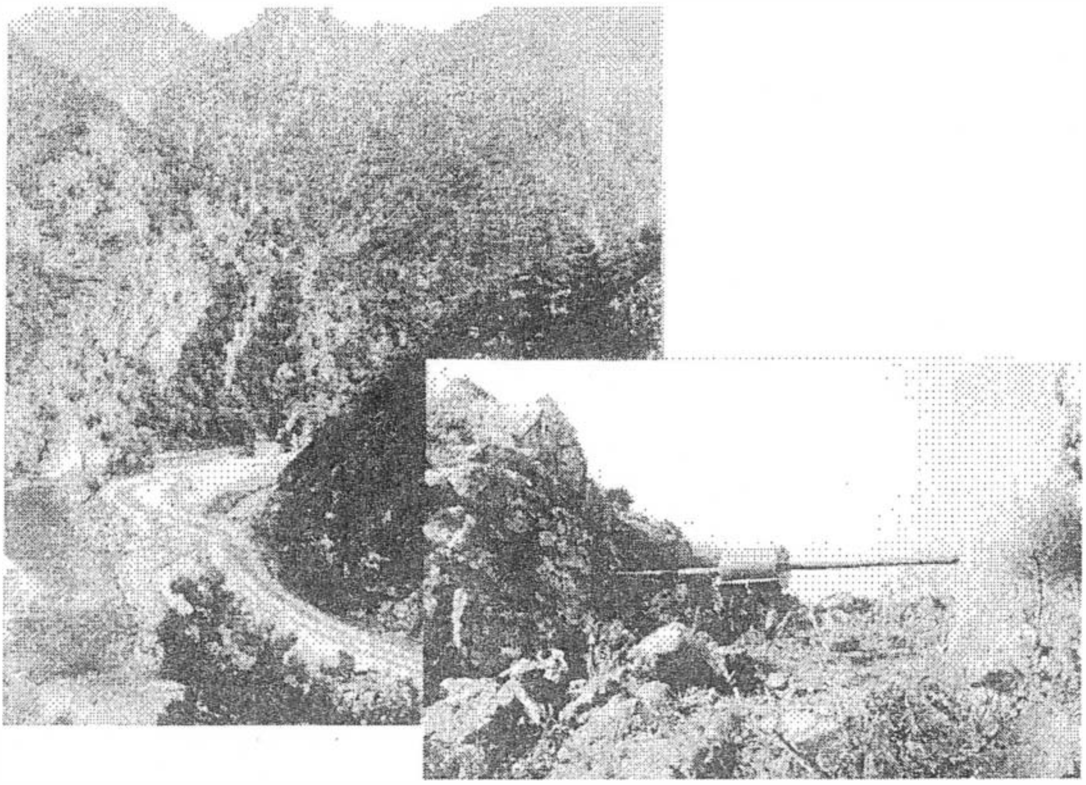

FIG 2A. Geomorphological position of tectonic deformations in the Struma fault zone (Kresna gorge) and the situation at registering station TM–5.

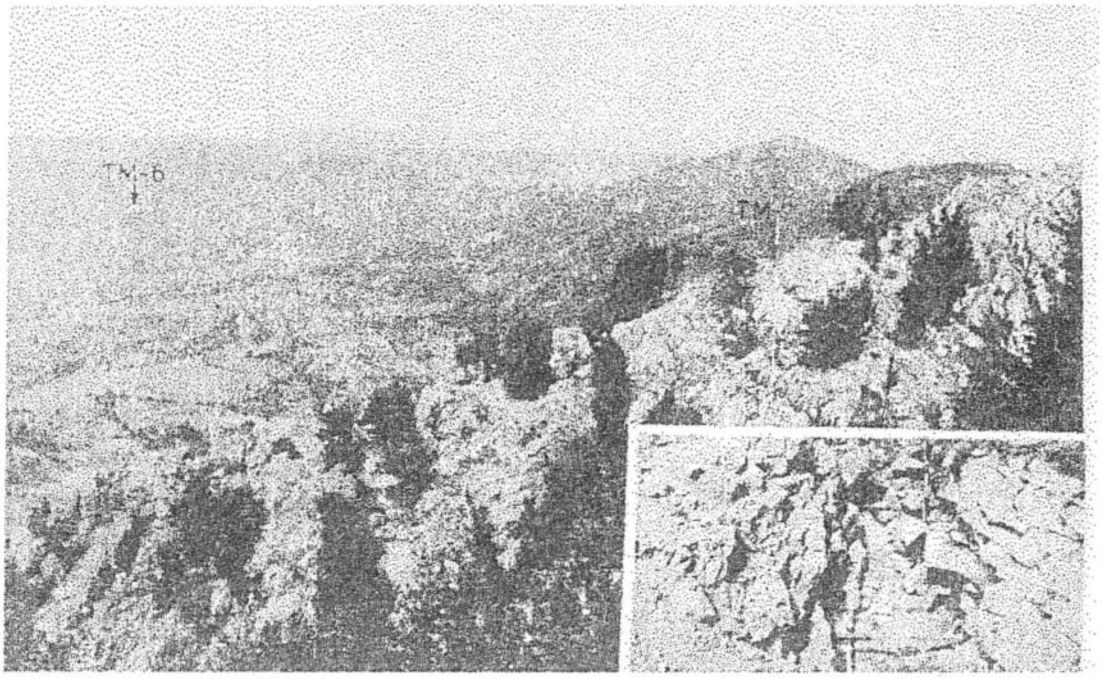

FIG 2B. Middle part of the slope developed along the S boundary of the Simitli graben to the W of the Struma River and a detail of the fracture with TM–7; in the background structural slopes of the Krupnik fault to the NE and the location of TM–6.

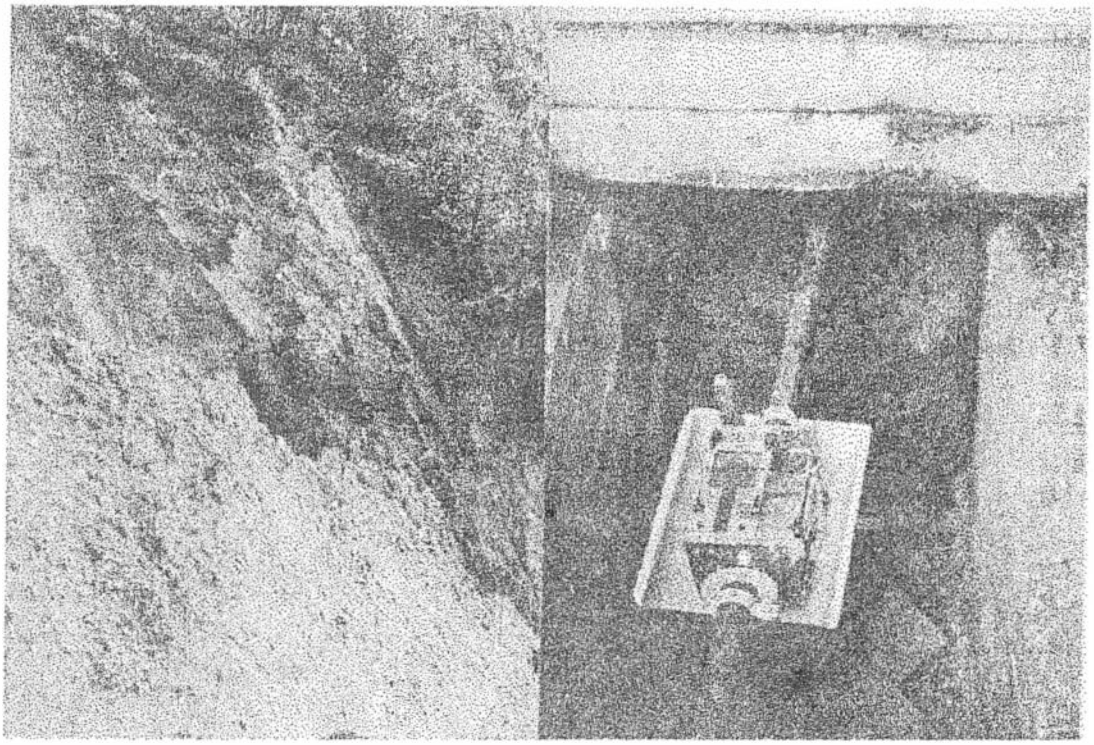

FIG 2C. Detail of the fault area of the Krupnik fault in the amphibolites close to TM–6 and the measuring system which overbridges the fault zone.

3. Results of Measurements, Analysis and Interpretation

The registered movements along fractures of different origin usually consist of two elements: a) periodical oscillations of different amplitude connected with temperature deformations of the rock massif, alterations in the humidity of the environment, long–term cosmic influences, etc. and b) more stable trends in displacements or instantaneous jumps [Košťák, Avramova-Tacheva 1984; Kalvoda, Košťák 1984; Avramova-Tacheva, Košťák 1986]. Important for the above mentioned purposes of the local measurements it is to establish the existence of a trend or jumps of the displacements, their value and character.

The results of the former measurements are represented in the diagrams Fig. 3 and 4. The temperature deformations of the measuring system are excluded. The diagrams show very complicated reactions of the rock environment. The normal reaction of a rock massif connected with volumetric temperature deformations in the course of a year (expressed by periodical alterations) is strongly obscured and for some components of the displacements in different periods nearly completely absent. It is disguised by manifested clear trends in the movements and characteristic reactions of near and farther earthquakes with epicenters generally situated to the S and SW of the region. Two periods of heightened seismic activity can be outlined for the time during which the measurements were made – from the summer of 1983 till the autumn of 1984, and from the beginning of 1986 till the middle of 1987. A more detailed analysis of the displacements at the three stations up to the end of 1985 and their connection with separate seismic events are attempted in [Avramova-Tacheva, Košťák 1986 and Košťák, Avramova-Tacheva 1987].

At the TM–6 station, situated on the main fault line of the Krupnik fault, the most active movements are manifested. The station is at the second one of the above mentioned sites situated between hard rocks (amphibolites) and incompetent environment (Pliocene sediments filling up the graben). A clearly expressed tendency of accelerating horizontal slip of the basin to the SSW or of the amphibolites to the NNE is determined, beginning after the first period of heightened seismic activity since the middle of 1984 (Fig. 4). During 1985 the rate of movement is lower, i.e. 1.4 mm.year^{-1}. It maintained nearly the same rate after a registered jump of 4.0 mm, connected with the earthquake on February 18, 1986 with an intensity of 4.7 according to the Richter scale and epicenter situated 20 km N of Salonika. At the end of the second period of seismic activity in North Greece, the Aegean Sea and Yugoslavia, after a seismic event on December 25, 1986 with epicenter approximately 210 km S of Zagreb and intensity of 7 degrees according to MSK–64, the horizontal slip in the same direction accelerated, and during 1987 until April 1988 it displayed an average velocity of 7.0 mm.year^{-1}. Another tendency is in the distinctly outlined uplifting of the basin (or subsiding of the amphibolite massif) with an average velocity of 7.5 mm.year^{-1} since the middle of 1984 until the end of 1985 and with a lower velocity – around 5.0 mm.year^{-1} during the following period until April 1988. At the same time the contact experienced compression which provoked its contraction, especially strongly expressed since the middle of 1984 till the end of 1985, with an average movement rate along the X axis of 4.0 mm.year^{-1}.

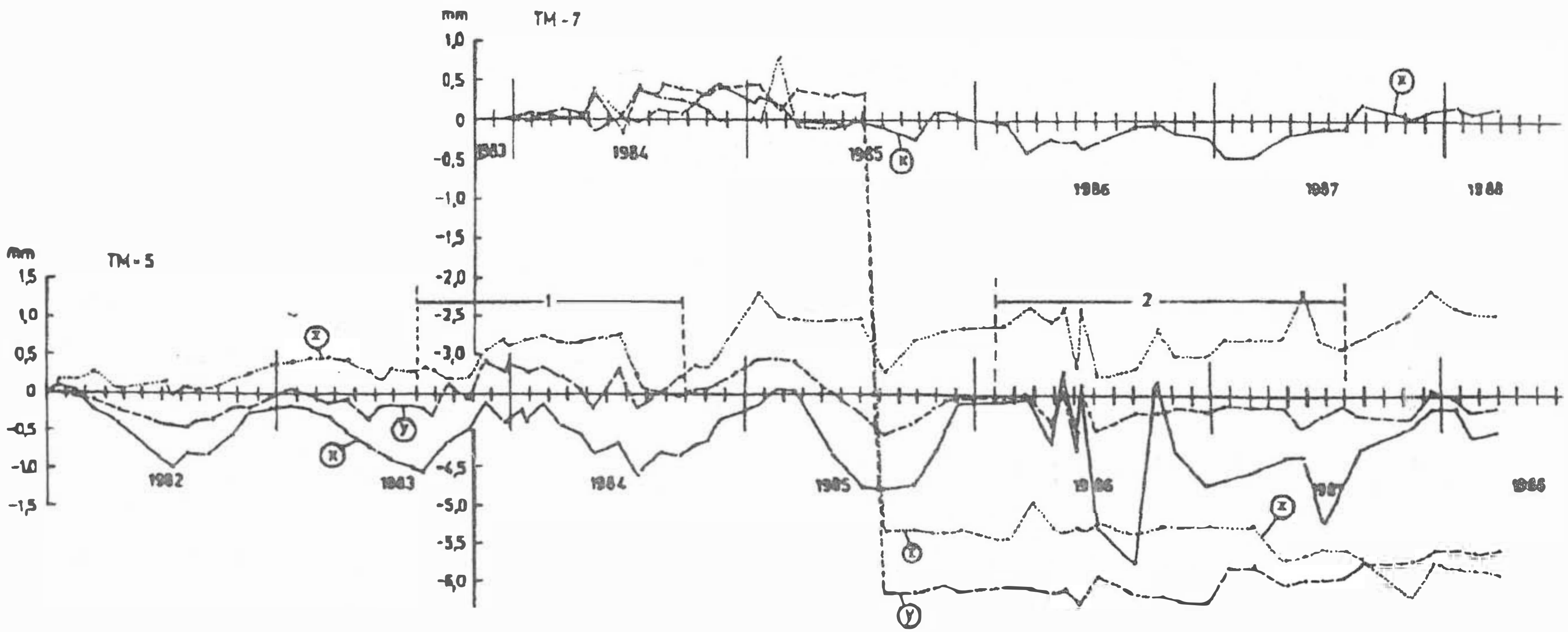

Fig. 3. Registered displacements at TM–5 and TM–7 stations. Explanations: X – expansion or contraction of the tectonic zone, Y – horizontal slip, Z – vertical slip; 1 and 2 – periods of heightened seismic activity in the Mediterranean seismic belt.

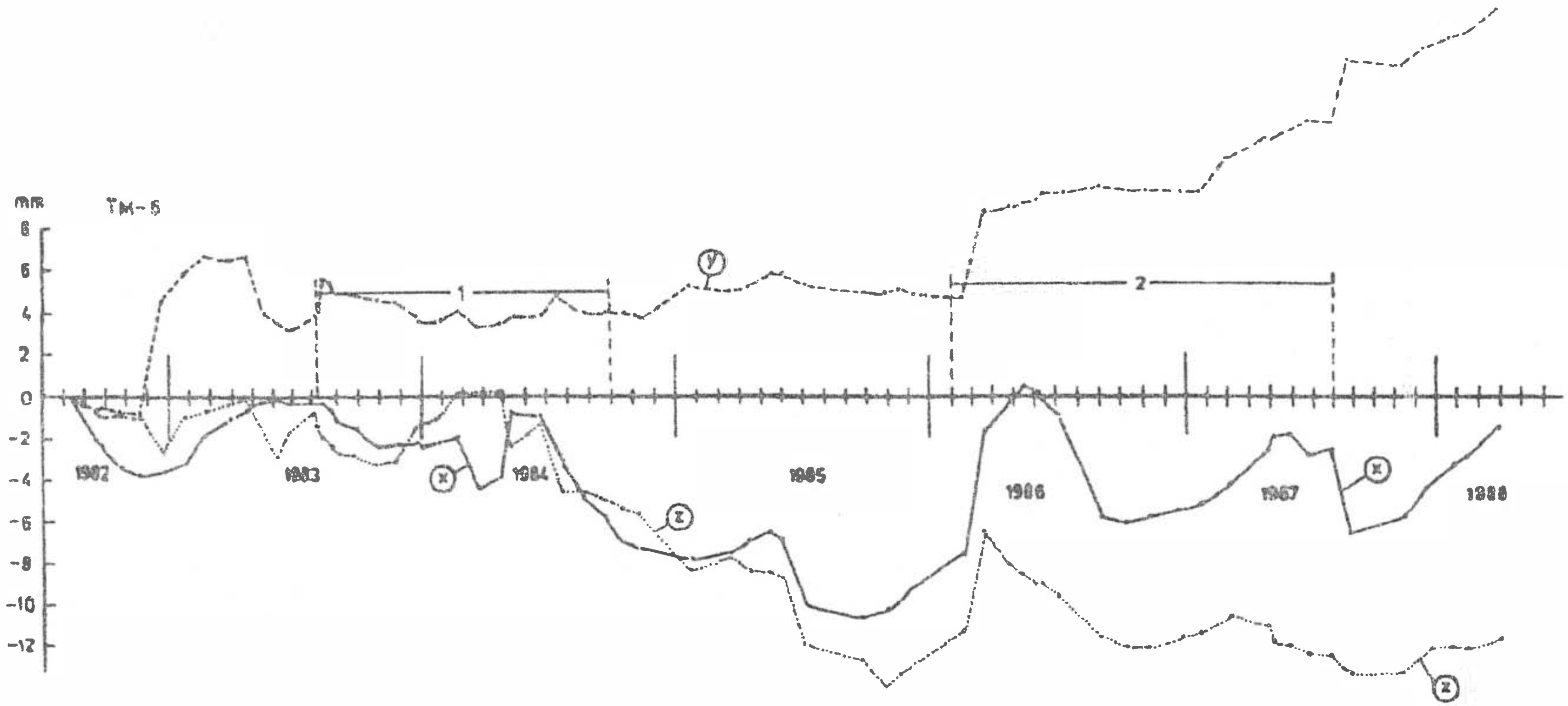

Fig. 4. Registered displacements at TM–6 station. Explanations see the text for Fig. 3.

After a short period of expansion of the contact up to the middle of 1986, a period of compression started again, but with a less strongly expressed contraction of the contact zone. The periodic motion is more clearly outlined in movements in this direction and conditioned mainly by volumetric temperature deformations.

This motion of the displacements unequivocally indicates the existence of recent tectonic movements of a rather high activity in this section of the Krupnik fault. Their components correspond to the alteration of the contact along the fault with a modification due to tensions in the course of time [Košťák, Kozák 1985; Košťák et al. 1985]. A detailed analysis of the data suggests a slow movement of the massif of the S boundary frame of the graben, E of the Struma River, in a N direction, thrusting in depth beneath the basin. The movement clearly engages a massif with a deep predestination. The last movement clearly reacts to earthquakes with epicenters mainly in North Greece, the Aegean Sea, the Adriatic Coast and the S part of the former Yugoslavia. Usually, after every larger displacement along the fault connected with a seismic event, a tendency of returning to the initial position is observed. This however cannot be achieved because of the general trend of movement. Records from the automatic registration of the measurements show that extreme displacements are not realized as instantaneous jumps but through acceleration movements *before* the earthquake [Shanov 1993], or as its *after–effect*. At the same time, events of near focuses, but situated to the N of the graben or immediately to the W of the investigated region (e.g. manifested on the January 24, 1984, May 15, 1986, March 23, 1988, etc.), have only small impact on the displacements. This directs the attention towards suggestions about the shielding role of the Gradevo fault and about the activation of shallow earthquake focuses.

The registered displacements in the fault zone of the Krupnik fault to the W of the Struma River (TM–7) are by one order lower than those registered at TM–6 (Fig. 3). It is difficult to discover periodic motion in them, except in certain periods for the X–component. The character of the movements and the emission of heat and radon gas along the examined fracture, show that in its depth it is connected with the Krupnik fault and that the measuring system registers tectonic movements. Trends in the movements however are not clearly expressed because of the strong deformation of the rock massif, where gravitational movements and the reaction to seismic events interfere. The reaction for some earthquakes is of the same direction as at TM–6 (e.g. during July 1985). A more distinct trend to horizontal slip of the lower N block to the W (or of the upper zone in the opposite direction) with an average velocity of $0.45\,\mathrm{mm.year^{-1}}$, accompanied by its uplift of $0.60\,\mathrm{mm.year^{-1}}$ and expansion of the fracture also of about $0.60\,\mathrm{mm.year^{-1}}$, was outlined during 1987 – as a comparatively more tranquil period with regard to seismic events. During July 1985 a quick shifting of the lower block by 6.5 mm to the E and 5.30 mm upwards was registered at this station without altering the width of the fracture. It was manifested after a powerful earthquake in Montenegro during May 1985 with a magnitude of 5.2 according to the Richter scale, and another one in the NE Bulgaria in the range of the diagonal swell. This shifting is more probably a seismotectonic reaction than a gravitational one. Conclusion about the tendencies in the local movements along the Krupnik fault in this section cannot be made from the data for the time being. The registration of movements at TM–7 however is particularly important in view of timely warning of possible quick landslides of bulky rock masses over important transport facilities.

The displacements along the tectonic zone of the Struma fault bundle (TM–5) are of the same order as in TM–7. The periodic motion of the deformations there is more clearly outlined, but it is also strongly deformed and complicated during periods of heightened seismic activity, particularly during the second period and afterwards (since the end of 1985). Brief periods of contraction of the tectonic zone were observed (Fig. 3) followed by expansion up to the starting position and brief horizontal slips in one of the two directions along the Y–axis, that is in the direction of the valley of the Struma River in the section. They are of small value up to 1 mm and reached 2.4 mm only along the X–axis during September 1986. Usually they are connected with earthquakes of different intensity, including some with epicenters N of the investigated region. The last one testifies that the Struma fault zone is a conductor of seismic energy. The direction of these movements most frequently corresponds to the movements in TM–6. This connection suggests that the studied tectonic zone is included in the big tectonic block of the S boundary frame of the Simitli graben to the E of the Struma River. The connection also shows that the faults of lower order, transversal to the Krupnik one and situated in the direction of Struma, along which the deep ravines in the granitoid and amphibolite massifs between the Struma and the Brezhanska Rivers are formed, are of shallower predestination. It is probable that the main line of contemporary activity along the Struma fault, with possibly larger displacements than those registered at TM–5, is situated to the W of the fault in the range of the gorge. During the initial three–year period of measurement (1982–1985), a certain more distinct subsidence trend of the lower S block with $0.5-0.6\,\mathrm{mm.year}^{-1}$ was established.

4. Conclusions

The results of the former local extensiometric measurements in the investigated region and their interpretation indicate that both deep faults exhibit present–day activity. This activity is more distinctly manifested in the Krupnik fault. The different character of the movement along it to the E and to the W of the Struma River is connected on the one hand with the local conditions and the principally different situations under which the respective measuring stations TM–6 and TM–7 were built, and on the other hand with the role of the Struma fault zone which intersects it and divides it in parts belonging to different structural blocks. The registered movements in the E section are considerably greater in value and more clearly expressed trend. Larger displacements and those registered at TM–5 are displayed at the Struma fault, as this station measures only the movements in a satellite zone to the main fault. Unfortunately, for the time being, the exact place where the surfaces of larger displacements pass through the Struma fault zone remains unclear.

The manifestation of the main fault surface of the Krupnik fault and the section of intersect of second– and third–order faults, indicates that their emerging is predetermined by tectonic tensions and recent tectonic movements connected with them. The recent landslides on the slopes of deep ravines, following the direction of the tectonic deformations, both in the Tertiary basin and the S boundary frame, also testify of a quick change of the erosion basis during Holocene, connected with the vertical movements of the region. The exposure of the last one as well as of the traces of ancient and recent rockfalls show dynamic activations of these faults, in the examined region with predominance of stresses from the S and SW. At the registering stations the seismic influences of these main direction cause an effect on the recorded present–day movement.

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LOKÁLNÍ TROJROZMĚRNÁ EXTENSIOMETRICKÁ MĚŘENÍ PŘI URČOVÁNÍ POHYBŮ NA ZLOMOVÉ ZÓNĚ KRUPNIKU, BULHARSKO

Elka AVRAMOVA-TACHEVA a Blahoslav KOŠŤÁK

Tři registrační stanice byly zřízeny na dvou hlubokých tektonických zlomech v JZ Bulharsku v blízkosti známého krupnického epicentra. Umožňují registraci a hodnocení místních pohybů, tektonických i gravitačních. Stanice jsou vybaveny terčovými měřidly TM–71 pro trhliny, které pracují s využitím principu moiré. Tyto přístroje zachycují posuny ve všech třech prostorových složkách. Jde o dlouhodobé kontrolní sledování.

Výsledky prokazují projevy dlouhodobého ploužení (krípu) a rychlé nevratné deformace v důsledku zemětřesení. Jasně je ověřena tendence zrychlujícího se horizontálního prokluzu krystalického masivu vůči sousední pánevní výplni s rychlostí okolo 7.0 mm.rok^{-1} a také poklesy masivu (nebo nasouvání pánevních usazenin na masiv) o rychlosti okolo 7.5 mm.rok^{-1} za podmínek tlaku v kontaktu.

Jednotlivá zemětřesení způsobila prokluzy až do výše několika mm. Tyto pohyby obecně reagují na seismickou aktivitu severního Řecka, Egejského moře a bývalé Jugoslávie. Nedávné gravitační svahové deformace aktivované v této oblasi byly bezpochyby podmíněny tektonickými tahy a deformacemi těmito tahy způsobenými.

Dynamická aktivizace těchto místních zlomů byla tak prokázána.