SLOPE MOVEMENTS IN THE WEST CARPATHIAN GEOLOGICAL-TECTONICAL UNITS

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Lejtőmozgások a Nyugati-Kárpátok geológiai-tektonikai egységeiben

Introduction

In the West carpathians there exist in general favourable geological, hydrogeological, morphological and climatic conditions for the occurrence of slope movements. Only in the territory of Slovakia there were registered and mapped by systematic engineering geological investigation approximately 5.800 slope deformations which cover an area of 850 km^2. Many of them cause destruction of or threaten the roads, railways, houses and other engineering structures. From all present geodynamic phenomena in the Czechoslovak West Carpathians part, the slope movements affect very seriously the environment and landscape. The demages caused by slope deformations are a serious problem mainly in the territory of Slovakia. It is why a great attention is devoted to the study of slope movements.

The impulse to start the engineering geological investigation of slope movements was the landslide which in December 1960 destroyed part of the mining town of Handlová (Záruba-Mencl, 1969). In the years of 1962-63 a systematic registration of landslide areas in Czechoslovakia was carried out (Matula-Nemčok, 1966). The registration was followed by a coordinated investigation of the conditions of occurrence and development of landslides and of other slope movements, which was realized mainly by the Geological Institute of the Czechoslovak Academy of Sciences in Prague and by the Department of Geotechniques of the Faculty of Engineering, Slovak Technical

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University in Bratislava. The growing number of data on the slope movements enabled the transition from the analysis of phenomena to a certain synthesis. A systematic study of slope movements produced documents for stating more generally valid conclusions on the studied geodynamic phenomenon.

As one of the results of systematic study of landslides and of other slope movements was their classification (Nemčok-Pašek-Rybář, 1972). Based on the mechanism and velocity of movement the slope movements are divided into 4 fundamental groupe (creep, sliding, flow and fall).

Creep. The term creep is used by the authors in the general rheologic definition to indicate a slow flow of substance. From the geological view point it is a long-term, mostly not accelerating movement of rock masses. The limit against the solid underlier is not clear in most cases. When the movement accelerates and reaches a critical velocity, it passes into sliding, flow or fall. In such a case creep is a preparatory phase of sliding, flow or fall.

Sliding, is relatively a fast, short-term movement of rock masses on the slope along one or more shearing planes.

Flow is a fast short-term movement of rock masses in viscous state. The mass in the separation area flows out and is displacing along the surface to a great distance. In some cases even water transport takes place of rock particles (but the water part does not exceed the part of the rock masses.

Fall is a sudden short-term movement of rock masses on steep slopes. The affected rocks are loosened and lose contact for a short time with the underlier. The movement takes place in a free fall.

The slope movement is separated in the classification (for ex., sliding) which is a phenomenom from slope deformation, which is the resulting form of this phenomenon (for ex., landslide). Types of slope deformations are schematically drawn within the frame of each fundamental group.

The slope deformations present their specific character in individual geological-tectonical units of the West Carpathians. Based on the homogeneity of the geotectonical development and structure of the individual West Carpathian parts Matula (1969) delineated the following 4 engineering geological regions:

A - Region of core mountains
B - Region of the Carpathian flysch
C - Region of the Neogene volcanites
D - Region of the Neogene depressions.

Slope deformations in core mountains

In the areas of high core mountains and core mountains rise the oldest (and in substance also the strongest mechanically) rock complexes, from the Proterozoic to the Mesozoic. The mountain cores are built by the Precambrian and Paleozoic metamorphosed rock complexes and the Varissian granitoids, which are covered by the mantle of younger surficial and Secondary sedimentary rocks in stratigraphic and tectonic superposition.

The slope movements are rare in the crystalline cores of the middle-mountains. In the high core mountains (Tatras, Low Tatras, Little Fatra, and the Chočské mountain ridge) are built steep slopes with differences of level 500 to 900 m. As the regional investigation of these mountains has shown (Mahr-Baliak, 1973), even in the crystalline cores of high mountains of the West Carpathians there is a surprisingly high number of slope deformations, in spite of the great mechanical strength of the rocks, building the cores. There are here types of slope deformations belonging to all the fundamental groups according to the above mentioned classification.

Many slopes in the high crystalline mountains of the West Carpathians are dislocated by estensive deep-seated creep deformations. Of the areas built by metamorphosed rocks and granittoids, they are found mainly in the Tatry Mts. where we registered 77 deformations (deformations on the Polish side of the Tatry Mts. not included) and 54 deformations in the Nízke Tatry Mts. Only 7 deformations were detected in the Malá Fatra Mts. No deformations have yet formed in the Velká Fatra Mts.

According to Ter-Stepanianš (1966) division they belong to the rotational depth creep deformations of slopes. They were studied in more detail in connection with some of the bigger engineering constructions in the Alps (Zischinsky, 1966). Of the engineering geologists Nemčok and Pašek (1969) were the first to describe them in the Carpathians.

The morphological forms of these deformations in the Carpathians are expressive mainly in the crest part. The exposures of shear planes on the surface are manifest as rock steps and furrows running parallel with the crest. Small lakes and double crests form on the ridges. The furrows are detectable on the deformations in granitoids of the central part (exposures of the shear planes inclined towards the slope). In more plastically deforming metamorphosed rocks the deformation in the central parts of slopes is expressed by the rippling of the slope, as well as enormous scattering of measured strikes and dips of foliation planes. At the foot of the slope the rocks are thrust out into the valley and transported rapidly by strongly eroding streams, or covered by accumulation forms of slope modeling.

Creep deformations of slopes in metamorphosed rocks show a form of gravitational folding and in more isotropic, more brittle and more solid granitoids a character of fan-like disintegration of mountain slopes (Nemčok, 1972-a). In both cases, however, a similar mechanism of movement can be assumed.

As an example of deformation in metamorphites we give the creep deformation on th SE slope of the Rắztoka ridge built mainly by biotitic and two-mica paragneisses and siliceous gneisses (proterozoic). Deep-seated creep deformations in the crest are manifest by a set of rock steps. The biggest of them attains more than 40 m in height. The total width of the deformed slope is 690 m. The relative height above the Žiarska valley is H = 812 m. The length of deformation is 1,660 m and the average slope angle is 26^{o}. The area of deformation covers 2.38 km^2. The sume of heights of rock steps is Δ H = 54 m. Fig. 1 shows as chematic cross-section under the condition of a contract - and dilatation behaviour of the rocks in the slope. In the upper and lower parts of the slope where there is a smaller normal stress the rocks behaves dilatantly and it is why its deformation occurs along sharply delineated shear planes (Mencl, 1968), Foliation planes are interrupted. In the central part of the slope high pressures are the cause of the contractant behaviour of the rock masses. A thick deformation zone takes place in which the foliation planes show a characteristic form of the letter S.

Among creep deformations in granitoid rocks the deformation in the eastern slope of the Polskắ Tomanowắ ridge attains the biggest height (H = 854 m). The lower part of the slope is built up of twomica granodiorites (Carboniferous) and the upper part of pegmatite-aplitoid granites of the upper marginal zone with relics of the mantle. The length of deformation is 1,925 m, the width 1,600 m and the area covers 2.52 km^2. The slope angle is 24^{o}. In the crest part the exposures of the shear planes are manifest as a set of rock steps of the height between 1.5 to 7.0 m. The sum of heights of the exposures of the shear planes is Δ H = 11.0 m. Four parallel furrows can be observed in the central part of the slope. The height of the outer walls of these furrows is 0.5 to 4.0 m. They are the exposures of the planes on which the rock blocks subsided antithetically owing to compression and crushing of a contractant zone. In the schematic profile (Fig. 2), it is indicated by a denser jointing. The course of shear planes inclined towards the slope in its central part can be well observed (and outlined relatively well in the profile) on the walls of the glacial cirque which formed in the N part of the deformation. Morphological forms found on the creep deformation in the terrain correspond well to the theoretical considerations based on the assumption of contractant dilatation behaviour of the rock in deformation. Feda (1973) dealt with the development of the deformation under this assumption.

Based on the regional study it was found that the creep deformations are not proportionally distributed in the individual high mountain ranges of Slovakia. We explain it by an unequal situation within the geomorphological development cycle. On the other hand a number of deformations occur to a corresponding degree in areas built up of metamorphites and granitoids. On the whole we found 137 deformations covering an area of 65,3 km^2. The average height is 351 m (max. 914 m), the average length 690 m (max. 1925 m), the average width 675 m (max. 3030 m), the average area 0,473 km^2 (max. 3,29 km^2) and the average angle of the deformed slopes $28^o 30'$ (max. 49^o).

The tectonic deformation of rocks creates suitable predispositions for the occurrence of deep-seating gravitational deformations. Interesting results in this sense were provided by the measurement of strikes of movement of deep-reaching deformations. (77 records) in the Tatras (Fig.3). An expressive maximum shows the SE strike. The main strike of joints and deformation zones in the Tatras is NE-SW with a SE dip. The graph in Fig.3 proves the assumption that deep-seating deformations take advantage of the tectonic predispositions and of tectonically weakened zones.

Dips of slopes disturbed by deepseating gravitational deformations are usually given within the range of $18^o - 50^o$.

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Zischinski (1969) gives dips in disturbed metamorphosed rocks within the range of 18° - 24°. According to Radbruch-Hall et al. (1976) the angle of dip of the deformed slope of Contact Mountain, Montane, is approximately 31°.

From a regional study in the high mountain ranges of the West Carpathians it results that the dips of deformed slopes range from 18° to 49°, with arithmetical mean of 28° 30′ (137 records). In granitoids deformed by the Alpine tectonics the dips of slopes range between 18° - 49° (92 records) and in less strongly metamorphosed rocks within the range of 18° - 37° (45 records). In Fig. 4 the heights of deformed slopes H are correlated with their lengths L in granitoid rocks. The curves of maximum and minimum angle of deformed slopes are to be included within the ranges of deformed zones (Mahr, 1977). The relationship between the sum of heights of the exposures of shear planes Δ H and the total heights of slope H is labelled ϵ_H. It is to be considered as a certain indicator of stability of the deformed slope. (Mahr - Nemčok, 1977).

The surficial creep in areas built up of metamorphosed rocks and granitoids is manifest in the form of debris and rock glacier slide. Nemčok and Mahr (1974) registered in the Tatry Mts. and the Low Tatry Mts. 49 moraines after rock glaciers.

Slope movements of the sliding group are rare in the crystalline core mountains. There were found only 21 localities of rockslides which relate mostly to metamorphites (Príslop, Malá kopa, Holý vrch).

The rockfalls are the typical slope deformation for the dexcribed area. Meanwhile the major part of rockslides is related to metamorphites, the rockfalls develop above all in more brittle granitoid rocks. In the crystalline rocks of the high core mountains of Slovakia 76 rockfalls were registered (Mahr, 1976).

From the flow group in the crystalline high core mountains there are above all hundreds of rock streams (mury).

Mury are a serious threat to the environment mainly in the Alpine valleys and in the Caucasus. In the high mountains of Slovakia there are known only two cases when the rock streams damaged the structures. In 1970 the rock stream destroyed a chalet in the recreation centre of Zverovka in the West Tatry Mts. (Ingr-Šarík, 1970) and a catastrophic rock stream which destroyed a part of the Štefanová village and in which 14 persons perished.

In the sedimentary series of the mantle core mountains from among the slope movements of deep-seated creep the block deformations are developed (Nemčok - Pašek - Rybář, 1977).

Coarse-sheeted and mass rock complexes (mainly limestones and dolomites) of the middle- and upper Trias, Dogger-Malmian, etc., lie on the Alpine folded semi-rock basement which is represented by the shale complexes (mostly clayey shales and marls) of the Keuper, Verfenian and Neocomian. These properties of the Mesozoic series applied well in the differentiation of rock masses. The gravitational slope movements made it either more pronounced or in many cases destroyed it. A morphological manifestation of this deformation development are the broken blocks of rigid complexes along predisposed, mainly tectonic planes which sink and rotate (block rifts) and later slide along the basement in the form of isolated blocks (block fields) into the valleys. The blocks are subjected to weathering, disintegrate and the creep movement passes into fall, sliding or flow.

The most attractive deformation of this type is represented by the deformation of the Sivý vrch crest and of the Radové skaly rocks in the Tatras (Fig. 5). Deformation in the crest part attains the width of 1.100 m (E-W), max. deformation length in the NW-SE strike is also 1.100 m, the average angle of the deformed slope is 20°, the relative height of deformation of the slope is 396 m.

As it is seen from the profile the dolomitic-limestone crest represents the denudation outlier of the Choč mantle which lies on the anticlinally arching and tectonically reduced strata of the Neokomian, Jurassic and Trias of the Krížna mantle and cover series. The axis of the antlicline is in substance corresponding with the crest strike (Nemčok-Baliak, 1977).

In the sedimentary series of the high core mountains of the West Carpathians Baliak registered (1978) 119 slope deformations of the block type, 111 landslides and 180 rock falls. The average length of deformations of the block type is 1,025 m, the width 764 m and the height of deformed slope 963 m. As to surface these deformations cover bigger areas than in the crystalline rocks.

Slope deformation in flysch highlands and hilly lands.

The region of the Carpathian flysch form a coherent stripe near the outher margin of the West Carpathians. Into this region in engineering geological zoning Matula (1969) incorporates also the Klippen belt.

According to the lithological view point the character of the region is simpler and more monotonous than the region of core mountains. The basement here is built up of rock complexes of flysch formation with the predominance of rhythmic sandstone-clayey alternation of strata.

The alternation of permeable rocks of higher mechanical strength (sandstones, conglomerates, etc) with impermeable, less solid, plastically transforming rocks (claystones, siltstones, marly shales), forms one of the geologic-tectonic structures suitable for the occurrence of slope movements (Nemčok, 1630

1977). Apart from the geologic and hydrogeologic conditions (formation of lifting horizons), there are in the region of the Carpathian flysch also suitable climatic conditions for the occurrence of slope deformations, because mainly in the western part of the region there are high totals of precipitations attaining 1.600 mm/year. In the region of the Carpathian flysch there were registered more than a half of the total slope deformations in the Czechoslovak part of the West Carpathians. More than 3000 slope deformations - mostly landslides, were mapped in this region.

In the regional investigation of the Czechoslovak sector of the Carpathian flysch it appeared that the slope movements present a different character in the flysch highlands than in the flysch hilly lands.

Flysch highlands are the most uplifted parts of the flysch zone. They are built up of tectonically uplifted arcs, meanwhile the flysch hilly lands spreading between them are relatively less uplifted tectonic depressions. To the flysch highlands belong, for ex., the White Carpathians, the Moravo--Silesian Beskydes, the Spišská Magura, etc.

These mountains are characterized by a monotonous geologic-tectonic structure. Geologically predominate the sandstones over the plastic members of the strata-series of the Paleogene and the Cretaceous. The strata-series is folded into lengthwise anticlinal synclinal zones in the Carpathian arc strike. The relief is relatively articulated with relative differences of level 200-600 m.

In flysch highlands there occur less-slope deformations than in the hilly lands. There predominate creep deformations. of the block type mainly along the predisposed planes. Huge sheets of sandstones move along a thin stratum of claystones or marls, dipped correspondingly with the slope. The movement starts usually when the erosion affects the continuity of the upper sandstone complex.

One of the slope deformations of this type developed on the north-eastern slope of the Bukovina near Jezersko in the Spišská Magura (Fig. 6). The layers present a corresponding strike with the main crest and dip under an angle of 15 - 20° to the NE. By a creep movement the upper part of the sandstone- series disintegrated into blocks which by a slow creeping movement displace into the valley. On the NE slope of the Bukovina a block field occurred with mutually displaced and inclined blocks. The blocks in two places dammed the Jezerský potok brook and formed two smaller lakes. The total slope deformation area measures 7 ha (Nemčok, 1972-b).

A further type of creep deformations in the flysch highlands are the block rifts and block fields which form on thick strataseries of predominantly pelitic rocks. Of similar character are, for ex., the creep deformations on the creep deformations on the crest of the Kubínska hoľa in the Oravská Magura and partially also the slope deformation on the crest of Lukšince in the Moravosilesian Beskydes (Fig. 7). In this locality the mutual movement of two blocks was measured for 4 years. According to the measuring results Novosad (1966) estimates the absolute velocity of the block movement on the northeastern slope of Lukšinec to 1 cm/year.

The landslides are a less frequent form of slope deformations in the flysch highlands. The sliding takes place above all along the predisposed, planer shear planes dipped conformably with the slope.

Flysch hilly lands are a less uplifted part of the flysch zone. To them belong, for ex., the Kysucké mountains, the Šarišská hilly land, the Vízovická hilly land, etc. They present a monotonous geological structure in a typical development of rhythmic flysch with equilibrium of psammites and pelites, or with the predominance of claystones, marlstones and siltstones in the strata-series. The relief of flysch hilly lands is characteristic by relatively low flat crests, extending in the direction of the Carpathian arc
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with relative differences of level 30-300 m. While denudation and transport of material predominate in the highlands, accumulation predominates in many places of the hilly lands giving rise to the formation of mantle rocks 15-20 m thick mainly in the lengthwise depressions. The occurrence of thick mantle covers are frequently related to slopes which cut the fronts or sides of monoclinally deposited layers. The slopes modelled parallely with the dip of layers are covered with a lesser quantity of mantle formations.

For flysch hilly lands typical slope deformations are sliding, flow and surficial creep of cover loamy-stony and loamy formations.

In the flysch hilly lands there is concentrated the greatest number of landslides, which had been known for a long time in this area. The form of their shear planes is planar, but most frequently combined, rotational-planar. The basal shear plane lies usually on the limit between the basement and the cover formations where the ground water outflows from the more permeable basement horizons are usually concentrated.

In the places of concentrated ground and surface water outflows, with regard to a predominant part of easily slaking of illitic minerals in pelitic fraction, there frequently take place dangerous earthflows. The best known one had destroyed in 1962 the locality of Lieskovú which was situated in its separation area and parts of two other localities in the valley of the Prečnica brook, into which the earthflow had flown, damming the brook. The earthflow was brought about after an abundant rainfall when the 15 m thich slaked loamy-stony debris went into motion. They were of slurry consistence, so that the surface of the earthflow was absolutely inaccessible during the first days. The length of the earthflow was 950 m and its cubage was estimated to 900.000 m^3. The greatest measured velocity of movement was 25 m/hour. (Repka, 1963).

The slope deformations in the Carpathian flysch region use to be of serious economic consequences and in many cases they required expensive corrective measures. What regards railways, for ex., they were the landslides near Podbiel, Nižná, Zarieči, Pužbachy and elsewhere. As for roads they were the landslides near Mestečko, Harvelka, Oravský Podzámok, Soboš, Holčíkovce, etc. Deformed and destroyed were several houses, as well as the mentioned locality of Lieskové, or part of the Krivé village.

Problems caused by landslides arose also in the construction of hydraulic works in the Carpathian flysch. As examples we give the securing of the Hričov-Mikšová differentiation channel, corrective measures of the Domaša and Orava reservoir banks amd stability problems in the construction of the Zermanice, Šance and Moravka dams. It is why a great attention is devoted to slope stability in designing hydraulic works in this region. In designing the Nová Bystrica hydraulic work in the Kysuscká hilly land a study on the slope stability of the adjoining area of the future water reservoir was prepared (Mahr - Malgot - Baliak, 1977). Forming part of the report was also the map of slope deformations as illustrated in Fig. 8. The landslides in the map are drawn according to the form and activity. Such a study gives the designer a possibility to chose more safely the dam profile, to suggest lines of replacement communications on the bank of the future reservoir and a certain possibility to predict the future transformation of the reservoir bank.

Slope deformations in the region of volcanizes

In the central part of the neovolcanite mountains slope deformations are rare. Quite isolated they are also on the boundaries, if lava and pyroclastics lie directly on rock Mesozoic and older formations.

The most extensive slope deformations in the West Carpathians, however, are found there where rigid rocks of the Neogene volcanic complex (andesites, rhyolites and their tuffs) lie on soft plastic sedimentary or sedimentary-volcanogeneous rocks (Paleogene claystones and clayey shales, Neogene clays, claystones, marls and clayey tuffites). Therefore there occurs one of the typical geological tectonical structure, suitable to cause slope deformations (Nemčok, 1977). The displacement of the plastic underlier by the weight of the overlying strata is described by Hollingworth et al. (1944) under the name of bulging and cambering. Ter-Stepanjan (1974) classifies this process into the compensating depth creep of slopes. Tensile stresses occur in the overlying rigid rocks as a result of the plastic underlier displacement (bulging). Brittle rigid rocks break off from the rocks mass, using the planes of mechanical discontinuity (Malgot-Mahr, 1978) and in the form of gigantic blocks sink into the underlier, or slide on it. So far as the blocks only move round or sink in place, they form block rifts with the characteristic relief gradients (Fig.9.).

The underlying rocks of relatively lesser strength are exposed to long lasting considerable stresses. Even if these stresses do not reach the strength limits deformation takes place in time, corresponding to rheologic properties of the underlying rocks. Creep deformations in the underlier occur in a big zone. The depth and intensity of this process depends on the overlier weight and on the properties of the plastic underlier. The process is accompanied by a gradual degradation of the properties of the underlying clayey rocks.

Blocks in the block rifts part and slide down the slopes. Their more expressive individualization takes place. Single blocks form elevations morphologically apparent. They are frequently of up-slope inclination proving thus a deep deformation of their underlier. A set of such blocks forms ablock field (Fig.9).

All this process starts when lateral or deep erosion reaches the contact between the overlying and underlying complex of rocks. It advances relatively fast till the final disintegration of the rigid complex (Rybář, Nemčok, 1968). It is bound above all to elevation tectonic structures (Malgot, 1977). The speed of disintegration depends also on hydrogeological and climatic conditions, as well as on rock properties. This is why slope deformations in varied stages of development are found on the boundaries of the volcanic mountain ranges of Slovakia.

The activity of slope movements is of primary importance from the safety view point of the engineering works. There are several geologic and geodetic evidences of present creep movement activities of block types on the boundaries of volcanic mountain ranges in Slovakia.

In the Hnadlová basin area, as wellas on the eastern boundaries of the Kremnické pohorie mountain range between andesite blocks there are fresh cracks not filled with debris reaching to depth of several tens of meters. This proves the present activity of movements, otherwise the cracks would have already been filled up and buried under.

The detection of absolute magnitudes of very slow creep movements of block type is difficult. The current geodetic methods would require measurements carried out for long time periods of several decades. It is more suitable to use measuring devices capable of measuring very small movements.

Points of a triangular network were measured in the Handlová basin in 1907 and in 1930. Some of them were placed on blocks of the block fields and block rifts. Repeated measurements at the points of the triangular network, based on moving blocks of volcanic rocks give undisputed evidence of the activity of block movements (Malgot, Pašek, Stella, 1974).

Two points placed on block rifts show an average movement of 1.1 mm/year and 4.0 mm/year. The average movement of blocks in the block field is 10 to 15 mm/year and individualized blocks influenced by landslides show 30 to 45 mm/year.

On the eastern boundary of the Kremnické mountain range 10 dilatometers type TM-71 (Košťák, 1969) were placed on the slope above the Veľká studňa ore deposit. The devices are placed on cracks 60 to 300 cm wide, between blocks of agglomeratic andesite tuffs. They can measure the mutual movement of two blocks in three space directions with a sensitivity of ± 0,03 mm. We have at our disposal at present 7 measurements carried out within the period of 25 months. Based on these measurements we can find out that the movement of blocks relative to each other takes place continuously with a speed of 0,5 to 0,6 mm/year.

The movement of blocks in the Handlová basin detected by longterm observation are relatively big. This may be caused for instance by non uniform movements. The values of long-term observations may contain quicker short-term displacements.

The difference of block movement speed in the Handlová basin as against the area on the eastern boundaries of the Kremnické mountainrange can be explained also by the variety of geotechnical properties of the underlying plastic complex (Mahr, Malgot, 1977).

The presence of block deformations may be of serious economic consequences. West of Banská Bystrica, in the Veľká Studňa locality there is a promising deposit of Hg-ores. The Hg mineralization (vermillion) forms impregnations or veins in crumbly sandstones of basal Paleogene.

The top parts of the steep slope above the Hg-ore deposit are disturbed by large-scale block rifts and themiddle parts by typical strongly dissected block fields (Fig. 10). Morphologically wellmarked blocks of agglomeratic tuffs attain a size of up to 50 x 100 m. The layer of blocks is 45 to 100 m thick, as was determined by boring. The blocks move on plastic Miocene clays, which above the deposit are 20 - 50 m thick. As it has already been mentioned the activity of movement was detected by the TM-71 type dilatometers. Lithologically, they are marly tuffaceous claystones with interlayers of sandy claystone containing coal lenses and interseams of tuffaceous sandstone. The creep zone beneath the blocks consists of soft claystones, strongly disturbed by nemerous differential slickensided shear surfaces of irregular course. At a greater depth the claystones are solid.

Deep depressions between the blocks of agglomeratic tuff recall karst sinkholes. The slope is step-like, inclined at 20 - 40°. The higher lying blocks are tilted into the slope, those at a lower elevation are inclined downslope. Frequent wide open fissures reach from the slope surface to underermined depths. The width of fissures is 0.3 to 4 m. Below the accumulated blocks extensive planar landslides showing signs of activity disturb the lower parts of slopes. Numerous springs with a discharge of up to 10 l/s issue in the head scarp. The thickness of the slid mass evidenced by boring reaches 10 - 20 m (Malgot - Mahr, 1977).

In the lower parts of the slope, the mineralized layer is near the surface (Fig. 10), under a civer of 10 - 20 m of colluvial loam or slipped material, but it descends westwards along the faults to a great depth. The Hg deposit is of medium to large size and with regard to the thickness of overburden the working of the ore in an opencast seems to be most economical. With the overburden ratio of 1 : 5, the slope will be undercut to a height of 40 m after the deposit is exhausted. This will doubtless activate the movements in the upper parts of the slopes.

An engineering geological investigation is taking place at present which will determine the definitive method of technology of exploitation and corrective measures.

Deep disintegration of clays and claystones of the underlying complex helps to create an unusual earth crust weathering. The final result of the degradation of rock properties is a state in which even slight action of any one factor brings about the loss of slope stability. Sliding movements are remarkably brought about also by ground water, emerging in the form of barrier springs at the foot of blocks. On the periphery of block fields a continuous ring of landslides takes place in this manner. By their movements landslides carry sometimes even individual blocks, of lesser dimensions.

According to form planar and flow landslides predominate here. Landslides of considerable dimensions occur here. Shear planes occur in depths 25 to 40 m. The shape of shearing planes is mostly combined or gravitational.

On the periphery of volcanic mountain ranges there occurred slides which were of the most serious economic consequences in the territory of Czechoslovakia. Thus in 1960 the well-known Handlová landslide destroyed part of Handlová town (Záruba, Mencl, 1969). The cubage of sliding masses was about 20 million m^3. The total length of landslide 1.8 km.

In 1977 a wide landslide flow was triggered on the northern boundary of Poľana and destroyed part of Ľubietová village. The length of landslide is 1.2 km, its width 450 - 500 m and depth 15 - 35 m.

In 1978 on the western slope of the Vtáčnik volcanic mountain range, under the influence of coal exploitation, a landslide was activized which damaged or destroyed 110 houses in the village of Podhradie. The length of landslide is 1.5 km, the average width 500 m and the cubage of sliding masses is estimated to 21,1 million m^3 (Malgot-Mahr, 1979).

The process of sliding overtakes usually only part of the slope. Territories of landslides, bordering the block deformations are therefore formed by sets of landlidesof varied types and stages of development. There are found here active, potential and also quietened landslides.

The activity of landslides depends on the geological-tectonical development of any area, on the progress of development of the geomorphological cycle, on the hydrogeological conditions, but mainly on the rock properties from which the landslide takes its origin.

It was detected in the Handlová basin that landslides in places where the underlier complex is built of Neogene clays are more active than in places where the plastic underlier complex is built of Paleogene claystones (Mahr, Malgot, 1977). The Paleogene claystones present a higher degree of lithification than the Neogene clays. Meanwhile in the Paleogene claystones the predominant clayey mineral is illite, in the Neogene clays the Montmorillonite predominates. The properties of the matrix rocks are reflected also in their deluviae. The material of landslides, originating from the Paleogene claystones presents a higher average porosity ($\bar{n} = 43.9$ %) a lower index of plasticity ($\bar{I}_p = 30.8$ %) a higher parameter of residual shearing strength ($\bar{\varphi}_r = 15^{o}24'$; $\bar{c}_r = 0.0$ kPa) than material originating from the Neogene clays ($\bar{n} = 48.8$ % ; $\bar{I}_p = 34.5$ %; $\bar{\varphi}_r = 12^{o}20'$; $\bar{c}_r = 0.0$ kPa).

Landslides in places where the underlying complex is built by the Paleogene claystones are of smaller dimensions than landslides on the Neogene clays. The average dip of these landslides is 7^{o} to 9^{o} and they are of lesser activity. Landlides on the Neogene clays have dimensions of the order of kilometers. The average dip of landslides is about 6^{o}. The landslides here form the sliding areas and are more active.

Therefore it can be concluded that for engineering works from the view point of slope stability the most favourable conditions are there where the underlying complex is built of the Neogene sediments.

The magnitudes of movements of a sliding character are sufficient to depreciate practically all types of engineering works. In the central part of the landslide near Ľubietová speed of 2.0 to 2.5 m/day (Ingr, Bohynik, 1978) were measured at the time of the highest activity.

On the flow slide in Handlová which in 1960 destroyed more than 150 houses, a total movement of 16 to 165 m for the first 150 days was measured in the parting area, 95 to 240 m in the central/transporting) area and 5 to 30 m in the accumulation part. The maximum speed of movement was in the central part of the landslide amounting to 6.3 m/day. A substantial slow down of movements of the order of cm/day took place in the central part of the landslide only after five months. 8 years after the landslide values of 1,0 to 1,7 cm/year were measured in the scar area.

Another type of slope deformation occurring in the sliding areas on the boundaries of volcanic mountain ranges of Slovakia are earthflows. They occur usually in the lateral valleys and depressions of the slope in places of concentrated surface and ground water flow. Sliding movements cause deformation of the soil structure and possibility is given to slaking. Under favourable conditions the slaked soil starts moving which presents the character of flow.

After the earth flow has stopped the soils of the sliding masses begin to consolidate gradually. The water is squeezed out of the pores and formation of bonds between the particles of these clayey soils takes place. Shapes of earthflows consolidated in this way are distinguished with difficulty from the flow slides. Earth flows frequently far onto foreign underlier, on which they could not take place as this does not constitute sufficient material for their occurrence.

In areas on the boundaries of the volcanic mountain ranges of Slovakia there often occur almost vertical high rockwalls. They are formed as a result of differential tectonic processes, by selective weatheringin the volcanic-sedimentary complex, but mainly as a result of block movements. Engineering works would be endangered below these rock walls by falling fragments and by rock falls.

On the boundaries of the volcanic mountain ranges of Slovakia where the rigid rocks 200 to 500 m thick lie on the plastic underlier there are usually found block rifts. Below them on the lower parts of the slopes there are block fields. Block deformations result in rock falls. Block deformations are bordered by landslide selvages (Fig. 11). Earthflows take place in landslide areas. The scar edges of block deformations in some places reach the line of divide. This process leads gradually to total destruction of the volcanic complex. On some slopes there are found only earthflows and landslides with fragments of volcanites in the material of sliding masses.

Slope deformations in the region of Neogene tectonic depressions

In the area of the inner Carpathian low country where a planar and rolling relief predominates slope movements occur rarely. The occurrence of slope deformations in this area is almost exclusively related to lateral erosion of rivers. The slope deformations present a character of frontal landslides.

In spite of the fact that landslides in this area are rare a relatively wide sliding area formed in the north-eastern part of the Danubian plain. Between the

Hlohovec and Sereď towns flows the Váh river along the western boundary of the Nitra rolling lands. The relative height of the left bank of the Váh alluvium attains near Hlovec at present 90 m and towards Sereď it decreases gradually to 23 m. The river bluff is formed by a strata-series of sands and clays (in the proportion of 1 : 1) with horizons of slightly consolidated sandstones (Pontian).

The lateral erosion of the Váh caused the formation of practically a continuous 18 km long stripe of landslides between Hlohovec and Sereď. In this area the Čepeň hydraulic work is to be constructed on the Váh. The landslides on the left bank of the Váh signify the most serious problem in the design of this hydraulic work. It is why an intense engineering geological investigation of these landslides is taking place at present.

Inner Carpathian basins are irregularly distributed between the mountain range zones. The basins are filled with Paleogene strata-series of flysch formation (Žilinská, Liptovská, Popradská and Hornádská basins). In the remaining 15 basins Neogene clayey-sandy strata-series, gravels or tuffites lie on the flysch filling. A relief of the rolling country type with a relative difference of level of 30 - 200 m modelled on these soft rocks.

In the inner Carpathian basins the slope deformations are not such a frequent phenomenom than in the flysch hilly lands and they do not attain so big magnitudes than slope deformations on the boundary of neovolcanites. Somewhat more than 1.000 slope deformations of a total area of 75 km^2 were registered so far in the basins.

They are therefore relatively small slope deformations with a small thickness of deformation 5 - 10 m. Bigger slope deformations occur only individually (usually of the stream-like type).

In spite of small magnitudes the slope deformations in the inner Carpathian basins are a serious problem in the national economy, because the basins are the most densely populated areas of Slovakia. Even nowadays the substantial part of house building and a considerable part of industrial structures, hydraulic works and transport communications are concentrated in this area.

From the group of creep movements there are in the inner Carpathian basins slow creep movements of the cover formations and singly also block deformations of travertine margins on the plastic filling of basins.

In the Hornád basin several travertine heaps formed from the springs of mineral waters emerging along the faults. The most marking deformations of the block type formed on the Dreveník travertine heap. The travertine 30 - 80 m thick lies here on the layers of the Central Carpathian flysch (Paleogene) with the predominance of clayey shales. On the margins of the travertine body blocks break off which sink into the plastic underlier, displace on it, tilt and form block fields (Nemčok - Svatoš, 1974).

The Spiš castle was built on the neighbouring travertine heap. Its peripheral walls are disturbed in several places and together with the blocks of travertine, on which they lie, are torn off and deflected from one part of the walls founded on a stable underlier.

A predominant type of slope deformations in the inner Carpathian basins are areal and frontal landslides on the banks of water courses. Stream-like landslides and earthflows occur less frequently.

Landslides are usually related to geological-tectonical structure, whose lower part is built by the Tertiary flysch, clayeysandy-gravelly or tuffitic fillings of alluvial cones and river terraces, or with glaciofluvial material (A. Nemčok, 1966).

The greatest number of landslides with serious consequences occurred in the Liptovská basin. The landslide near Okoličné has been threatening for already several decades and disturbs the Žilina-Košice railway and the corrective measures taken so far have been without success. In building the first class Liptovský Mikuláš - Ivachnové road corrective measures had to be taken on several landslides (near Lipt. Michale, Lipt. Kríž and others).

The greatest problems, however, were caused by landslides near the right bank anchorage of the Liptovská Mara dam. The dam body itself was successfully founded on an undisturbed flysch underlier between two big landslides. A danger threatening the hydraulic work is mainly the landslide tending into the reservoir space, closely behind the dam. It is a stream-like landslide 900 m long and 500 m wide in average. Its thickness attains 40 m in the accumulation part. The landslide was stabilized by gravel fill (about 700.000 m^3) in the accumulation part, by 27 horizontal boreholes terminating above the level of the maximum water in the reservoir and by a set of collecting ditches.

The landslides in all the inner Carpathian basins cause serious problems in the construction of hydraulic works (Starovec, Klačany,) transport structures (Slatina, Potok, Priekopa, Bojnice) and houses (Košice, Handlová, Prievidza, Zvolen).

In the Zvolen basin on the western slope of the Sarvaška hill a landslide took place in Autumn of 1974 after long lasting rains which endangered the hospital polyclinical pavillion under construction in Zvolen (Fig. 12). Its width in the scar was 40 m, 70 - 90 m in the accumulation part, 100 m long and about 7 m deep. The digging of the underpassage in the northern part of the pavillion activized a part of an older landslide. Observation points were placed on the surface of the landslide which during the first 24 hours have shown a movement of 3-5 cm. It was constantly raining and the movement was accelerating (attaining 12.5 cm/day). The head of the landslide was already 1,5 m from the wall of the object under construction. It was feared that the landslide will damage not only the object under construction, but it will widen and damage other of the 14 hospital pavillions situated below down the slope. Corrective measures were quickly suggested and immediatly realized. These consisted of building up a stabilizing fill, tightening of cracks and fissures on the landslide body, digging of a peripheral ditch and pumping from large diameter boreholes was suggested.

After finishing these corrective measures on October 30, 1974 (the sixth day) the movement began to slow down (Fig. 13) and in the third day after finishing the works the landslide was practically stopped (Mahr-Kuchár, 1979).

Definitive corrective measures were suggested after finishing the engineering geological investigation of the sliding slope. The underlier is built by alternating horizons of sandstone and conglomerate tuffites with tuffitic clays. The sliding deluvial clayey loams had a plasticity index $I_p = 24 - 43$ %, liquid limit $w_c = 48 - 75$ % and residual angle of shear resistance $\varphi_r = 13^o$. In the central part of the slope there are loam-coated sandy gravels of one of the Hron terrace. The landslide was completely corrected by drainage gravel walls (Fig. 14) and by 6 horizontal boreholes. The connection with the road was realized by 1 floor higher.

Conclusion

Slope deformations in the West Carpathians are a geodynamic phenomenon which causes serious national economic losses. The present regional investigation has shown that slope movements of various kind and varied activity in Slovakia threaten about 200 km of roads, 27 km of railways, hundreds of masts of transmission lines, many hydraulic and industrial structures and parts of 203 villages and towns.

The engineering geological investigation is gradually clarifying the conditions of occurrence and development of slope movements and registering the movements of slopes threatening engineering structures.

From the registered slope movements and deformations typified out are those which could be of the most serious consequences to the national economy. An engineering geological investigation is carried out of these selected slope deformations and corrective measures suggested on its basis, i.e. the protection of an engineering structure threatened by the deformation.

For designing new engineering structures there are maps in which are drawn the slope deformations which are of good help. The maps are stored in the Bratislava Geofond and accessible to every engineering geologist or geotechnician. It will then be a matter of economic analysis whether an engineering structure will be constructed in the chosen site and correction measures will be taken on the landslide (always more frequent method with regard to the protection of the soil fund), or the line will be changed and another site selected.

In some areas of Slovakia the slope deformations cover 25-35 % of the surface. In similar sliding areas an engineering geological map prepared on the basis of slope stability is unavoidable for the general urban development of the region. From these maps, which a civil engineer can understand with difficulty, zoning maps are derived (Mahr-Malgot, 1978). The zoning maps in the landslide areas then serve for suggesting any kind of structure in the area and for the coordination of the environmental development.

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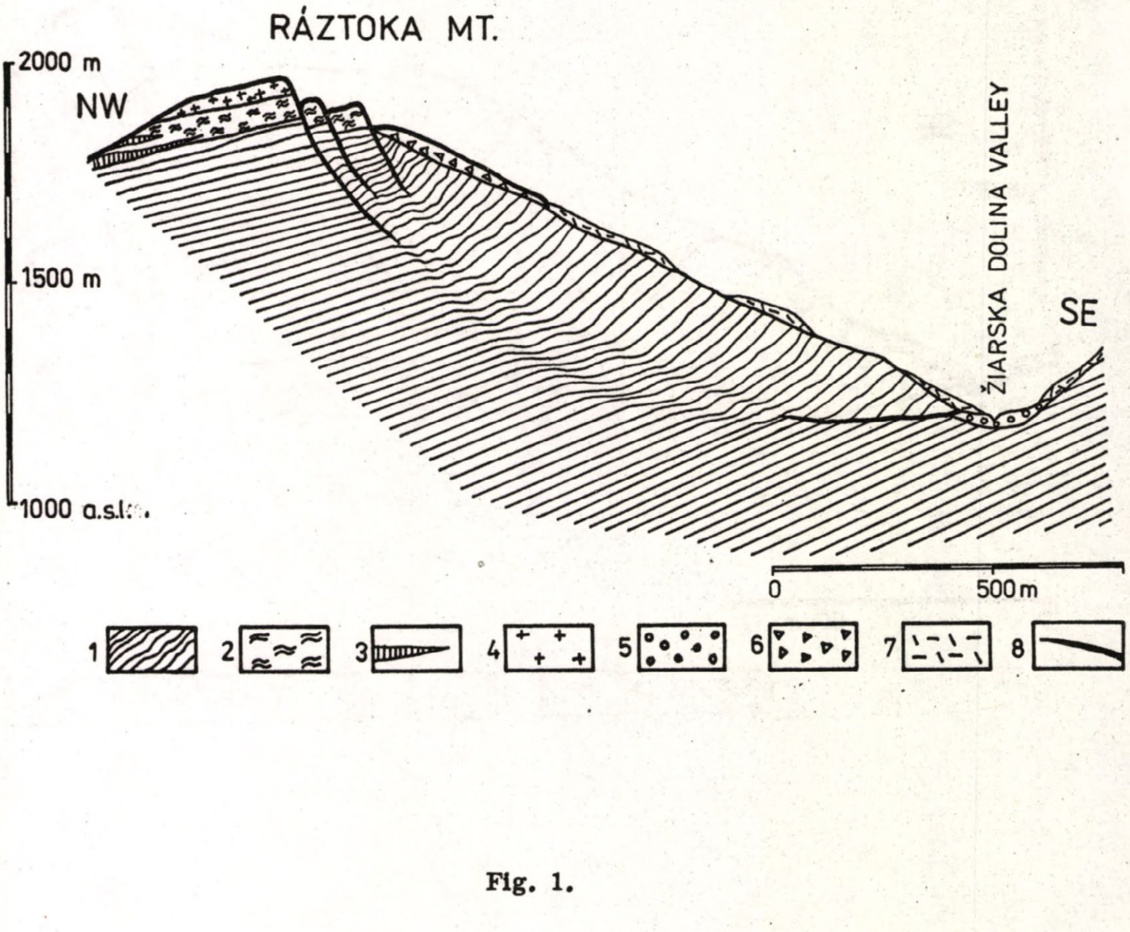
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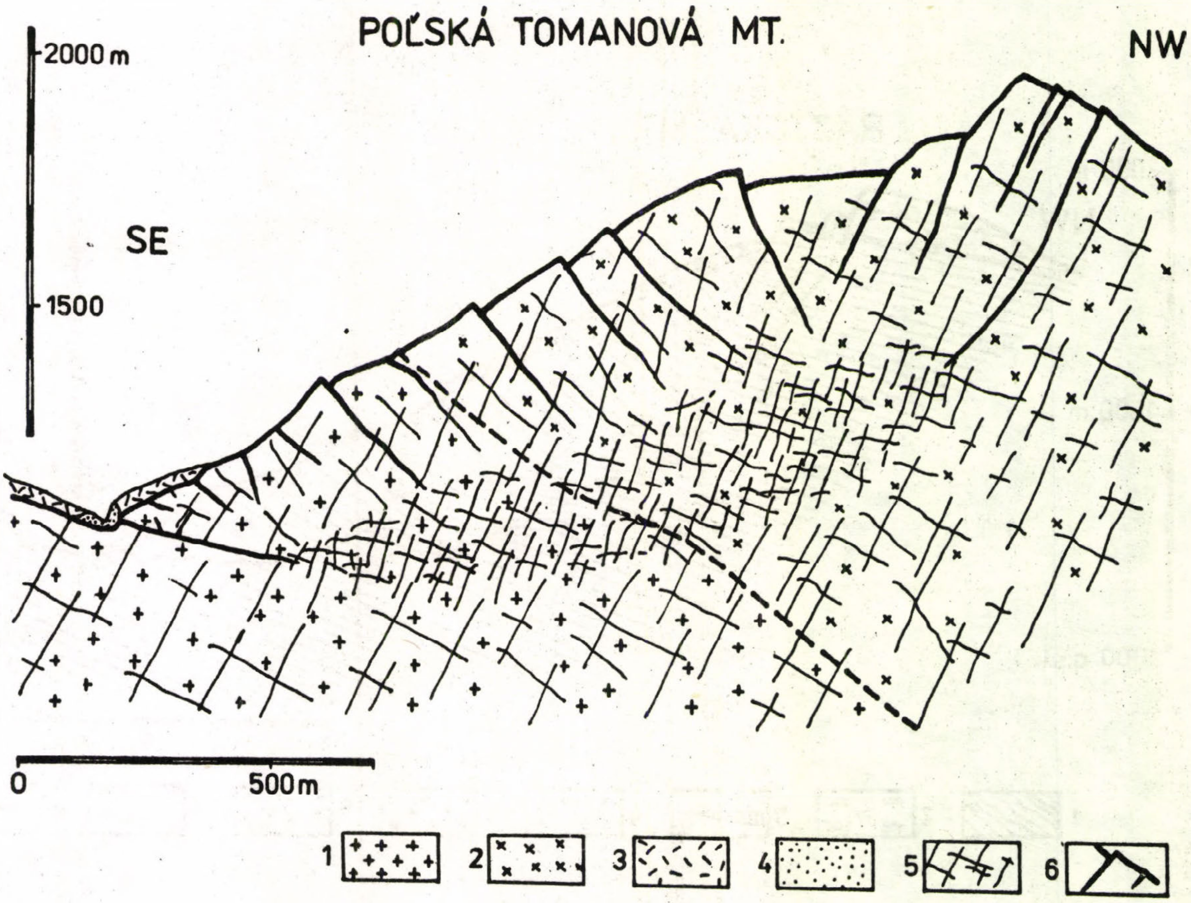
Fig. 1.



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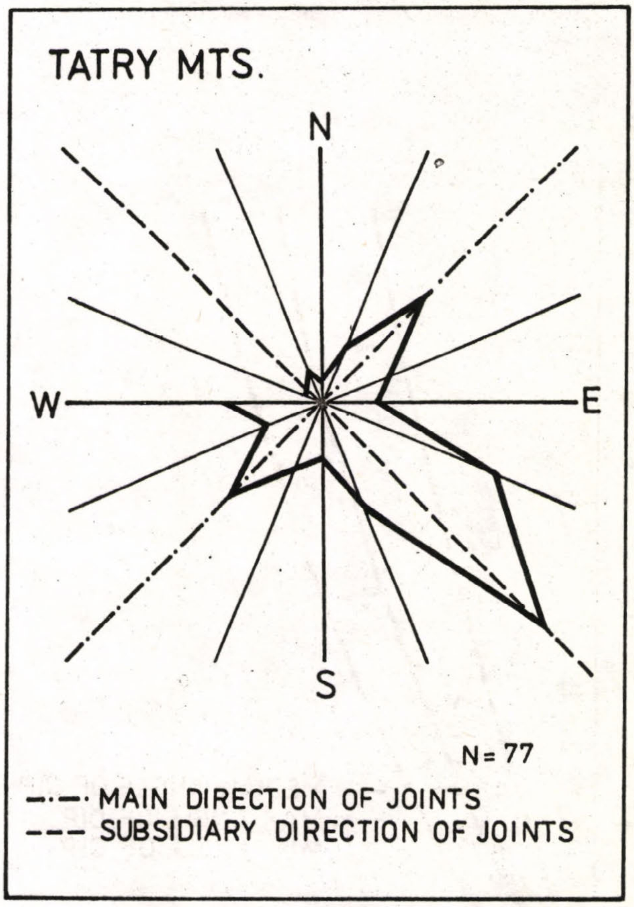

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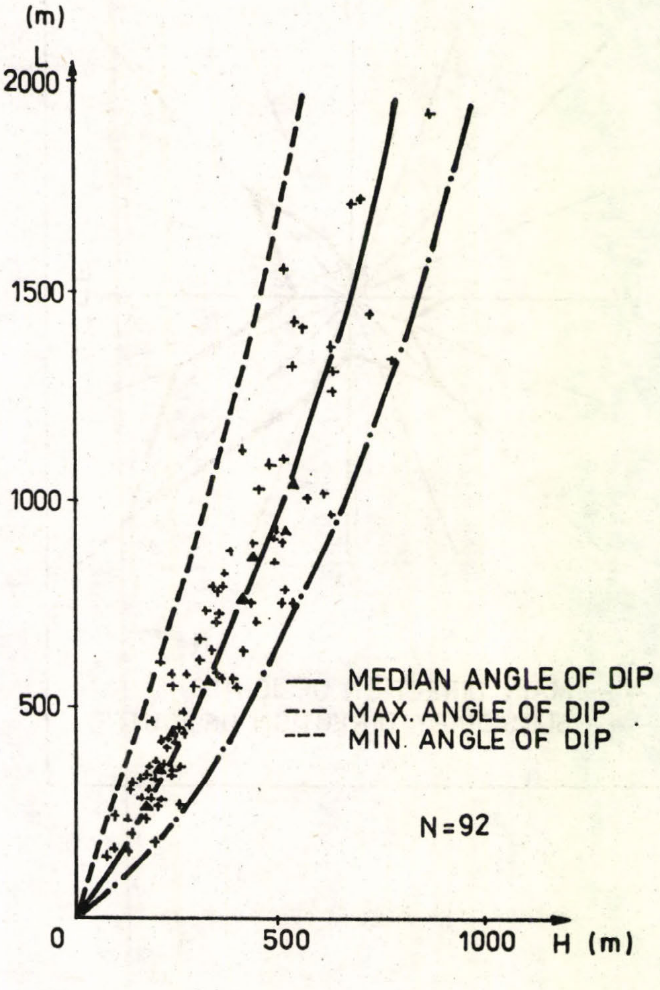
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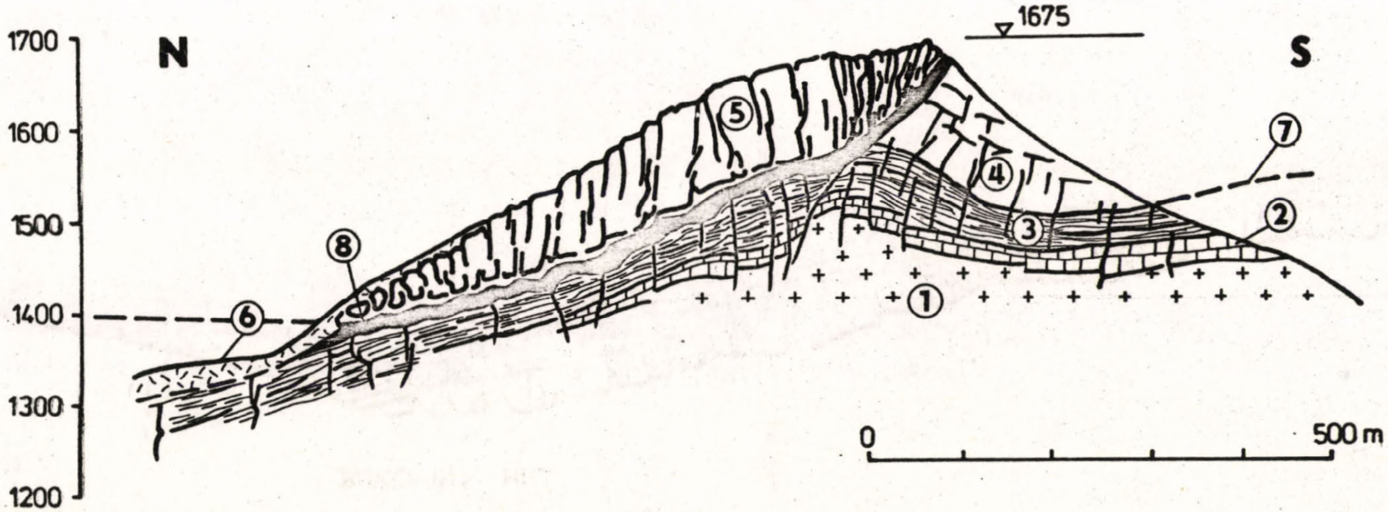

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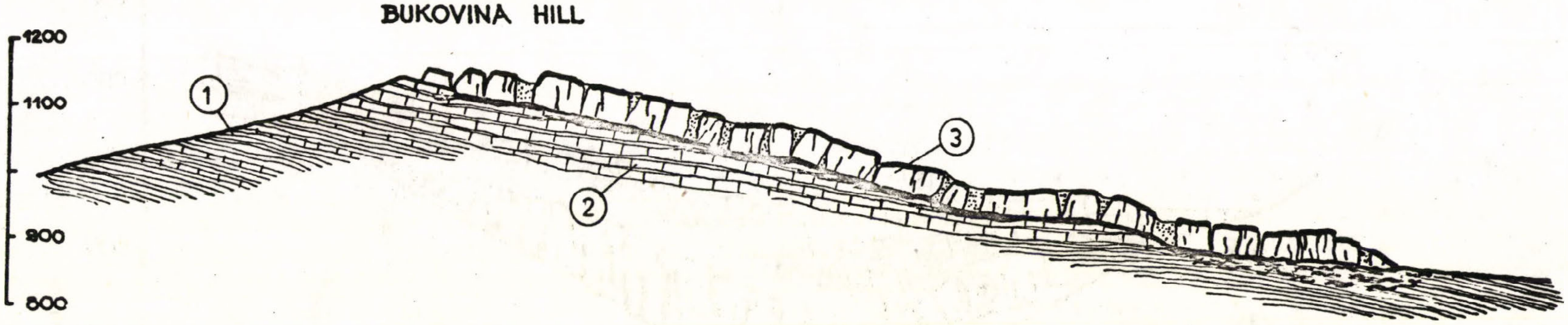
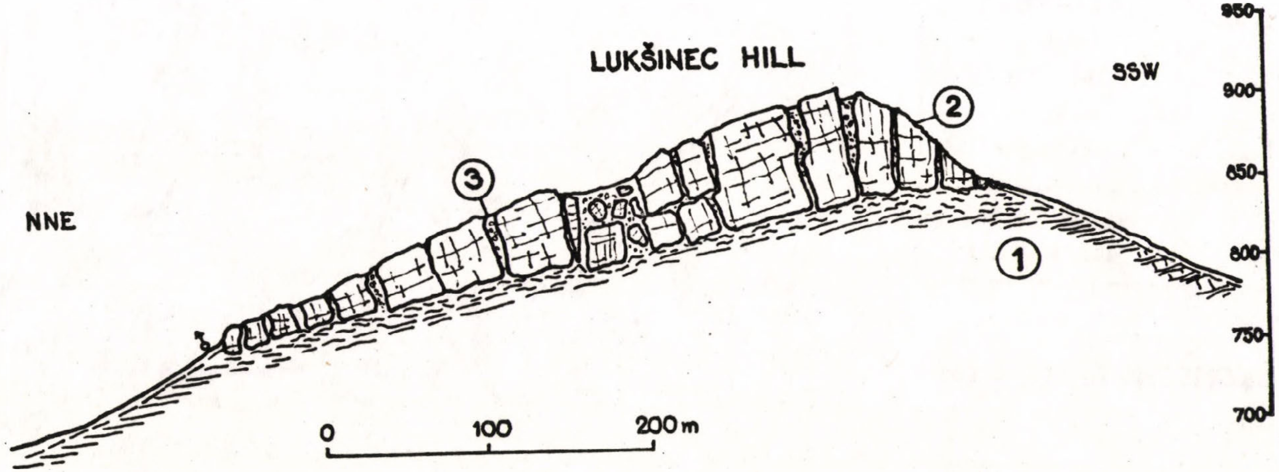


Fig. 6.



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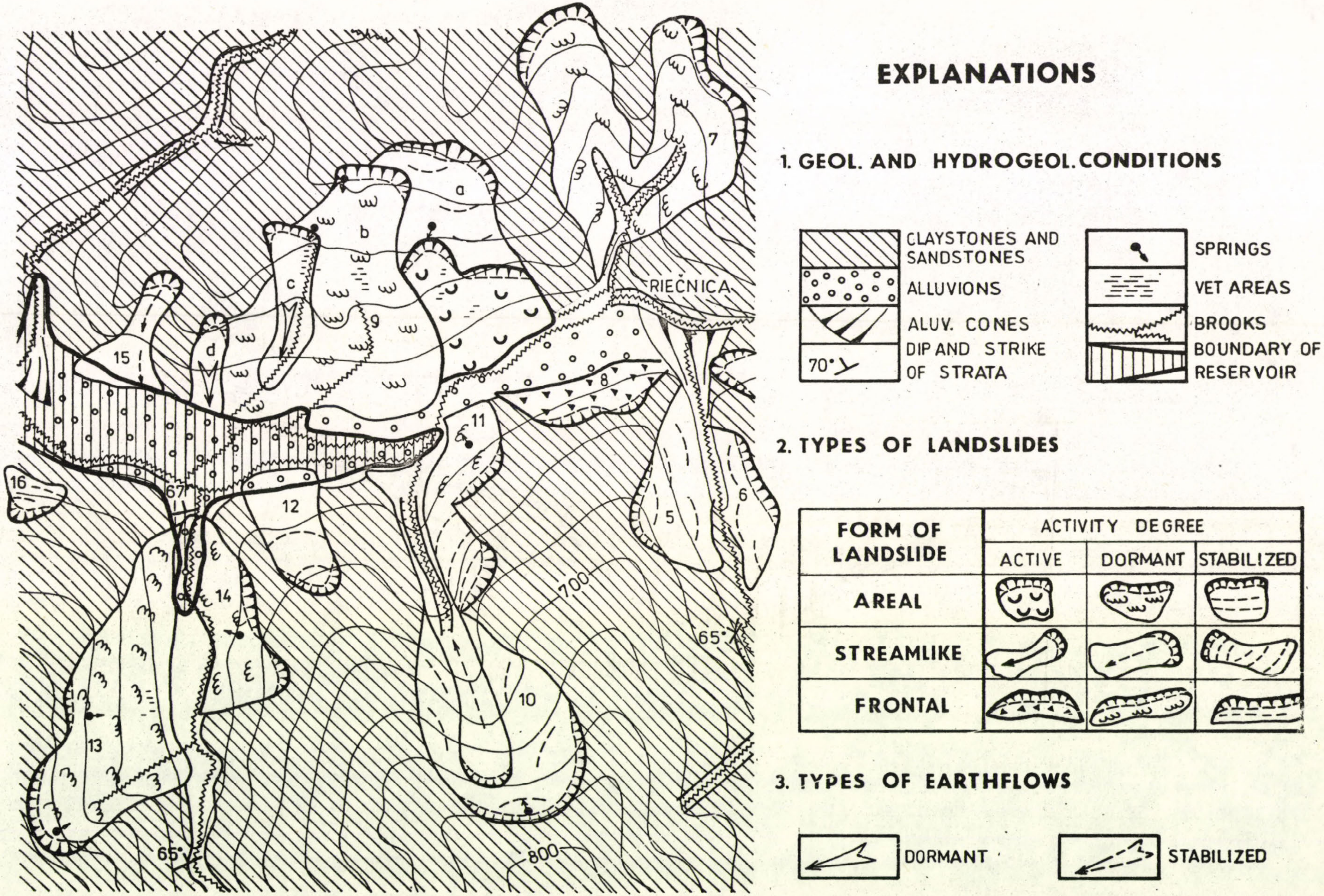
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EXPLANATIONS
1. GEOL. AND HYDROGEOL. CONDITIONS
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ALLUVIONS
ALUV. CONES
DIP AND STRIKE OF STRATA
70°
SPRINGS
VET AREAS
BROOKS
BOUNDARY OF RESERVOIR
2. TYPES OF LANDSLIDES
FORM OF LANDSLIDE
ACTIVITY DEGREE
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AREAL
STREAMLIKE
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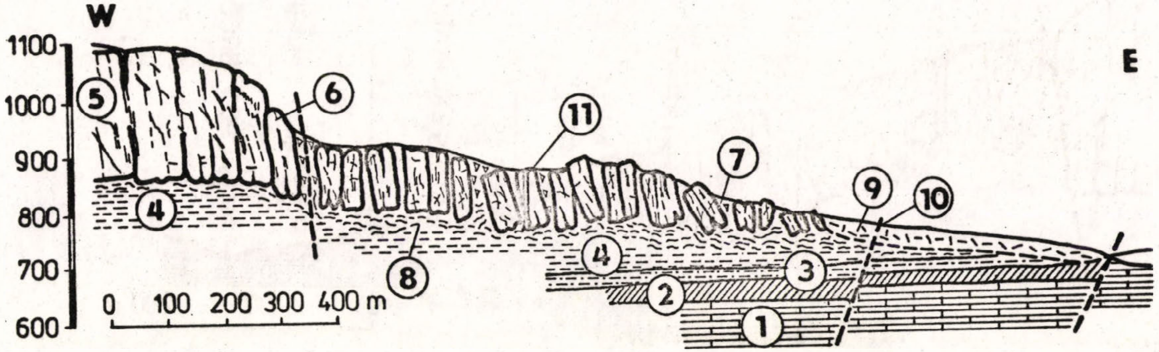
3. TYPES OF EARTHFLOWS
DORMANT
STABILIZED

FIG. 8.



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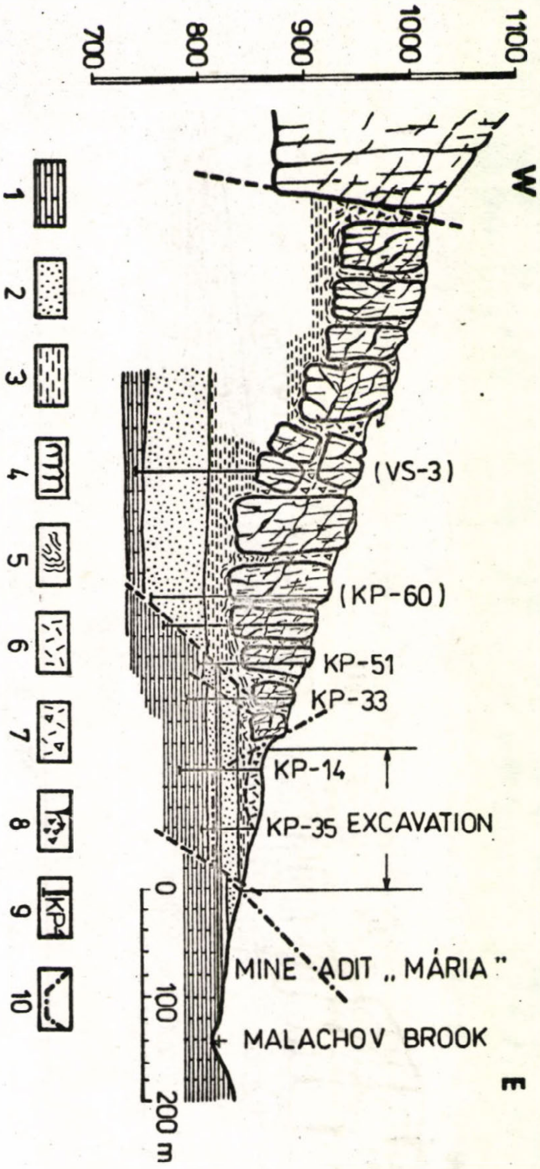
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Fig. 10.

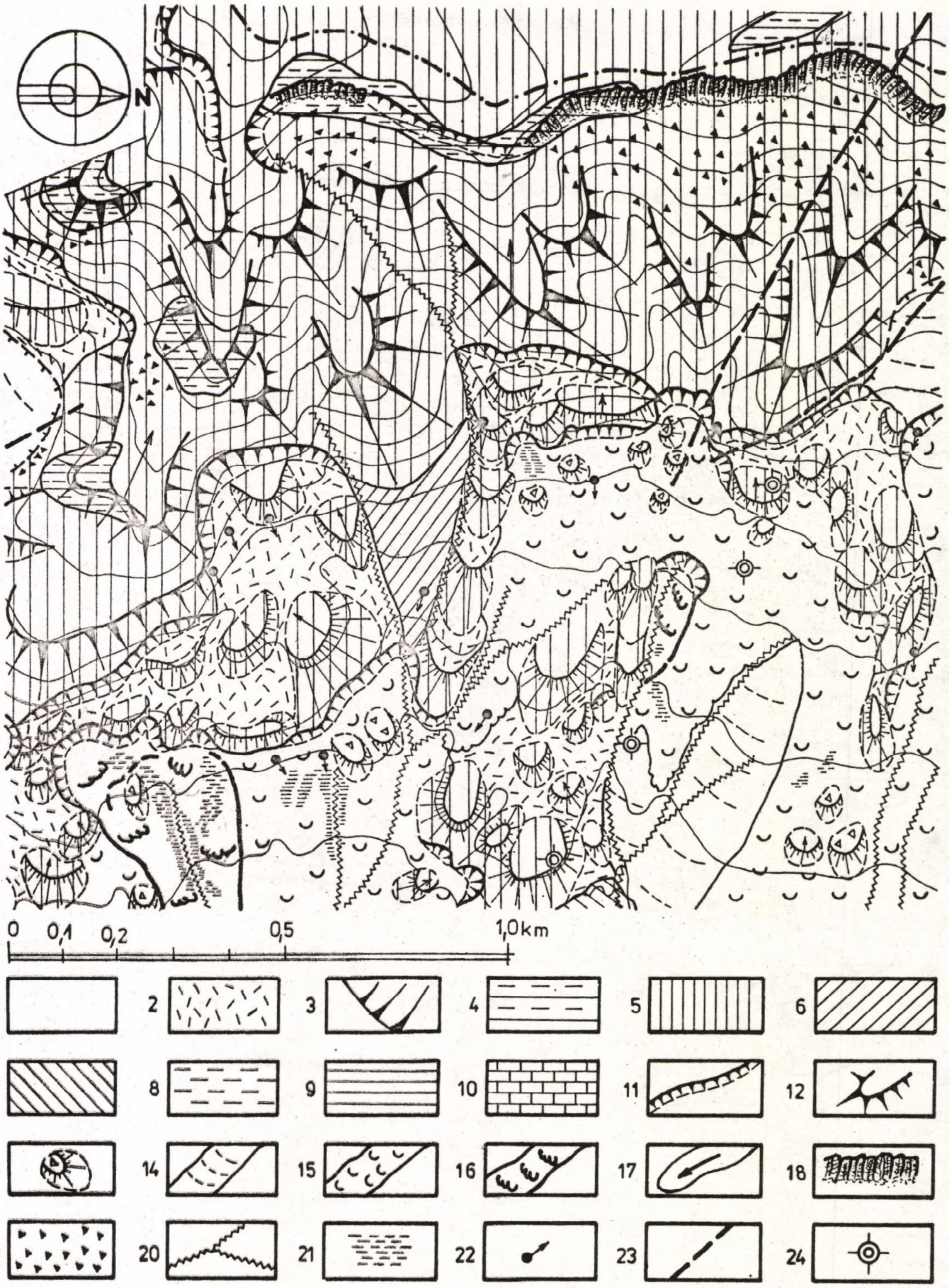
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Fig. 11.

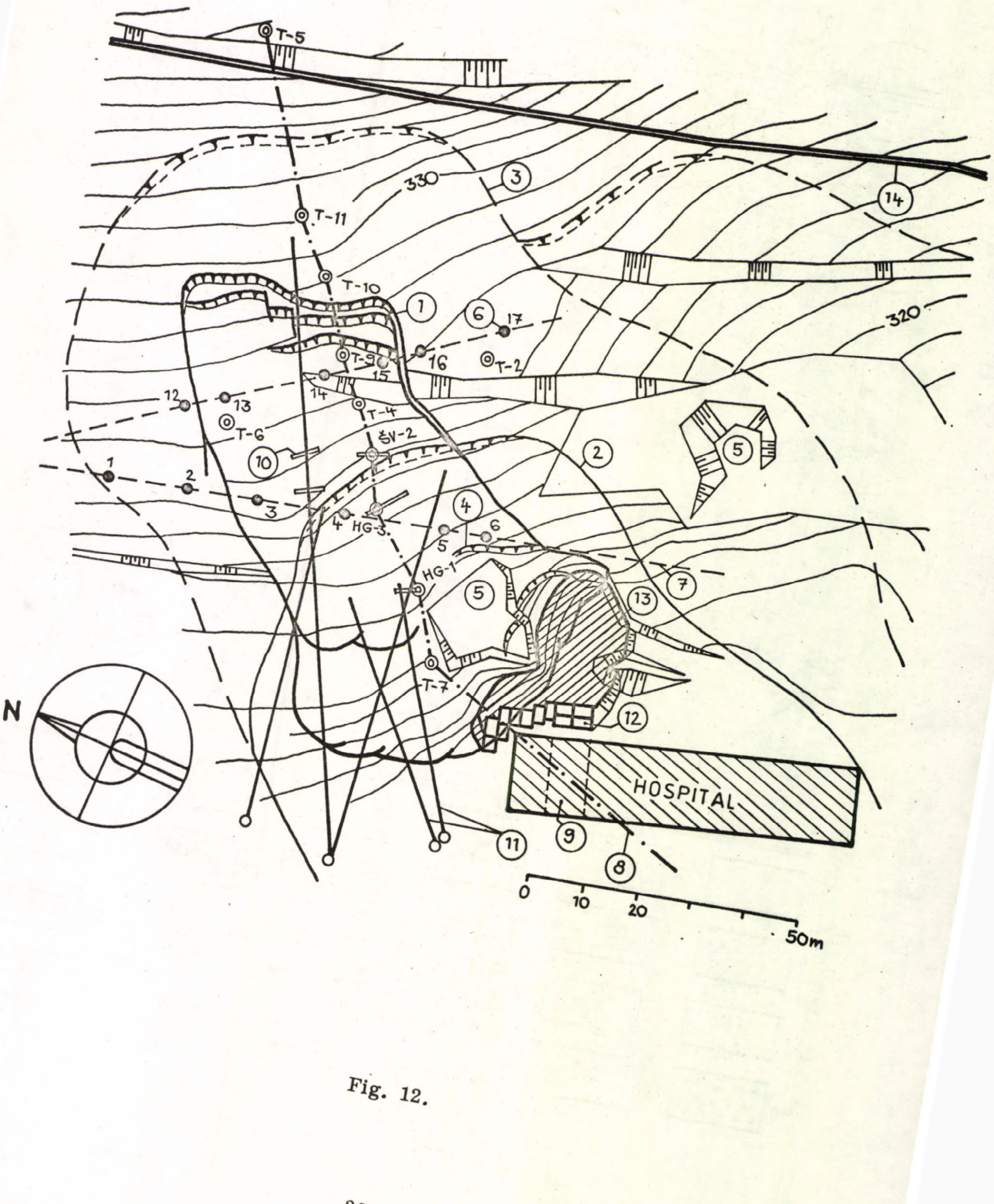
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Fig. 12.

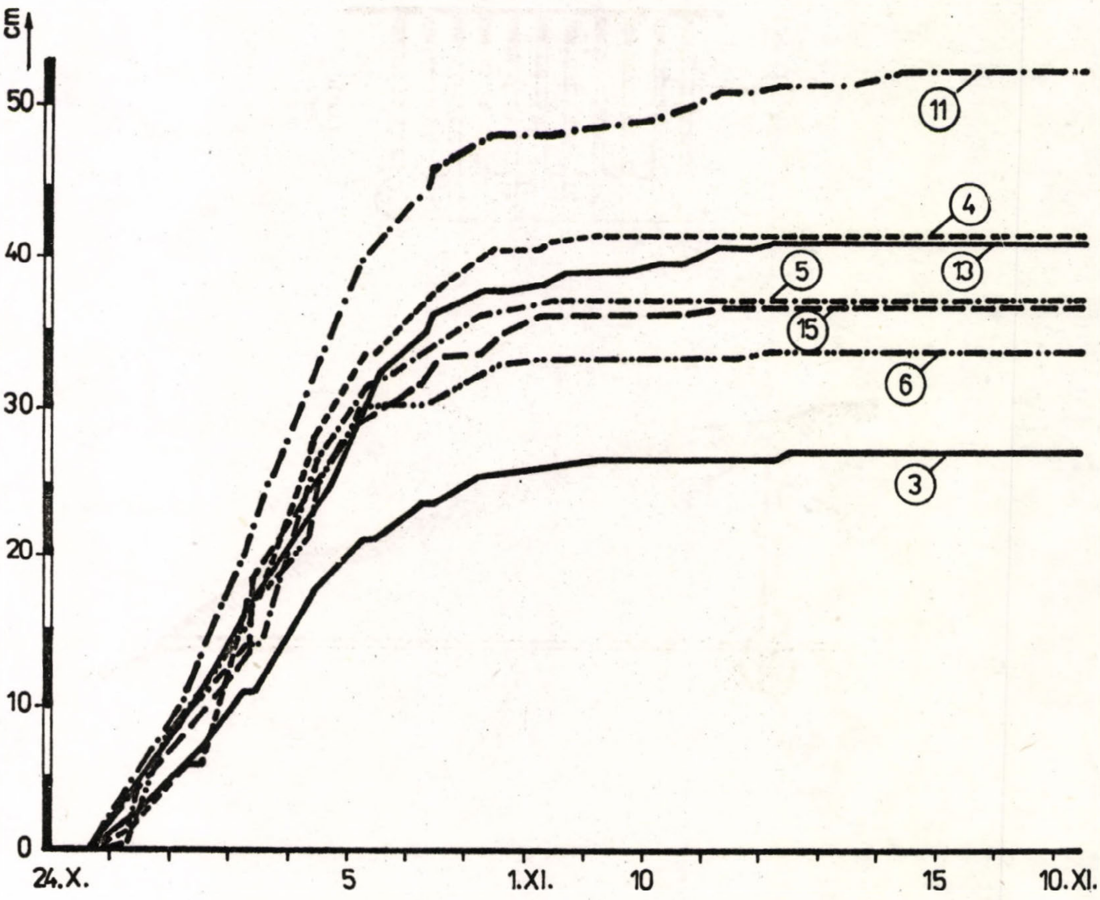

Fig. 13.

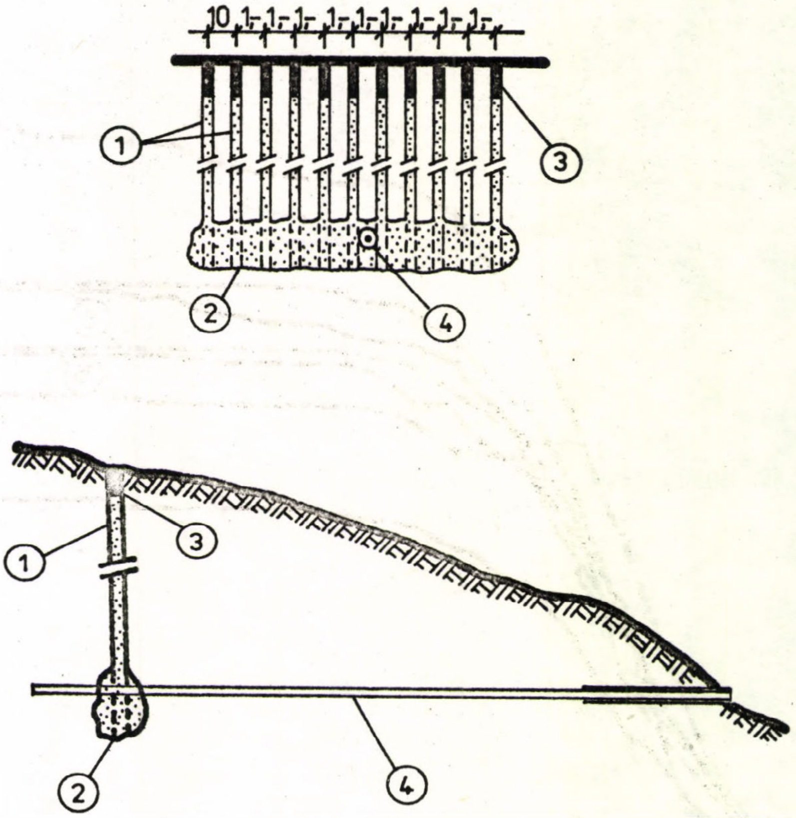

Fig. 14.

Explanation of figures

Fig. 1: Cross-section of a creep deformation in the SE of the Ráztoka ridge slope. 1 - paragneisses and siliceous gneisses with distine foliations, 2 - migmatites, 3 - amphibolites, 4 - hybrid granites, 5 - blocks and gravels of moraine deposits, 6 - dumps of rock falls, 7 - slope debris, 8 - indication of dilatation shear planes.

Fig. 2: Cross-section of the Poľská Tomanová ridge castern slope. 1 - two-mica granodiorites, 2 - pegmatite-aplitoid granites (1-2 Paleozoic), 3 - slope debris, 4 - gravels and sands of fluvial deposits (3-4 Quaternary), 5 - indication of jointing, 6 - indication of dilatant shear planes.

Fig. 3: Frequency of vector directions of deepreaching gravitational deformations in the Tatras.

Fig. 4: Dependence of relative height H on the lenght of failed slope L in the Carpathian granitoids.

Fig. 5: Cross-section through the ridge of Sivý vrch (Nemčok - Baliak, 1977). 1 - biotitic quartz diorites and granodiorites (Paleozoic), 2 - limestones, dolomites, coloured shales, dolomite intercalations and quartzites of the Carpathian Keuperian (Triassic), 3 - shales and sandstones, marly limistones and shales (Jurassic - Neocomian), (2-3 High Tatra envelope series and Krížna nappe), 4 - dolomites and limestones (Triassic Choč nappe), 5 - block in the Triassic limestones and dolomites, 6 - trenches, step-like scarps (5-6 Quaternary), 7 - thrust faults, 8-shear zone.

Fig. 6: Cross-section of the Bukovina hill near Jezersko (Nemčok, 1974). 1 - marly schistose claystones with sandstones, 2 - sandstones with marly shales (1-2 Paleogene), 3 - block field.

Fig. 7: Cross-section through the Lukšinec hill (Novosad, 1966). 1 - flysh claystone with sandstones, 2 - sandstones (1-2 Cretaceous), 3 - debris.

Fig. 8: -

Fig. 9: Cross-section through east margin of Kremnické hory mountains (Malgot, 1975). 1 - limestones and dolomites (Triassic), 2 - conglomerates (Paleogene), 3 - clayey shales, 4 - claystones, 5 - andesites and agglomerates (4-5 Neogene), 6 - block rifts, 7 - block fields, 8 - creeping zone, 9 - landslides, 10 - faults, 11 - boreholes.

Fig. 10: Geological cross-section through slope deformation on Veľká Studňa (Malgot - Mahr, 1978). 1 - limestones, dolomites (Triassic), 2 - sandstones, limestones (Lower Palaeogene) 3 - clays, claystones (Upper Palaeogene), 4 - blocks of agglomerate tuffs (Neogene), 5 - creeping zones, 6 - landslide body, 7 - stony debris, 8 - rock-falls, 9 - boreholes, 10 - projected excavation.

Fig. 11: An example of the map of engineering geological conditions on the boundaries of volcanic mountain range (Malgot - Baliak - Mahr, 1976). 1 - alluvium, 2 - stone-loamy material of the block fields, 3 - alluvial cones (1-3 Quaternary), 4 - andesites, 5 - agglomeratic tuffs, 6 - tuffitic clays (Neogene), 7 - claystone with sandstone intercalations, 8 - conglomerates, sandstones (7-8 Palaeogene), 9 - limestones, 10 - dolomites (9-10 Mesozoic), 11 - scar walls, 12 - block in the rift field, 13 - blocks in the block fields, 14 - stabilised landslides, 15 - dormant landslides, 16 - active landslides, 17 - earthflows, 18 - scar wals of rock falls, 19 - talus, 20 - brooks, 21 - wet areas, 22 - springs, 23 - tectonic lines, 24 - boreholes.

Fig. 12: Schematic map of landslide. 1 - head scar of active landslide, 2 - dormant landslide, 3 - stabilised landslide of older generation, 4 - secondary scars, 5 - dump, 6 - observation geodetic points, 7 - geodetic line, 8 - profile lines, 9 - subway, 10 - drainage gravel walls, 11 - horizontal boreholes, 12 - concrete blocks, 13 - rockfill, 14 - ditch.

Fig. 13: Displacement of observed geodetic points.

Fig. 14: Scheme of drainage gravel wall. 1 - boreholes fill up by gravel, 2 - cavity forming out blasting, 3 - clay, 4 - horizontal borehole.

Kivonat a "LEJTŐMOZGÁSOK A NYUGATI-KÁRPÁTOK GEOLÓGIAI-TEKTONIKAI EGYSÉGEIBEN" c. előadásból

Mahr T.

Szlovákia területén 5.800 lejtő deformációt térképeztek 850 km^2 területen. Az inditékot a térképezésre az 1960. évi Handlova-i nagy földcsuszamlás adta. A lejtőmozgásokat négy csoportba osztották: vonszolódás, csuszás, folyás, omlás. Földtani tájak szerint a csoportositás a következő volt: a maghegységek területe; a kárpáti fliss-terület; a neogén vulkánok területe; a neogén medencék.

A kristályos kőzetekben ritka a lejtőmozgás, itt a tektonikus igénybevétel késziti elő a talajt a gravitációs mozgásra. Metamorf kőzeteknél 18-47 fokos lejtőkön találtak deformációkat.

A fliss területeken a lejtőmozgásokat a kemény permeábilis kőzeteknek puha vizzáró rétegekkel való váltakozása segiti elő. A fliss magas hegységekben gyakori a tömbökre darabolódás, aránylag kevés a csuszás; viszont a fliss dombvidékeken legtöbb a csuszás és a földfolyás.

Vulkáni kőzetekben ritka a lejtőmozgás, kivéve ahol a neogén vulkanitok plasztikus üledékes kőzeteken feküsznek. Gyakoribbak a kőtengerek és földfolyások. A neogén medencékben a lejtőmozgásokat főképpen az erózió okozza. Mozgás figyelhető meg a travertino képződményekben ott, ahol azok paleogén fliss kőzeten vagy agyagpalán települnek. Gyakoriak a mozgások a liptói és zólyomi medencékben.

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A helyi vizsgálatok Szlovákiában azt mutatták, hogy 200 km utvonalat, 27 km vasutvonalat, többszáz vezeték oszlopot, sok vizmüvet és ipari üzemet és 203 falut és várost fenyeget a lejtőmozgás veszélye. A pozsonyi Geofondban mérnökgeológiai térképeket tárolnak a mozgás veszélyes területekről. Szlovákia egyes részein a lejtőmozgás a terület 25-35 %-át veszélyezteti. Ilyen helyeken nélkülözhetetlen a mérnökgeológiai térkép.

1. ábra: Keresztszelvény a Ráztoka hegy DK-i lejtésének vonszolódó deformációjáról.
1. paragneisz és kifejezetten leveles kovagneisz, 2. migmatit, 3. amfibolit, 4. hibrid granit, 5. tömbök és moréna kavics, 6. tömbök, sziklaomlás, 7. lejtőtörmelék, 8. nyirólapok jelzése.

2. ábra: Keresztszelvény a Polska Tomanova hegy keleti lejtőjén:
1. Csillámos granodiorit, 2. pegmatit-aplitoid-granit (Paleozóos), 3. lejtő törmelék, 4. folyóvizi kavics és homok (Quarter), 5. kőzetrepedés jelzés, 6. dilatációs nyirólap

3. ábra: A tátrai gravitációs deformációk gyakorisági irányvektora.

4. ábra: Összefüggés a relativ magasság (H) és a mozgó lejtő hosszusága között (L) a Kárpát granitoidokban.

5. ábra: Keresztszelvény a Sivy vrch hegyen, 1. biotit kvarc diorit és granodiorit (Paleozóos), 2. mészkő, dolomit, szines pala, dolomit interkalációk és a Kárpátok Keuper kvarcitjai (Triász), 3. palák és homokkövek, márga mészkő és pala (Jura) (Magas Tátra takaró és Krizna takaró), 4. dolomit és mészkő (Triász Choc takaró, 5. triász mészkő és dolomit tömbök, 6. árok, lépcsős mart., 7. kompressziós vető, 8. nyirás-zóna.

6. ábra: Keresztszelvény a Bukovina dombon, 1. márgás, palás agyag homokkővel, 2. homokkő márgás palás (Paleogén), 3. kőtenger, blokk-mező

7. ábra: Kereszt-szelvény a Luksinec dombon, 1. fliss agyag és homokkő, 2. homokkő, 3. törmelék

9. ábra: Kereszt-szelvény a Kremnické hory keleti szélén, 1. mészkő és dolomit, 2. konglomerát (Paleogén), 3. agyagpala, 4. agyag, 5. andezit és agglomerát, 6. tömb hasadékok, 7. kőtenger, 8. vonszolt zóna, 9. csuszás, 10. vetők, 11. furások

10. ábra: Geológiai deformációk a Velka Studnán 1. mészkő, dolomit (Triász), 2. homokkő, mészkő (Felső Paleogén, 3. agyagok, agyagkő, 4. agglomerát tufa tömbök, 5. vonszolt zóna, 6. csuszó test, 7. köves tömbök, 8. kőomlás, 9. furás, 10. tervezett kifejtés

11. ábra: Példa a mérnökgeológiai viszonyok térképezése vulkáni hegységek határán, 1. alluvium, 2. a kőtengerek köves-agyagos anyaga, 3. alluvialis törmelékkup, 4. andezit, 5. tufa agglomerát, 6. tuffitos agyag, 7. Agyag, homokkő és mészkő betelepülésekkel, 8. konglomerát, homokkő, 9. mészkő, 10. dolomit, 11. szikla fal, 12. Kőtenger, 13. tömbök a kőtengerben, 14. megkötött csuszás, 15. szunnyadó csuszás, 16. élő csuszás, 17. földfolyás, 18. kőomlás fala, 19. völgyfenék, 20. patakok, 21. nedves hely, 22. forrás, 23. tektonikai vonalak, 24. furások

12. ábra: A földcsuszamlás vázlatos térképe, 1. élő csuszás homlokvonala, 2. szunnyadó csuszás, 3. megkötött régi csuszás, 4. másodlagos csuszás front, 5. törmelék mező, 6. geodéta megfigyelő pont, 7. geodéta vonal, 8. szelvény vonalak, 9. földalatti vasut, 10. lecsapoló kavics fal, 11. vizszintes furások, 12. cement blokkok, 13. kitöltés, 14. árok

13. ábra: Geodéta megfigyelő pontok elmozdulása

14. ábra: A lecsapoló kavicsfal vázlata, 1. Kavicssal töltött furólyuk, 2. robbantással képzett üreg, 3. agyag, 4. vizszintes furólyuk