ACTA MONTANA IGt AS CR(1993)
Series A, No. 4(90), 25—52

COMMENTS ON THE ORIGIN OF TRANSLATORY LANDSLIDES IN THE MARITSA-IZTOK BASIN, BULGARIA

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Abstract: The occurrence of translatory landslides of unusual extent is typical of the Maritsa-Iztok brown-coal basin in Bulgaria. They affect the slopes of open-pit mines, slopes of spoil banks as well as natural slopes along water streams. The author investigated the causes of slope failure in the Maritsa-Iztok basin and he attributes the decisive influence to the relieving of the abnormal horizontal stress of seismotectonic origin.

Key words: translatory landslides; slope stability; influence of tectonics; open-pit mining

1. INTRODUCTION

The open-pit mining of brown coal in the Maritsa-Iztok (East Maritsa) basin (Bulgaria) was started after 1960. Since the beginning, landslides of extraordinary size and forms have occurred on this site. The basic layout is shown in Fig. 1. The anticlinal mound is forced up at the slope base, in the upper part of the slope a wedge-shaped depression similar to a tectonic graben (fault trough) is being formed, and the intermediate slope part is being shifted as an entire block towards the frontal mound. The main phase of the movement is usually very fast: it does not last more than several hours. This type of slope failure is adequately called translatory or lateral landslide.

Several similar manifestations of instability appeared, step by step, also during construction of external waste dumps. Similar sliding forms were established also on natural slopes of water streams, frequently even in slopes with general gradient below 2°. At that time, P. Gečev with some of the local collaborators pointed out the possible unfavourable effect of relieving the horizontal stress state of seismo-tectonic origin on the slope stability. He also collected some evidence supporting his conception. However, with a few exceptions, the idea did not meet with understanding of leading experts, who clung to the opinion of Soviet consultants. The cause of the deformations was looked for, in particular, with research of mechanical rock properties (e.g. Todorova, 1974), including the rheological ones (Stoeva, 1973). Structural alterations of clays in the shear zone were studied as well (Anguelov *et al.*, 1983).

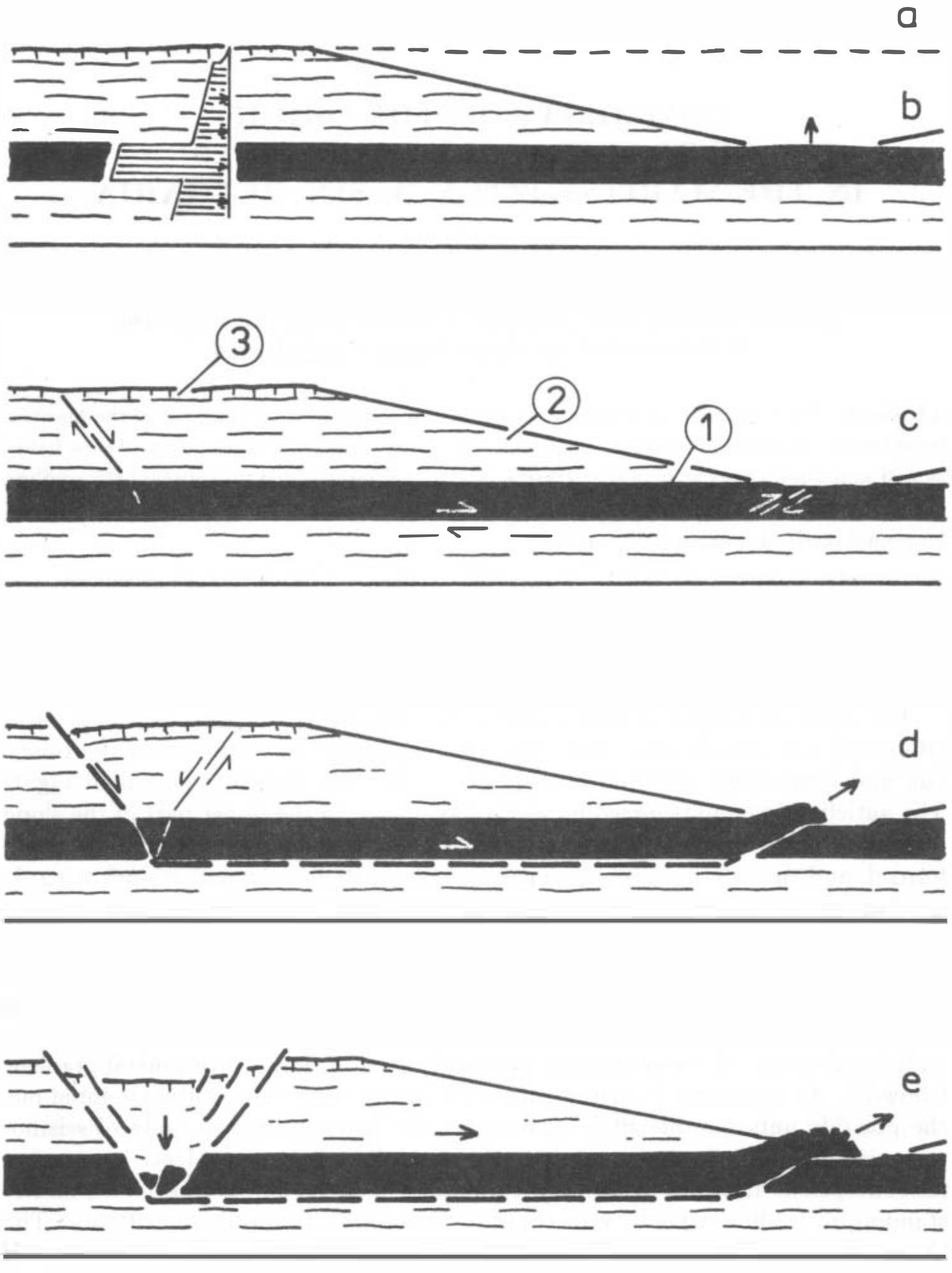

Fig. 1. Development scheme of translatory landslides under assumption of the release of horizontal stress.

Slope failures by landslides of the lateral type base occurred in the Maritsa-Iztok basin up to now. However, the operators gradually managed to reduce the effect of landsliding on the open-pit and waste dump slopes to an acceptable extent.

The opportunity has been offered to the author, within the frame of international collaboration, to get acquainted with various phenomena directly in situ and to provide his own documentation. Subsequently, he tried to analyze himself the causes of land-sliding, making profitable use of results of experimental physical modelling. The author feels obliged to the collaborators of the Bulgarian Academy of Sciences, Laboratory of Geotechnics in Sofia, the Projection Institute Minprojekt in Stara Zagora, and to the collaborators of the enterprise DM Maritsa-Iztok in Radnevo, for the opportunity to work in the Maritsa-Iztok basin.

2. INFORMATION CONCERNING THE BASIN

The Maritsa-Iztok basin is filled with Pliocene sediments of the underlying, coal-bearing and overlying strata series.

The *underlying strata* measures are formed largely by clays to claystones. In the upper zone, there are frequent slate bands and lenses of finely to medium-grained sands, usually with stressed water horizons. Their thickness does not exceed 6 to 8 m. The extension of the lenses in both the vertical and horizontal direction is irregular and is related to the direction of introduction of the detritic material into the basin.

The *coal-bearing measures* are formed by three coal seam zones. The 3rd seam lies on the basis and has the thickness of 1 to 6 m. It is separated from the 2nd overlying seam by blue to grey-green silty claystones of average thickness of 3 m. They are permeated by a dense network of subhorizontal cracks and are designated as "schistous clays". In the cover, they are quite distinctly separated from black clays and clayey coal of the 2nd seam zone.

The 2nd coal seam has the average economically useful thickness of 17 m and is divided, by placements of Carboniferous black clays in thickness up to 0.5 m, in three parts. The transition between the coal and black clays is usually quite indistinct. In the overlying rock of this main seam, about 10–15 m of black clays with coal inserts are usually found. The uppermost 1st seam in the basin is developed only sporadically.

The *overlying strata* measures are up to 80 m thick and are mostly formed by clayey soils. Deposits of the Quaternary age are unsignificant.

For a long time, no attention has been paid to the *tectonic structure*. During the initial survey phase, the depositing conditions were evaluated as relatively calm. Only the unusually complicated mining conditions, related to mining geology, induced a more profound study of tectonic conditions. The basin is, in fact, heavily dissected into a system of blocks, in whose delimitation three main fault systems participate (Nedjalkov, 1985): SE–NW (105–125°), NNE–SSW (15–35°), and E–W (90°). The Sokolitsa river is bound on the fault system limiting the basin from the southern side. The NNE–SSW system may be considered as overriding; of it, the horizontal displacements are characteristic. The Sazliyka river (Fig. 2) is bound on this system, limiting the basin from the western side.

The Sazliyka fault is an integral part of the Tvarditsa lineament, which is considered by Bončev (1979) a typical structural collision zone between two lithospheric

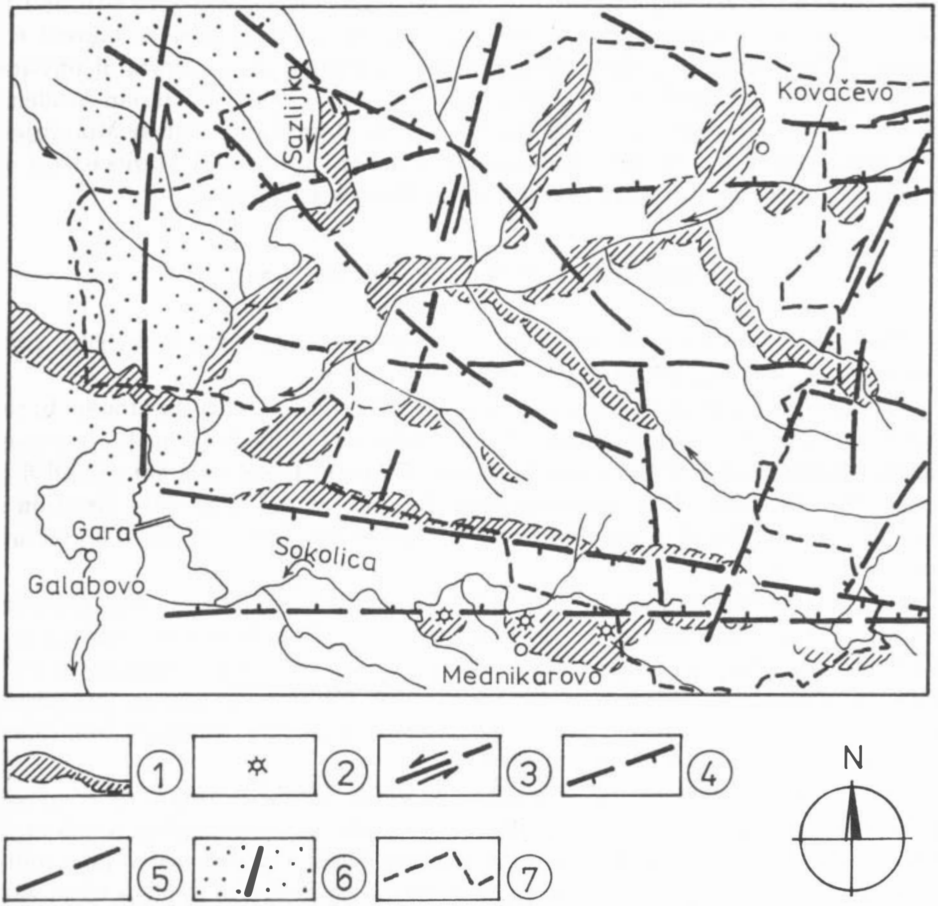

Fig. 2. Chart of the natural geodynamic processes within the area of the Maritsa-Iztok brown-coal basin (set-up according to information by Nedjalkov 1983, 1985). 1 – recent and fossil landslides, 2 – mud volcanoes, 3 – lateral strike-slip fault, 4 – normal fault, 5 – unspecified fault, 6 – Sazliyka fault zone, 7 - limits of the brown-coal basin.

plates in SE Europe. The Tvarditsa line has the character of a transform fault, evolved in the late Alpine tectonic cycles. During the other epochs, this lineament had the character of a right- or left-lateral strike-slip fault. Alterations in the behaviour of the lineament can be understood as consequences of force action within the mobile space between the two lithospheric plates.

The Sazliyka fault was investigated in detail by Nedjalkov (1983). The in-situ research proved horizontal displacements along the fault of 2 to 3 km and also the left-side rotation of one partial block.

The knowledge of the course of the collision zone apparently enables the directions of main stress in the surrounding space to be determined. However, recent research results from Northern and Central Europe demonstrate that such a conception is erroneous. During the last two decades, the field of recent stress state has been associated here with the collision zone between the African and Eurasian plates. Becker and Paladini (1990) are deducing that the regional stress state field in Northern and Central Europe is not related to the course of collision zones, being rather related to convection currents in the asthenosphere. Regional stress alterations are explained by the topography of the contact lithosphere-asthenosphere. Therefore, it would become ineffective to make an interpretation of the main orientation of the maximum horizontal stress in the area of the Tvarditsa lineament. As well, it is impossible to do it without appropriate in-situ stress measurements.

A somewhat different picture of the tectonic structure of the territory than that resulting from works of Bončev (1979, 1982) and Bončev *et al.* (1982) is obtained from results of remote sensing of the Earth. Gočev and Mamova (1977) state that the actual tectonic activity is genetically connected with seismoactive faults and blocks. They illustrate large horizontal displacements along most of the recorded faults. The Maritsa-Iztok basin lies, according to Gočev and Mamova, on the Radnevo block. In their map, the authors mark also directions of the actual horizontal displacements as well as the rotation sense of partial blocks.

If we accept the statement that the Sazliyka fault together with the accompanying parallel faults has the character of a lateral strike-slip fault, then all main deformation manifestations in the Maritsa-Iztok basin can be considered as pertinent to that fault zone. This is in good agreement with general information on strike-slip deformations (Christie-Blick and Biddle, 1985), when the lateral movements are accompanied, within the wider adjacent zone, by formation of grabens, horsts, mounds, thrust faulting, and also rotation of blocks and their slanting.

The block movements in the basin territory have been occurring from the Pliocene up to now. While exact data on horizontal shifting of tectonic blocks are missing, data about vertical movements are available though they differ from various sources. Dobrev and Stanoev (1985) summarized data on vertical movements of the Earth's crust from different Bulgarian authors. According to Totomanov, Vrablyanski and Mladenovski (1979, in Dobrev and Stanoev, 1985), the Maritsa-Iztok basin lies in a zone with uplifting trend of +1 to +2 $mm.yr^{-1}$; according to Kanev and Mladenovski (1973, in Dobrev and Stanoev, 1985) in the zone of 0 to +1 $mm.yr^{-1}$. These data should be considered as global, related to the whole territory of Bulgaria. When comparing them with the levelling results on local networks, apparent inconsistencies can be found.

The territory belongs to areas with the highest seismicity in Bulgaria. According to Bončev (1982), it lies in one of the two zones with the highest seismogenic potential. The lines of two first-order lineaments and flancs of the Diagonal Swell are crossing in this zone.

One factor decisive for the *seismic risk* exposure of the territory is the occurrence of seismic disjunctive knots. Such a knot lies close to the village of Gara Galabovo, where the epicentrum of an earthquake with intensity of 9 to 10 grades has been historically recorded (Ivanov and Gečev, 1965). There is an intersection of the fault zone Sazliyka, which is part of the Tvarditsa lineament, with the Sokolitsa fault zone. According to the chart by Kostadinov, Karagjuleva and Reisner (in Bončev *et al.*, 1982), this intersection of faults is considered a 3rd order disjunctive knot.

According to Gočev and Mamova (1977), who evaluate the seismic activity of the territory on the basis of satellite photographs, the Radnevo block carrying the Maritsa-Iztok basin ranges among blocks with the highest seismic activity in Bulgaria.

The Maritsa-Iztok basin must be considered as an active tectonic zone with a high dynamic potential. Actually, the activity manifests itself by movements of subgrade floes, by increased seismicity, formation of mud volcanoes, and also by the development of unusual landslides on very gentle gradient of slopes.

3. LANDSLIDES ON NATURAL SLOPES

The slopes of some water streams, only gently cut into the smooth relief, are affected by slow sliding movements at an unusually gentle gradient. For example, the sliding slopes along the Sokolitsa river have a gradient of only around 1°30′. This territory lies within the zone of an active fault line, with the occurrence of mud volcanoes. More frequent are old and/or buried landslides, discovered in the open-pit coal faces or in trial holes. It is typical of all these landslides that they have a translatory character and that their occurrence is largely connected with slides encountered during the operation of open-pit mines and waste dumps. Individual landslides cover the area of several km^2 and attain, exceptionally, depths exceeding 100 m.

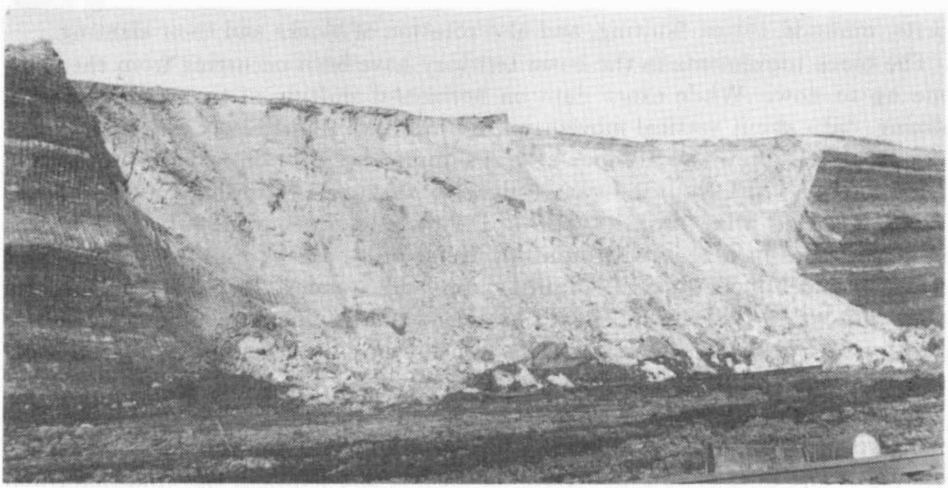

Fig. 3. Graben in the upper part of the coal seam filled by overlying claystones; fossil landslide documented in open-pit mine Trojanovo 1. Photo J. Rybář.

The author had the opportunity to document a fossil deformation of translatory type, matching the scheme in Fig. 14A, in open-pit coal mine Trojanovo 1 (Rybář, 1971). In the documented face, a steep overthrust in coal was discovered. The top of the overthrust was cut off by the erosion of a young river stream, whose bed was filled with clayey and sandy fluvial accumulations. The bulging of anticline evidently continued through the settling time of the lower parts of fluvial deposits. The continuity of the coal seam was interrupted about 250 m from the reverse fault site and the space was filled with overlying clays and claystones (Fig. 3). At a distance of 500 to 600 m from this site, another interruption of the continuity of the seam could be observed. The interruption was accompanied with several open cracks steeply dipping towards the driving-out site. The cracks were concave-arched and frequently opened 10 to 30 cm (Fig. 4). Deformations were bound only to the upper part of the coal strata measures. The lower part of the seam, separated by a clay position, remained untouched. The depositing conditions were evidently faulted during the relieving process of the seam by fluvial erosion.

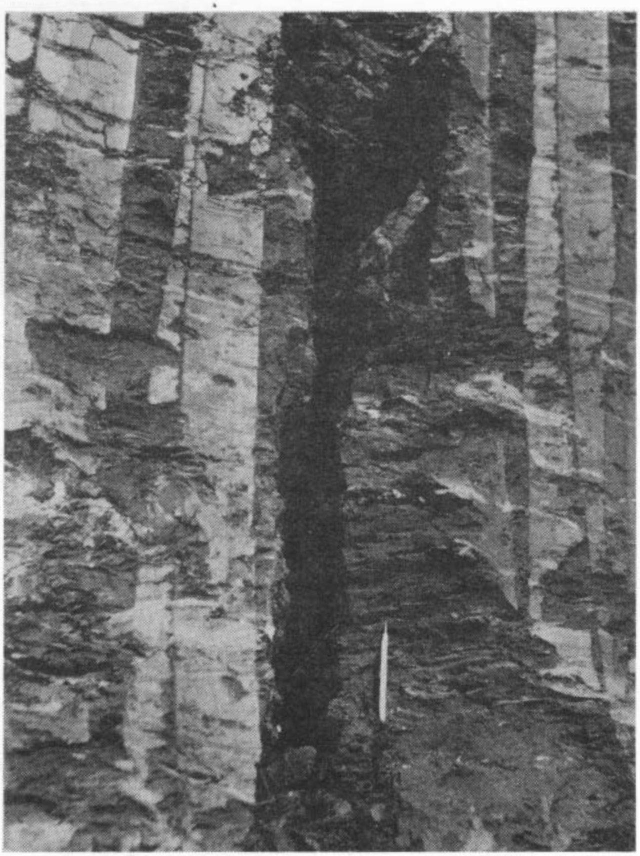

Fig. 4. Illustration of one open crack found in the graben's (from Fig. 3) hinterland. Photo J. Rybář.

Fossil landslide deformations in various development stages could be observed in open-pit mine Trojanovo. Fig. 5 shows the beginning of a graben in the coal seam. White-to-grey parting bands in the coal dropped, in the meantime, by 10 to 20 cm.

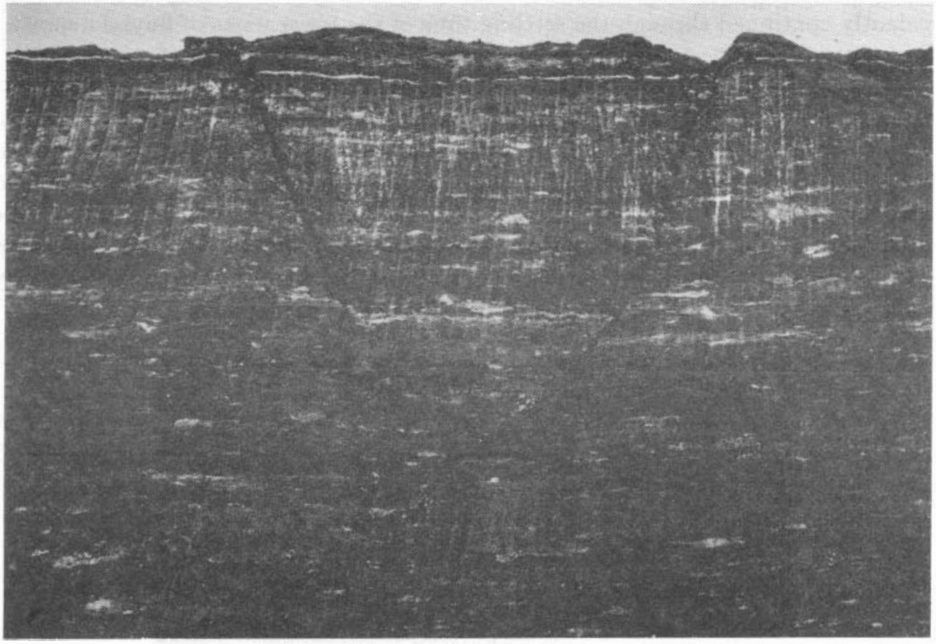

Fig. 5. Radical area of the graben at its initial development stage; coal is permeated with white-grey partings. Photo J. Rybář.

Similar sliding processes take place also nowadays on both the natural slopes and the man-made ones. While, when relieving the coal seam by a man-made cut, the deformations in the open-pit mine occur quite suddenly, under natural conditions the denudation processes cause deformations of a long-term character.

The expansion of landslides on natural slopes in the basin and their connection with neotectonic movements were discussed by Nedjalkov (1985). He entered both the verified and supposed landslides in Fig. 2. Evidently, he had not sufficient supporting data to distinguish between the fossil landslides and the recent active or temporarily calmed-down ones. The slope processes are considered as a result of the action of fossil as well as recent endogenic and exogenic processes. Fig. 16 illustrates an example of the fossil landslide relict connected with the fault zone of the Sokolitsa river.

Nedjalkov draws the important conclusion from his work, that the landslides are bound exclusively to the territory with the occurrence of productive coal-bearing sedimentation, which is, at the same time, territory with the tectonically most shattered subsoil. He reports that there is no other territory with a Tertiary cover, tectonically broken to such a degree as the coal-bearing area. This can be, of course, commented by the fact that such a conclusion can be affected by the much lower volume of research of areas beyond the coal basin. Important is the statement that slide surfaces are mostly connected with intermediate seam contact zones. Not infrequently, the slide surfaces are slightly dipping against the slope. The slide surface of most landslides is bound to thinly stratified claystones ("schistous clays") between the 2nd and 3rd seam. Exceptionally, the slip surface is found beneath the 3rd seam or in slate bands in the uppermost seam. Landslides connected only with overlying sediments are less frequent, and they have never the character of translatory landslides.

4. SLOPE FAILURES IN OPEN-PIT MINES

Most affected by slope failures was open pit Trojanovo 2. The first catastrophic landslide took place in August 1964, when the cutting for the mine railway plunged into the 2nd coal seam. However, a slight bulging of the cutting floor had been observed already before the earthworks reached the coal seam. In the final phase, a mound about 15 m high and 800 m long was driven out of the cutting floor (Fig. 6).

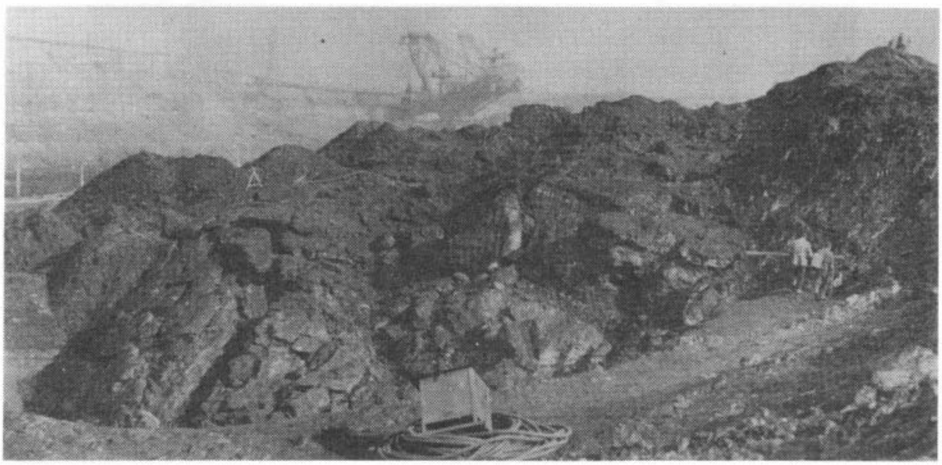

Fig. 6. Mound in coal driven-out in open-pit mine Trojanovo 2 during the landslide in 1964. Photo J. Rybář.

A wedge-formed graben (10 to 15 m deep and 45 to 50 m wide) was formed about 400 m off the mound, in the upper part of the slope. The intermediate part of the slope shifted horizontally (Fig. 7) by up to 11 m towards the mound. The horizontal slip surface ran about 3 to 5 m below the 2nd coal seam, as established later. After appeasement of movements, there was a general concern that a new breakdown could occur after continuation of sinking the cutting into the coal seam. However, new deformations did not occur till 1966, although the slope gradients were substantially steeper than those of the broken-down slope.

A similar slope failure took place in January 1966. After cutting into the coal seam, the coal was driven out, during several hours, in the form of an anticline. At a distance of about 500 m from this mound, a large graben ("fault trough"), about 130 m wide, was formed. The general slope gradient varied within 5° to 11.5°. The depositing conditions were checked by several drill holes and the approximate depth of failure was established. The failure was connected with claystones beneath the coal-bearing base. It could be established that these claystones did not exhibit any extremely low strength parameters. Ivanov (1970) quotes that, with shear strengths confirmed for individual rock types by tests, the resulting degree of slope stability was not lower than 2. He also noted that the slopes of individual cuttings in coal and in overlying claystones remained stable at heights of 18 to 20 m even at as high slope gradients as 70° to 80°. The correctness of the profile was confirmed in 1967 when the exploitation exposed both the slide-on surface on the site of anticline and the marginal faults of the graben in the separation area of the landslide.

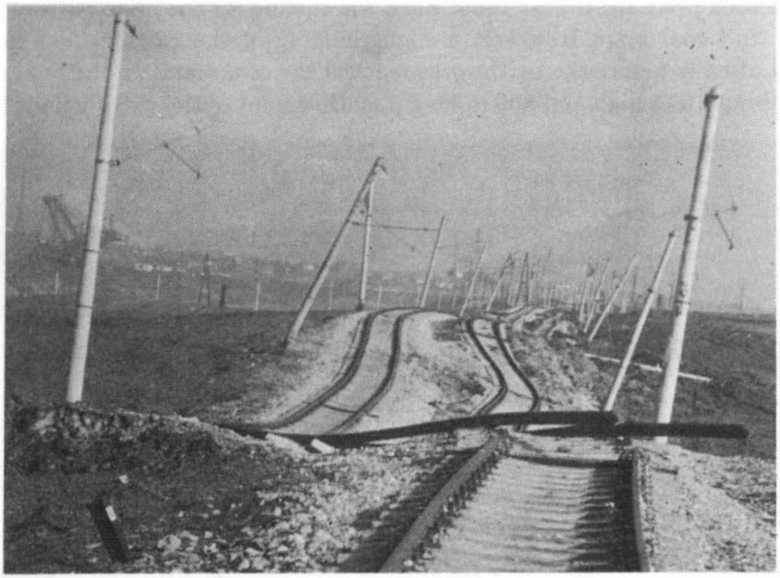

Fig. 7. Displaced rails in the central part of the landslide in open-pit mine Trojanovo 2 in 1964. Photo J. Rybář.

The *largest slope failure* in the same open pit occurred in 1968. After a preparatory phase lasting about five months, the main movement took place during four hours on December 25, 1968. The next day (December 26), the movement practically calmed down. In the upper part of the slope, three parallel ditches were formed and a mound was driven out in coal at the pit bottom which, on the counter-slope, leaned against the internal waste dump. The profile of this landslide was described by Georgiev *et al.* (1974). The area of 1.4 × 1.0 km has been affected by this slide. A horizontal displacement of 100–110 m was observed in the central part of the slope. Owing to the fact that the limitation of the slide on flanks was not parallel to the movement, a lateral mound was formed on the left flank of the landslide (Fig. 8) and, contrary to that, an empty trough was formed on the right flank. The volume of moved rocks is evaluated at 55 million m^3, out of which 18.5 million m^3 was coal. General slope gradient prior to failure was 6°20′, superelevation 70 to 80 m. Out of the overall 1200 m length of the coal cut, the section of 1000 m was destroyed. The entire railroad transport in the mine was interrupted. Most excavators were removed in time, but some of them remained within the slide area. They were shifted horizontally without being damaged.

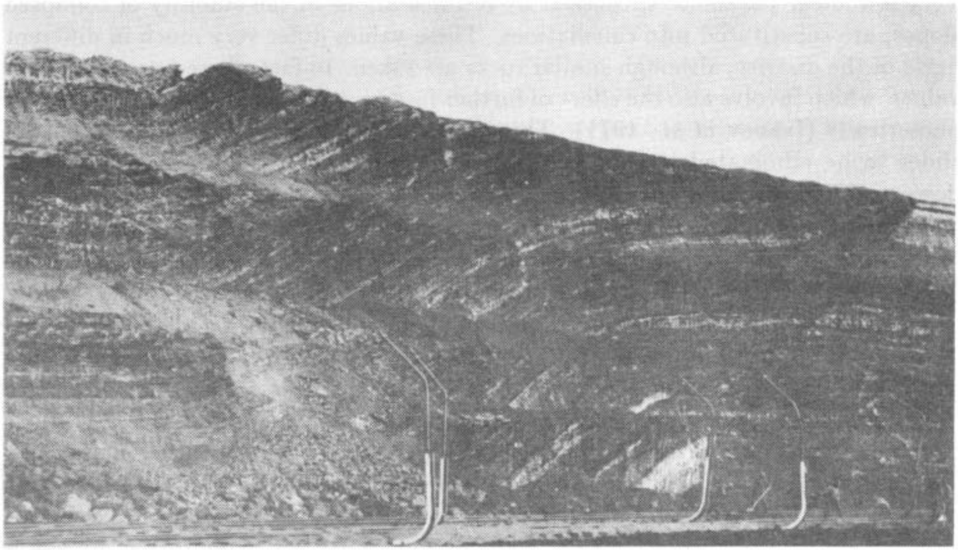

Fig. 8. Open-pit mine Trojanovo 2. During the landslide in 1968, the coal seam was slipped on the wall side; the thrust fault deformation was discovered later by excavation. Photo J. Rybář.

Some features typical of the landslides in open pits of the Maritsa-Iztok basin can be met also in lateral landslides of another genesis. For example, a lateral landslide afflicted the settlement point of Abbotsford (New Zealand), destroying 69 h

houses were not broken down, but displaced by 46 to 48 m. The sliding surface was bound to the contact between strata series of sandstones and clay inserts. In the development of this landslide, Bishop and Norris (1986) see an analogy with the rift and thrust tectonics.

The mechanism of the failure process at analogic slides in the Isar river valley in Bavaria was analyzed by Baumann (1985, 1988). Horizontal slide surfaces will follow some soft Tertiary claystone beds.

When calculating the stability of newly designed slopes in the Maritsa-Iztok basin, results obtained by recalculating the precedent landslides are considered. The *geometric form* of landslides is perfectly known. Behind the upper edge of the slope, a graben is being formed, limited in the overlying claystones by surfaces dipping 50° to 55°, in coal with a gradient of about 60°. The wedge thus formed sinks (Fig. 1e). The intermediate block is shifted along the surface parallel to the strata layers situated in claystones between the 2nd and 3rd seam. In most cases the depositing is subhorizontal, sometimes even with a slight dip against the slope. A mound is usually formed in the forefield of the toe of slope, the slide surface cuts the coal seam at a dip of around 30°. In calculations, an equilibrium condition of active and passive forces acting on the intermediate block (Georgiev, 1969) is considered as basis. The weight of the graben-filling wedge is applied actively. Very low shear parameters, checked by re-calculations of the stability of collapsed slopes, are substituted into calculations. These values differ very much in different parts of the district, although similar rocks are taken. In fact, these are contractual values, which involve also the effect of further factors, which cannot yet be expressed numerically (Ivanov *et al.*, 1971). This procedure enabled the dangerous forms of slides to be eliminated to minimum, even if at the price of flattening the slopes down to 3° to 5°.

Special methodological instructions were issued for the slope formation within the Maritsa-Iztok basin in 1981. Actually, also the updated computing technique (Zlatanov and Stoeva, 1990) is used for solving problems of slope stability.

In order to moderate the adverse effect of slope flattening on the effectiveness of exploitation, procedures, which do not exclude the origin of slow slope deformations, were tested in individual sections of the basin. They rather allow the slope deformations to take place in an extent that does not jeopardize the continuity of the exploitation process (Mitev, 1987). A permanent control surveying became an integral part of exploitation in less stable parts of the basin. After attaining a certain boundary value of the deformation rate, for example 6 mm × 24 hrs^{-1}, or a certain total deformation (e.g. 500 and 1500 mm), the exploitation process is re-scheduled.

5. WASTE DUMP FAILURES

A difficult problem in the Maritsa-Iztok basin is presented also by the stability of waste dumps, namely the external ones, in whose subsoil there lies the unexploited coal seam.

Fig. 9 shows a simplified profile of a waste dump, the dumping on which activated (in 1966) ancient and/or actual natural sliding movements. In 1967, a mound 40 m high was driven in the valley bottom, exactly in the zone, where originally a

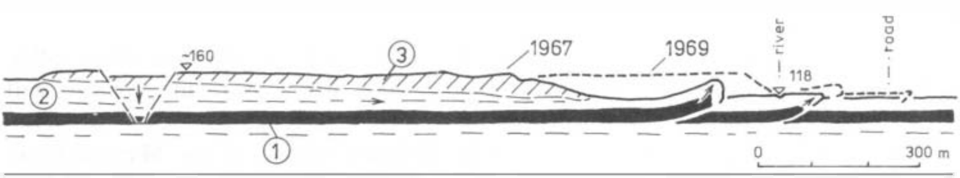

Fig. 9. Schematic profile of the displaced spoil bank.
1 – clays, **2** – clays and claystones, **3** – spoil bank.

duplication of the coal seam was established. According to topographic charts there was a low elevation at the site of the main mound already before the dumping began. This means that there was a natural deformation taking place while the slope gradient reached only about 1°30′. In October 1969, the mound was already covered by the waste dump. The driving-out expanded into the forefield of the waste

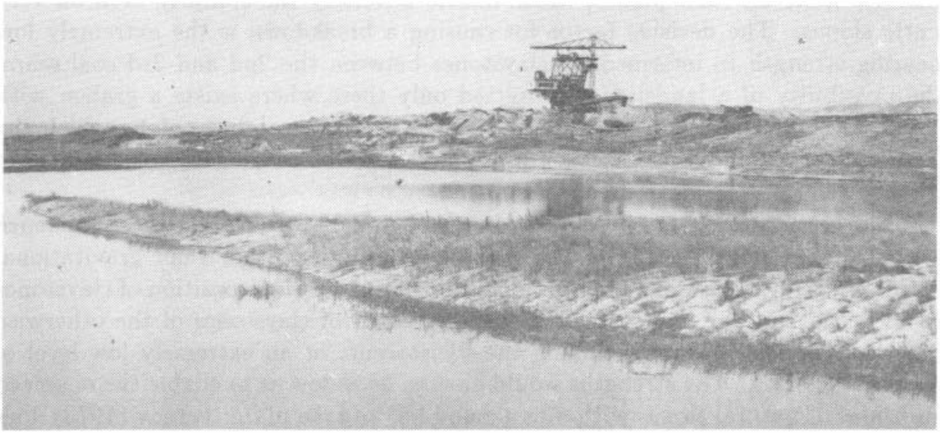

Fig. 10. Driving out of mounds in the forefield of the spoil bank closed a small river bed; a lake was formed. Photo J. Rybář.

dump. The river bed was buried, a lake formed (Fig. 10), and communications were interrupted. The movements in the waste dump propagated and calmed-down very quickly. As soon as the overburden dumping machine interrupted dumping in a certain area, almost immediately the deformation in the surrounding area calmed down. This corresponds with the conception of an elastically reacting coal seam in the bedrock. However, the deformation was attributed only to the reduced strength on ancient fault planes. The general dip between the facial mound and the graben in the separation area was below 2° (1°50′). According to the author, the deformation cannot be explained without the existence of endogenic factors. It was also confirmed that it was impossible to dump waste successfully on a slope that had been involved in movement already before dumping.

Some similar features are characteristic of the case that occurred at the village of Mednikarovo on the basin's southern border. A fly-ash mud settling pond was constructed here on a very gentle slope. The original slope dipping below 2° was interrupted by both the fossil and recent sliding movements. The construction of the pond's dam induced the surcharging of the intermediate slope part with the occurrence of slide grabens, and subsequent very pronounced revival of slope movements. The coal seam in the river bed of the Sokolitsa river was driven out in the form of anticlines. Mud volcanoes alternatively appeared and became extinct. The sliding, unusually gentle slope lies on the northern border of a tectonically uplifted floe limited by an active fault zone in E–W direction, against the subsided floe of the brown-coal basin.

The prevailing opinion may be summarized as follows: The depositing conditions in the brown-coal Maritsa-Iztok basin are impaired by ancient contact slide surfaces, systems of grabens and anticlinal mounds. Only residual shearing strength can exert its effect on fault planes, which affects adversely the stability even on very gentle slopes. The decisive factor for causing a breakdown is the extremely low shearing strength in intermediate claystones between the 2nd and 3rd coal seam. The possibility of a landslide is admitted only there where exists a graben with an effectively acting earth pressure and a stratified failure plane, along which the displacement takes place. A favourable orientation of cuts against the course of existing deformation structures is assumed.

However, according to the author, it is not possible to explain the occurrence of predisposed failure-prone planes without considering other than gravitational forces. Only in the case that we would admit that in a certain position of claystones between the 2nd and 3rd seam, the shear strength of claystones of the otherwise intact massif was always, including the Pleistocene, at an extremely low level of ultimate strength. The strengths would have to be as low as to enable the observed landslides of natural slopes with dips around 1.5° to take place. Ivanov (1970) does not exclude the fact that the predestinated shear planes can be a product of the action of residual stresses.

The author's own conception issues from the fact that the rock medium in Tertiary brown-coal basins is generally formed by three basic rock complexes, i.e. complex of coal sediments, complex of clayey sediments and complex of arenaceous sediments. Each of these complexes reacts in a different way when subjected to both endogenic and exogenic forces of the basin's filling. This is the case of a *rheologically differentiated medium*. The competent layer concentrates the stress and preserves its elasticity. The incompetent surrounding is unable to do it and retreats under the action of force without stress concentration. During the horizontal stressing of the sedimentary fill of the brown-coal basins, the function of the competent layer is taken over by coal.

When the basin sediments are laterally tectonically compressed, and also in the neighbourhood of faults with a subsidence trend, additional horizontal stresses (σ_h), proportional to the moduli of deformability of individual layers (Fig. 11a), arise in both the competent (A) and incompetent layers (B). These stresses are relaxed with time and such a relaxation can take place, in some clays, very quickly (σ_B). When unloaded (by river erosion, mine cuts or tectonic effects), the stress preserved in the competent layer is relieved. The forcing-out into the evacuated space (erosion of artificial cut, towards the tectonic depression) occurs. Because the elastic and viscoelastic strain component (Fig. 11b) of the competent layer (ε'_A) largely exceeds the strain of the incompetent layer (ε'_B), a continuous shear plane is always formed at the lower contact site. The overlying rock of the competent layer behaves passively and is deformed in dependence on the competent layer.

The above-mentioned conception resulted into a scheme explaining the development of translatory landslides within the Maritsa-Iztok basin (Fig. 1).

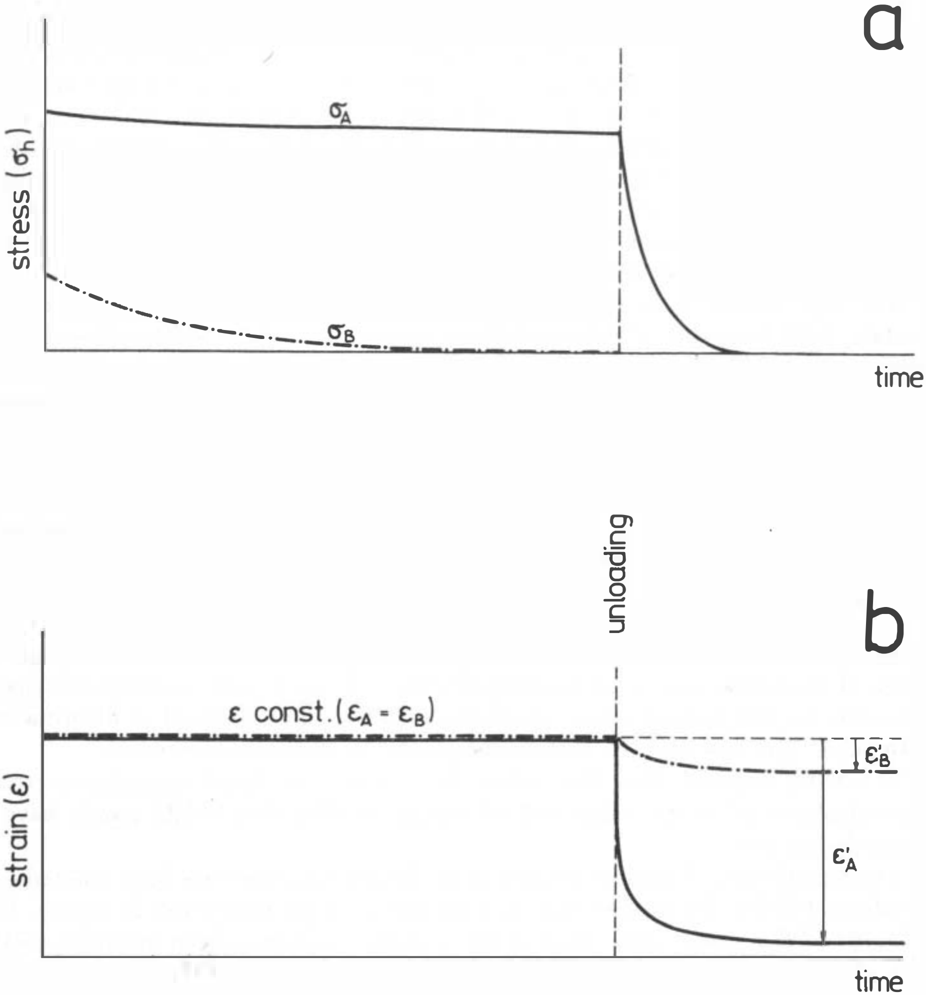

Fig. 11. Chart explaining the behaviour of a competent (A) and incompetent (B) layer in a rheologically differentiated environment. a – the time-dependent course of abnormal horizontal stress state, b – time-dependent course of deformation (strain) upon stress release.

In order to be able to include the conception of the effect of abnormal horizontal stresses on the stability of slopes into the factual solution of particular basin's sections, it proved necessary to prepare a simplified model of the stress state within the basin area and its neighbourhood. It is only to regret that no in-situ stress measurements were made and that we are lacking also the localized observation records of various stress state manifestations, observed during the exploitation. This concerns phenomena similar to those pointed to by P. Gečev during the first years of mining, such as elliptical flattening of the concrete fill in an old borehole or flattening of the profile of an opening drift into the coal seam.

Only an *ideal model of stress conditions* can be suggested. It results from the deductions of structural geologists, geophysicists, geomorphologists and, in particular, from Nedjalkov's studies, that the foundation of the basin and its Cainozoic cover consists of an unstable system of blocks of irregular shapes and sizes. Differential vertical movements are not alone to take place in this system, because there are also horizontal block displacements, rotation of blocks and their bevelling phenomena to be observed. The decisive structures for the behaviour of the system are obviously the faults in the Sazliyka zone, which have the character of lateral strike-slip faults, as well in the zone of Sokolitsa with a subsidence trend.

The *high seismic activity* of the area contributes also to the instability of the system. Joint Bulgarian-Czechoslovakian measurements in the seismoactive region of Krupnik in SE Bulgaria (Avramova-Tačeva and Košťák, 1986) reveal that the subhorizontal displacements along the tectonic fault planes occur, above all, during the seismic tremors.

It should be assumed that, in places, the pressure stress accumulates on contact planes of partial tectonic blocks, while in the sedimentary cover these stresses concentrate in the competent coal seam, which is evidently able to retain this stress and to transfer it to a longer distance. It has to be assumed that the stress field in the block system continues to develop and that there are, in addition to pressure zones, also zones of tension. Photoelastic models (Košťák, 1982) of the block systems confirmed that the stress field was changing with the omnidirectional compressive stress of the block system. A bearing skeleton is formed with concentrated stress sites next to deaf relaxed zones, the skeleton itself being subjected to deformation with time. The flow of force continuously looks for competent elements.

It can be deduced that there exist, in a coal seam, local compressive stress concentrations of recent seismotectonic origin, or that they might partly have a residual character.

The significance of residual stresses in the brown-coal seam has been pointed out by Mencl (1968). He proved that in both the open-pit mines and in nature, the relieving of this stress state affected the stability of slopes in the overlying rocks. It is recommended to leave the broadest possible gap between the upper coal face and the undermost overburden face. However, this principle cannot be applied in the Maritsa-Iztok basin, where landsliding does not occur only in the overlying rocks, but the shearing planes are situated under the seam. On the contrary, here the coal seam has to be charged, at the toe of slope, by a certain thickness of the overburden.

Dermietzel (1970) pointed to the possibility of considerable additional horizontal stresses originating along the oblique fault planes with active subsidence movements.

The effect of accumulated (latent) deformation energy on the stability of slopes was studied by Bjerrum (1967). He proved that the relieving of the latent energy accumulated in the competent layer resulted in reduced shearing strength on the contact with the surrounding rocks.

Some Bulgarian collaborators attempted to explain the unusual deformation of slopes with insignificant gradient by the occurrence of artesian waters in sandy lenses in the underlying clays. However, landslides took place also in areas where the effect of water under pressure could be excluded.

More serious is the objection that the horizontal stress state could eventually not be bound to the coal seam, but to clays and claystones in its bedrock. The interruption of the coal seam continuity in the separation zone beneath the graben could, in fact, agree better with the horizontal stress state in underlying clays. It is namely very difficult to imagine how such large extension zones could be formed in the compressed elastic layer after its relieving. Let us consider a model in the form of a compressed spring. After releasing one of its ends, the spring continuously extends without interrupting the continuity on its fastened end, although tensile stresses are acting here temporarily. A breakage of the spring could occur if the tensile strength of the spring material were too low. In the case of coal, also a zero strength could be considered at the tectonic fault site. In analogy with the coal seam, we cannot entirely reject the dynamic effect accompanying the stress state release towards the bottom of the cut, especially if very quick movements are involved. Far away from the cut, the coal seam can be broken by tensile stress, whereby the deformation grows more pronounced, during the next stage, by the gravity effect of the wedge of overlying rocks thus formed.

The existence of residual horizontal stress in clays outcropping at the toe of the slide was established and confirmed by measurements by Mencl (1967) in Paleogenic claystones in W Slovakia. The failure mechanism was much similar to the Bulgarian case. An anticline was forced out at the bottom of the cut and, far beyond the upper edge of the slope, a graben was formed. The intermediate part of the slope was shifted horizontally towards the incut (Záruba and Mencl, 1982).

In addition to that, the author considers the following facts a proof of the existence of horizontal stress in the coal seam in the Maritsa-Iztok basin:

- Unusual deformations are encountered only on slopes where the coal seam lies at the slope toe or close beneath the valley bottom. The composition of overlying layers, their physical and mechanical properties, and morphology of the slope do not affect the development of deformations.
- Deformations are encountered only in certain zones of the basin, evidently in concentration zones of seismotectonic stress. Sliding always occurs only on one side of the cut. After calming of movements, slopes remain stable also at steeper gradients than those which produced the deformations.
- At sites, where catastrophic slope failures will occur later, manifestations of stress state relief can be observed in coal faces. This concerns small horizontal sliding-on at the bottom of coal incuts[1], flaking-off in the coal faces, development of cracks on the surface of coal seam.

[1] Swelling of coal layers and flaking-off at the bottom of coal faces (Fig. 12), accompanied by sonic effects, have been observed by the author in the brown-coal basin of Belchatów in Poland; they are considered a proof of increased tectonic stress. The open-pit mining of coal within a narrow tectonic graben close to Belchatów caused phenomena of induced seismicity (Rybář, 1988).

- Two drifts in the coal seam, driven from an exploration pit and perpendicular to one another, were found deformed. The profile of one of them was flattened by horizontal pressure. Similarly, an old drill hole filled with concrete mixture, was discovered in open-pit mine Trojanovo 2 and its cross-section was flattened into an ellipse.

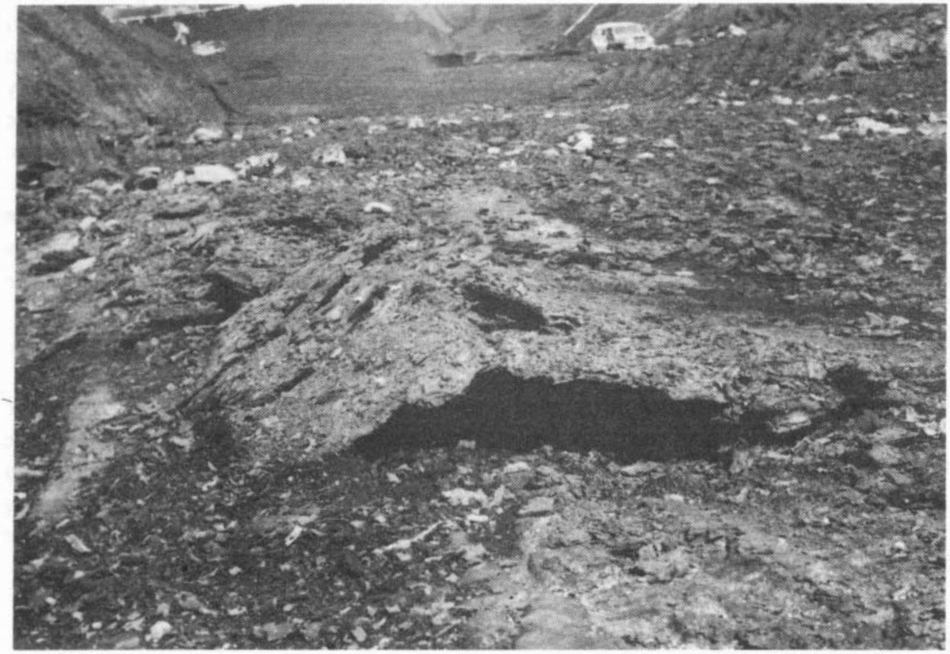

Fig. 12. Bursting of coal plates at the bottom of open-pit mine Belchatów in Poland. Photo J. Rybář.

- The largest slope movements on natural slopes with unusually gentle gradient (around 1°30′) take place in the tectonically exposed southern border of the basin.
- The concept illustrated by Fig. 1 was confirmed also by physical modelling.

7. MODELS OF LATERAL SLIDES

Physical models, which the author conducted at the Institute of Soil and Rock Mechanics of the University of Karlsruhe with the support of the Alexander von Humboldt-Stiftung (Rybář, 1974), contributed much to the understanding of the mechanism of development of lateral slides. The study concerned the case of slides affected by relieving the horizontal stress concentrated in the elastically reacting layer at the foot of the slope. The arrangement of the mechanical model experiment is evident from Fig. 13. The competent layer, in nature consisting of a coal layer,

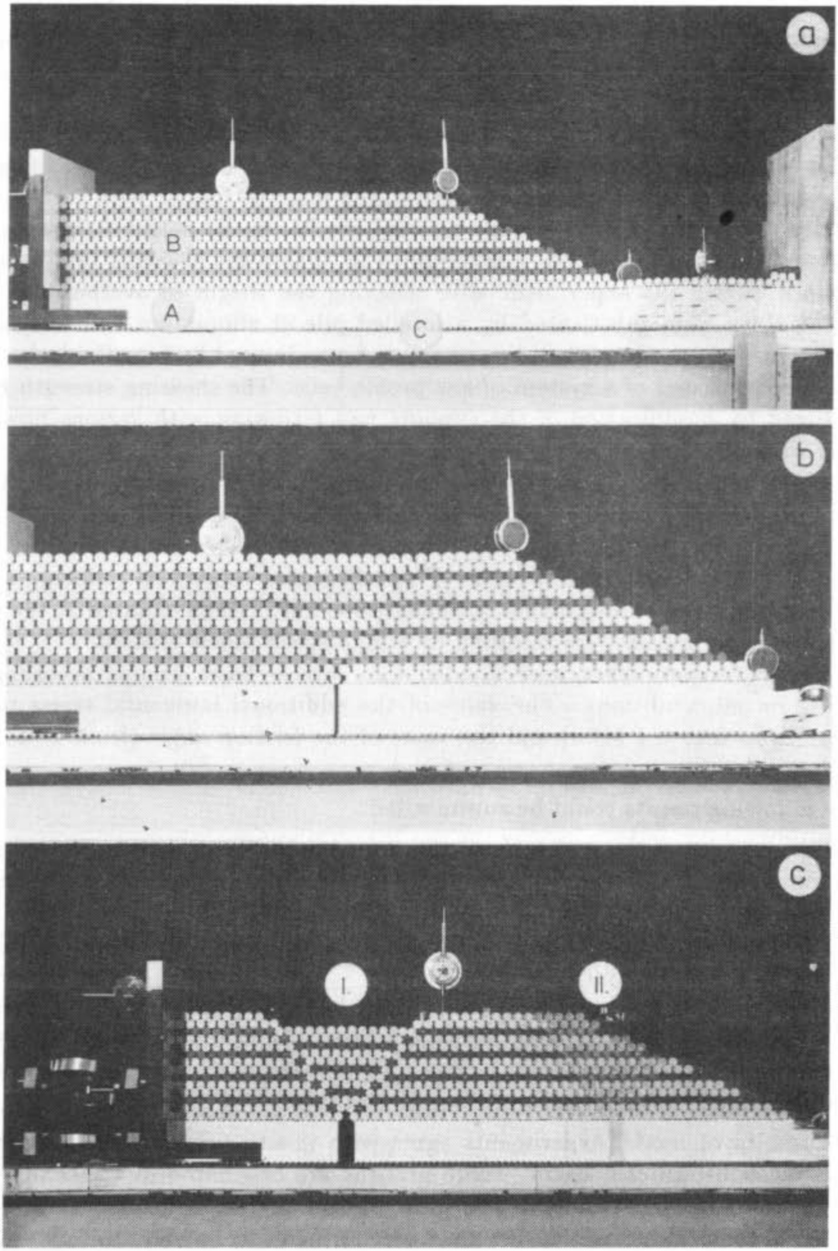

Fig. 13. Model experiments of translatory-type (lateral-type) landslides. a – swelling of the cutting bottom; b – in the slope's hinterland, a graben has just been formed, the intermediate block has been displaced; the direction and the extent of displacement are evident from the displacement of white marks on bells; the additional horizontal stress was relieved already before, which triggered the formation of graben I; with continuing excavation, graben II begins to develop.

was substituted, in the model, by layer A made of tiny blocks of elastic Silopren (synthetic material). In the direction perpendicular to the model plane, the blocks were reinforced by a metallic wire, thus reducing the three-dimensional problem to a bi-dimensional one. The model scale was 1 : 250.

During the short-time loading of the model experiment, the Silopren material behaved elastically, the viscoplastic strain component being negligible. The low tensile strength of the coal seam was introduced into the model, with certain simplification, by means of vertical gaps between blocks. In the neighbourhood of the steady rest, the form of blocks was modified to enable the shearing failure which took place during the experiment after relieving the weight of overburden. The overlying clays were substituted by a levelled pile of aluminium bells (layer B). The movement of the lower bell line on layer A was limited by "road" blocks. The sliding face consisted of a system of low-profile bells. The shearing strength could be changed by modification of the support pad (strewing with various powders, coating with oil, etc.).

Layers A and B were gradually horizontally compressed by means of the mobile follow rest. After attaining the predetermined horizontal additional stress, the relieving has been started close to the fixed rest, following a pre-determined time schedule. The deformations of layers A and B during individual relieving stages were measured. The photographic documentation has been effectuated at the same time; some experiments were recorded by a high-speed movie camera.

The model experiments were divided into several basic groups according to changing initial conditions. The value of the additional horizontal stress to the A layer (from 0 to 0.4 MPa) and the value of the friction angle (from 1° to 16°) were changed.

The following results could be summarized:

a) The distance of the graben from the slope toe increases with increased additional stress. In an extreme case, the entire model mass withdrew from the mobile follow rest.

b) The distance of the graben from the slope toe increases with decreasing friction resistance in the slide layer.

c) After relieving the horizontal stress state during formation of the graben and the front mound, another graben develops in the neighbourhood of the slope toe, when continuing the stress relieving. The position of this secondary graben changes only in dependence on the resistance in the slip layer.

The results of model experiments agree with in-situ field observations in the Maritsa-Iztok brown-coal basin, where grabens are originated at unusually large distances from the front mound. The most distant graben is formed as first one, while the grabens closer to the slide face were formed successively. In this way, the slides induced by horizontal stress relieving differ from the translatory landslides following the seismic effects in sensitive clays at the town of Anchorage. There, the movement propagated retrogressively from the slope toe towards its hinterland. This has also been confirmed by model experiments, reported by Seed and Wilson (1967).

Verified deformation types of the sedimentary fill of brown-coal basins, related to relieving of tectonic stress, are shown in Fig. 14.

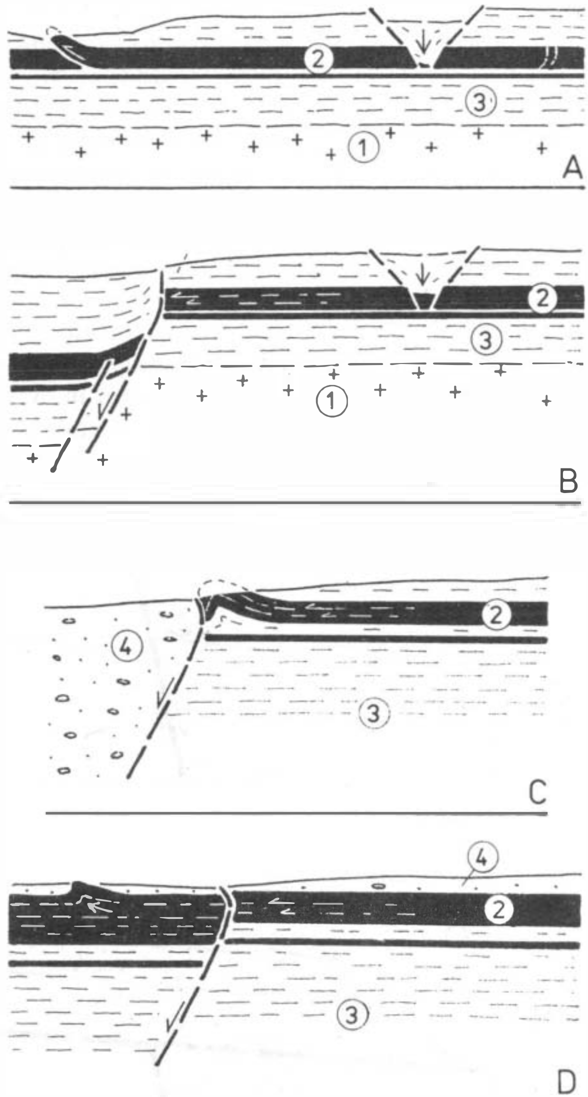

Fig. 14. Types of gravitational deformations (A to D) of sedimentary fill of brown-coal basins, related to tectonic activity upon blocks of the disintegrated subgrade structure. 1 – foundation, 2 – coal, 3 – mostly clays and claystones, 4 – mostly sand and gravels.

A. Lateral slides of an integrated coal seam (Fig. 14A)

A horizontally deposited coal seam under tangential stress behaves, compared with clays and sands, as an elastically reacting layer with the ability to accumulate considerable elastic energy. The relieving of this stress state takes place when relieving or failing the integrity of the coal seam by natural or artificial cuts, and is accompanied by deformations, which, in the case that there exists, in the bedrock, a layer with much lower shearing parameters, have the character of lateral landslides. Such deformations are schematically shown in Fig. 1.

B. Lateral slides at the borders of tectonic grabens (Fig. 14B)

Gravity lateral-type deformations are originated, in the basin fill reinforced by a competent coal layer, also on the occasion of stress alterations due to local tectonic subsidence. Several practical examples were verified by the author, together with J. Dudek (Rybář and Dudek, 1976) in open pit mines ČSA and Merkur in the North-Bohemian brown-coal basin. In consequence of the recurrent movements of subsidence character during the geological history at the site of the local tectonic depression and in consequence of uneven compression of underlying and intermediate (between seams) clayey and arenacenous sediments, partial gravitational movements took place. From the elevation zones, the rock masses pressed their way towards the depression zones according to the scheme in Fig. 15. The movements were effectuated along the stratified slipping planes bound to clayey inserts within the coal seam and/or to the stratification in overlying claystones. The overlying claystones are pervaded with systems of grabens, bounded by oblique antithetic shear planes.

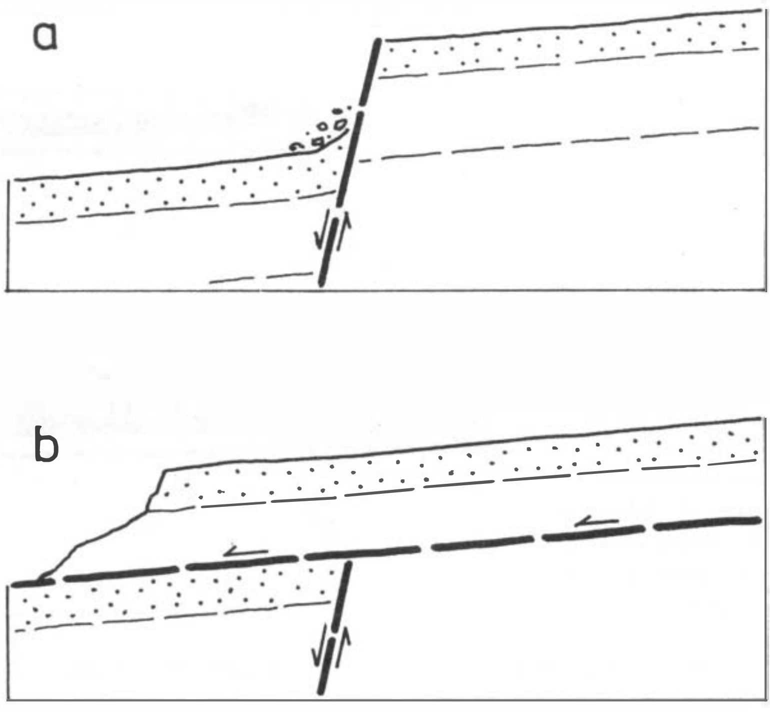

Fig. 15. Chart explaining one case of the transformation of vertical tectonic movements into tangential gravitational movements.

Vertical tectonic movements is also a possible cause of the case quoted by Nedjalkov (1985) from the southern border of the Maritsa-Iztok basin (Fig. 16).

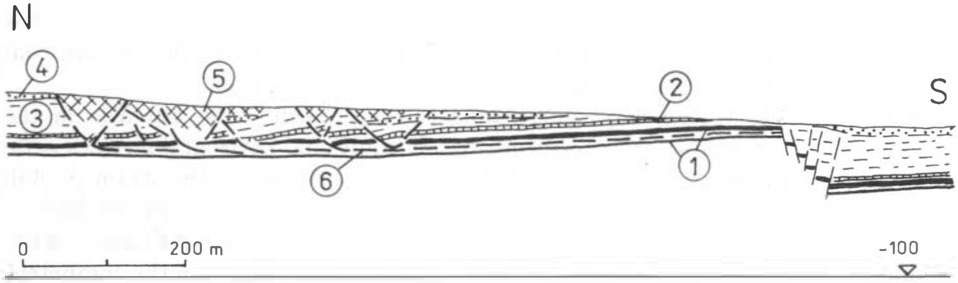

Fig. 16. Profile of the fossil landslide on the right bank of the Sokolitsa river (modified according to Nedjalkov, 1985). 1 – coal, 2 – coal clays, 3 – overlying mostly clayey sediments, 4 – fluvial sediments, 5 – heterogeneous fill of the wedge-like depressions, 6 – sliding surface.

C. Seam folding in an elevated block (Fig. 14C)

A special case occurs when the sinking fill of a tectonic graben is formed of incompressible sands and gravels. The expanding coal seam from the elevated tectonic block is pushed up, at the site of minimum overburden, towards the surface, and is folded. Such a case was documented in the Lower-Rhine basin by Quitzow (1958).

D. Folding of a coal seam in a downwarped block (Fig. 14D)

Quitzow (1963) documented also the case of folding of upper positions of the coal seam along a tectonic fault in a slightly depressed block. Relieving of the stress state towards the sinking block is manifested by the pressure from the elevated block on the fill of the sinking block. The fault faces are overturned and interstratal shifts and folding take place.

9. CONCLUSIONS

Translatory landslides are a relatively rare phenomenon, but the damage caused by them is not negligible. Such landslides are usually very deep and extensive, with the volume of the involved mass up to several tens of millions m^3. Morphological shapes of recent landslides of the translatory type are conspicuous. They have, in artificial cuts, usually a catastrophic character.

The translatory landslides affecting the Maritsa-Iztok brown-coal basin in Bulgaria have a specific character. Failures of natural slopes, open-pit faces and spoil-banks have been documented at unusually gentle gradients (sometimes below 2°). According to the author's work, the stability of slopes is evidently affected by abnormal horizontal stress state of seismotectonic origin. His conception is supported by the fact that the rock medium in Tertiary brown-coal basins is generally formed from three basic rock complexes, namely complex of coal sediments, complex of clayey sediments, and complex of sandy sediments. Each of these complexes reacts differently to the action of endogenic and exogenic forces on the basin fill. The competent layer concentrates the stress and preserves its elasticity. The incompetent adjacent layers are unable to do it and retreat under the action of force without stress concentration. When horizontally stressing the sedimentary fill of brown-coal basins, the function of the competent layer is taken over by coal.

When laterally tectonically compressing the basin sediments, but also in the neighbourhood of faults with subsidence trend, additional horizontal stresses arise in both the competent and incompetent layers, proportional to the strain moduli of individual layers. Upon relieving, the stress preserved in the competent layer is released and the mass is forced out into the loosened space. The overburden of the competent layer behaves passively and is deformed in dependence on the competent layer.

The existence of abnormal horizontal stresses in the coal seam of the Maritsa-Iztok basin is documented, by the author, by the following facts:

- Unusual deformations are observed only in those slopes where the coal seam lies at the slope's toe or close beneath the valley bottom. The composition of overlying layers, their physical and mechanical properties and the morphology of slope do not affect the development of deformations.
- Deformations originate in certain zones of the basin, obviously in concentration zones of seismotectonic stresses. Slope failures occur always on one side of the cutting only. After the movements have come to rest, the slopes remain stable even at much steeper gradients than those leading to deformations.
- Manifestations of stress state relieving can be observed on coal faces on sites where a catastrophic failure will occur later.
- Two drifts into the coal seam, perpendicular to one another, and driven from a well pit, were found deformed. The profile of one of them was flattened by horizontal pressure. An old drill hole, filled with concrete, was found with the profile elliptically flattened.
- Most extensive slope movements on natural slopes with unusually gentle gradient (around $1°30'$) occur in the tectonically exposed basin part at its southern border.

Fossil deformation forms of sedimentary fill of brown-coal basins are usually hardly distinguishable during the surveys. When designing artificial slopes in sediments faulted by such forms, the fact should be considered that some adequately oriented systems of stratified and oblique fault planes can lead to the formation of zones where the total shearing strength approaches the residual values. Calculations of slope stability, which would not take account of the occurrence of ancient predetermined surfaces, could involve erroneous conclusions.

In seismically and tectonically active areas, to which also the Maritsa-Iztok basin belongs, it is important to document all phenomena of increased stress and/or provide for their in-situ measurements. Designing of slopes in such areas is very difficult. Empirical methods proved competent in Bulgaria.

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K PŮVODU TRANSLAČNÍCH SESUVŮ V PÁNVI MARICA-VÝCHOD V BULHARSKU

Jan Rybář

Pro hnědouhelnou pánev Marica-Iztok v Bulharsku je typický výskyt translačních sesuvů neobvyklých rozměrů. Jsou postiženy svahy uhelných lomů, svahy výsypek i přirozené svahy podél vodních toků. Výzkumem příčin porušování svahů v pánvi Marica-Iztok se rovněž zabýval autor, který přisuzuje rozhodující vliv uvolňování abnormální horizontální napjatosti seismotektonického původu.